NADCA Standards for High Integrity and Structural Die Casting Process

NADCA
NORTH AMERICAN DIE CASTING ASSOCIATION

2018
7th Edition

NADCA Publication #403

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Overview

Weight reduction has been a major focus of many industries over the past decade or more. The automotive industry for example has concentrated on downsizing and light-weighting to meet governmental, marketing and performance pressures. To accomplish targeted weight reductions, the carmakers have increasingly looked to the use of aluminum and magnesium alloys. Additionally, the automakers, along with other industries, are investigating new and developing processes for casting aluminum and magnesium components. These processes offer near-net shape capability, improved strength, and excellent ductility, along with the pricing structure required to meet automakers' needs. The three processes that have already met target production needs and, as the technologies further develop, are expected to continue to expand their applications, are High Vacuum Die Casting, Squeeze Casting and Semi-Solid Metal Casting (SSM).

Each of these three processes has been through a typical development process, including examination and improvement by the academic community, the normal trial and error of the first entrepreneurs and, finally, the risk acceptance by the first practitioner and consumers. Each process has now progressed beyond this initial stage and are now rightfully classed "production ready" and a number of parts produced by each process are incorporated in current automotive models around the world, as well as being used by a number of other industries.

While all of the current squeeze casting applications utilize aluminum alloys, both aluminum and magnesium components are being commercially produced by high vacuum and semi-solid casting. In addition, copper, zinc, and to a limited degree, ferrous alloys have also been cast in each of these processes, but none of these other alloys are being produced on a commercial basis. Further, research work is ongoing on a variety of materials and process improvements around the world. However, since aluminum and magnesium have played a major role in the development of these three processes, what follows is most applicable to the high vacuum, squeeze, and semi-solid casing of these two metals.

Process Similarities

Although each of the three processes differ in the details of how the castings are produced, they are all similar in that they are seeking to produce high quality castings containing minimal levels of gas porosity, shrinkage porosity, and other defects, and each are capable of being fully heat treated without blistering. Although there are significant differences between the three processes, all have a number of similarities as outlined below:

- <u>Alloys</u> – The alloys that are used for these three high integrity casting processes are all chosen to be capable of generating an excellent combination of strength and ductility. For the aluminum alloys, this means choosing alloys containing low levels of iron (generally ≤0.2% Fe).
- <u>Metal Quality</u> – To generate excellent mechanical properties, it is necessary that the metal quality be very high. Before casting, it is common for the alloys to be filtered and treated to minimize dissolved gases, oxides and all other non-metallic inclusions, and that handling techniques be used that treat the metal gently as it is transferred to the casting machine (to minimize oxide inclusions).

- Casting Machines – All three processes use die casting machines that are capable of injecting the metal into the cavity under closely controlled conditions. There are two possible variants (although in each case the indirect process is more common commercially):
  - o Direct – The pressure is applied directly to the metal (liquid or semi-solid) from a hydraulically activated source. Hence processes utilizing this approach are referred to as direct squeeze casting or semi-solid forging (SSF).
  - o Indirect – Pressure is transmitted from the hydraulic source through a runner system to the metal being solidified in a die cavity. This approach is common for all three processes.
- Heat Treatment – Controlled thermal treatments can be used to develop excellent strength-ductility combinations.

Process Variants

There are also significant differences between the three processes, which are described below. In addition, each of the three processes have dissimilar histories, both in time and in the maturing cycle, and a short history of each process is also provided.

1. High Vacuum Die Casting

   Vacuum has been applied in die casting for some time, but it was only in the 1990s that very high vacuum in combination with new alloys and best practices regarding metal quality, process controls, etc. offered the ability to produce high integrity structural die castings for car bodies that could be welded, heat treated and were crash worthy. The high vacuum die casting process maintains the high injection velocity used with conventional die casting, but reduces the air pressure within the die cavity to 50 milli-bars or less (5% of an atmosphere), so there is little air to become entrapped in the castings. Specially designed fan or "antler" gating systems in combination with sophisticated die designs, especially with respect to thermal management of the die, generates a single homogeneous metal front while filling the die, to minimize the entrapment of any air, lubricant or contaminants remaining in the cavity and avoid oxide inclusions from joining metal fronts. Several heat treatment technologies and many different alloys are now available to meet the high property requirements of car companies, producers of recreational vehicles, marine applications, etc. Parts range from less than a pound (450 gms) to over 30 lbs (14 kg) and from just a few inches (>25 mm) long to 60 inches (1.5 meters) long. Typical wall thicknesses are in the range of 0.08 to 0.16 inches (2 to 4mm).

2. Squeeze Casting

   The principle that pressure applied to molten metal during solidification will enhance its properties has been known for over 150 years. In fact, the original patent was applied for in England in 1819. The Russians have used direct squeeze casting for piston manufacturing for over 100 years. However, the process did, in effect, lie somewhat dormant until the 1970's when first, direct squeeze casting was reactivated for several defense applications as well as for pistons, and later indirect squeeze casting was used to make aluminum automobile wheels for a Japanese car manufacturer.

The fact that squeeze casting could provide essentially porosity free castings surfaced at the same time that the auto industry was searching for ways to reduce weight at minimum cost. The process swept rapidly across Japan over the next ten years replacing iron parts, i.e., control arms, steering knuckles, cylinder liners, pistons, engine supports, etc. A number of other industries also took advantage of the unique character of squeeze casting, i.e., bicycle, air conditioning, valve and pump, etc.

Direct squeeze casting was first introduced to the US by Doehler-Jarvis in the 1960's, and has been used since the late 1980's in the United States and Europe for piston manufacture, particularly ceramic inserted. Then in 1990 the first indirect squeeze operation was installed in the United States. Today there are squeeze machines installed worldwide producing a variety of components ranging in size between as little as 3.5 ounces (100 grams) to a crossmember weighing 31 pounds (14 kilograms).

3. Semi-Solid Metal Casting

Semi-solid metal (SSM) casting is different than all other casting processes, as instead of using a fully liquid feed material, it uses a feed material that is partially solid and partially liquid. SSM casting has also been practiced in some form for over 100 years. However SSM casting as we know it today evolved out of a series of studies performed by Professor M.C. Flemings and his students at MIT in the late 1960's and early 1970's. It was noted that when the normal dendritic microstructure was modified to a non-dendritic, spheroidal structure, the resulting material having a remarkably low shear strength even at relatively high solid fractions - it became thixotropic.

The resulting quality and integrity of parts formed using the semi-solid process were evident in improved mechanical properties. Further, it became obvious that the process could be applied to a number of different alloy systems. The original MIT patent rights were eventually obtained by Alumax, Inc., a primary aluminum producer, now a part of Alcoa. Beginning in the very late 1980's and early 1990's, Alumax started producing semi-solid parts for automotive applications. When key original patents expired in 1992, the commercial application of the process rapidly expanded around the world.

The semi-solid process originally commercialized by Alumax involved the production of a pre-cast billet having the globular semi-solid microstructure. Slugs cut from these billets were re-heated to the semi-solid temperature range for casting. This process is referred to as thixocasting. Although thixocasting achieved commercial success, and is still in use today, the pre-cast billet approach was considered costly by many end-users. Therefore, alternate approaches to semi-solid casting have been developed, where the semi-solid slurry is generated directly from the liquid. These processes are referred to as rheocasting, and there are a number of different variations in commercial production or under development around the world. In addition, a specialized semi-solid process for magnesium alloys called thixomolding has been commercialized, and this process uses a press similar to an injection molding machine. All three processes (thixocasting, rheocasting and thixomolding) are in commercial production making parts for a number of markets, including automotive, motor cycle, electronics, aerospace and sporting goods. Similar to squeeze casting, semi-solid machines are installed around the world producing aluminum and magnesium parts ranging in size from a tenth of an ounce (few grams) to more than 22 pounds (10 kilograms).

Conclusion

All three processes, High Vacuum Die Casting, Squeeze Casting and Semi-Solid Metal (SSM) Casting, have demonstrated the ability to produce high integrity components for a wide range of industries. These processes are being practiced, in some form, in Europe, North America and Asia. High Vacuum Die Casting is today the most practiced process of those and now very fast growing in all regions of the world. More and more OEMs are either purchasing components made in high vacuum die casting or are (also) producing them, and a significant supply base is now available for such components and competitive prices. There are still some economic hurdles to jump before either of the other two processes have universal acceptance; however, significant strides in cost reduction have been made over the past several years and further gains can be expected in the future.

Acknowledgements

A special thanks to the following individuals for their knowledge, time and effort used to revise this book to the 6th edition:

- Hal Gerber
- Martin Hartlieb
- Adam Kopper
- Steve Midson

Revision Changes

The 7th edition of this book is a minor update with the following changes:

- Clarification and corrections to section 4 (Engineering & Design: Tolerancing).
- Updated images in section 7
- Minor changes to the checklists in section 8
- Fixes to typographical errors and minor clarification to existing information made throughout the book

High Integrity High Pressure Casting Processes

Section 1

1

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Introduction

High Integrity High Pressure (HIHP) casting processes represent a relatively new range of casting processes which combine the near-net shape benefits associated with traditional high pressure die casting with novel approaches to produce high integrity, heat treatable, weldable, light alloy components. In general, high integrity high pressure casting processes can be categorized as ones in which metal in either a fully liquid or semi-solid state is injected in either a non-turbulent manner or in a very controlled way with high vacuum into a re-usable steel die, and subsequently held under high pressures throughout the solidification process to produce sound, fully heat treatable components. As such, HIHP casting processes compete against other traditional premium quality shaping processes such as forging, low pressure permanent mold casting and its variations, dry-sand molding and fabrication, for the production of lightweight structural components. HIHP cast parts can be found today in safety critical automotive suspension applications, recreational goods, and car body structures and other engineered structural applications.

In order to satisfactorily produce components which comply with the above criteria, HIHP casting processes must solve the several critical issues of 1) entrapped gas, 2) solidification shrinkage voids, 3) hydrogen porosity, (Fig. 1-1a, 1-1b & 1-1c) and 4) various sorts of oxides and other inclusions. Gas porosity occurs when the air pre-existing in the cavity or shot system or gas that might evolve due to the break-down of lubricants and coatings in the system becomes entrapped in the casting during the filling process. Gas entrapment is avoided by two separate methods. First, is by controlling the injection process so that the die is filled in a non-turbulent manner (see the left hand casting in Figure 1-2). Alternatively, high density raw material, engineered vent area locations, overflow masses, and applied vacuum within the cavity can be utilized to remove moles of gas that could potentially become trapped during the rapid, high pressure fill.

In the conventional high pressure die casting process all remaining unvented, trapped gases are squeezed so effectively during fill and solidification that they are barely visible; even under x-ray examination. Such pressurized pockets of entrapped gas cause problems during heat treatment since the gas expands upon heating, creating localized regions of stress which exceed the yield stress of the heated alloy, resulting in blistering. These blisters not only present an unacceptable surface, but they also degrade the mechanical performance of the components. By preventing gasses from being trapped during the filling process, high vacuum, squeeze and SSM castings can be heat treated. In a similar manner, the lack of entrapped gases also allow these castings to be welded or joined by other fusion methods without blistering or out-gassing.

While solidification shrinkage porosity represents a more tolerable issue, since it does not directly impact the heat treatability of the components, it too, represents regions of weakness in the cast components and must be avoided. It is the application of high pressure, especially in SSM and Squeeze (to a slightly lesser degree in high vacuum die) casting, which is important in eliminating solidification shrinkage, since it forces additional liquid metal into the mold as the casting is solidifying, feeding both macro- and micro-shrinkage porosity.

A principle advantage of HIHP casting is the ability to feed solidification shrinkage until late in the freezing process, aided by cavity metal pressures which often exceed 10,000 psi (5000-8000 psi in high vacuum die casting). This results in castings which are remarkably free of (micro)porosity. Unlike permanent mold, sand or investment casting, it is unusual to find microporosity in HIHP castings. High pressure high integrity castings utilize hardened steel dies to withstand the high metallostatic pressures (Fig. 1-3). This combination of metal tooling and high pressure (which keeps the cast alloy in intimate contact with the die surface) promotes very high cooling rates in the castings, which results in exceptionally fine micro-structures. The fineness of the microstructure can be characterized by the parameter "secondary dendrite arm spacing" (SDAS), which is a measure of the local solidification rate, and is observable under a microscope.

Because the cooling rates are so high, the secondary dendrite arm spacings associated with HIHP casting processes are often as much as an order of magnitude smaller than equivalent sand or permanent cast components (see Table 1-2a). The combination of fine-scale microstructures and lack of microporosity mean that HIHP castings typically exhibit superior mechanical performance compared to castings produced by other processes.

High vacuum, squeeze and SSM casting equipment and tooling are comparable cost-wise to other high pressure processes (slightly higher in the case of high vacuum die casting), but significantly higher than most equipment used in sand and permanent mold casting. The productivity and product capabilities (near net shape, wall thickness, etc.) of high vacuum, squeeze and SSM casting, however, can more than offset less capital-intensive processes so that "annual pounds of salable product per investment dollar" is very competitive, provided that annual volumes warrant or utilize high productivity. Combined with the inherent near-net shape benefits (Fig. 1-4), these attributes often make HIHP castings an unbeatable choice for many of today's demanding structural light metal applications. HIHP castings can be produced with tolerances which match or, in some cases, exceed those of conventional high pressure die casting (see Sections 4 & 5). In addition, close tolerance die cavity dimensions and the ability to moveable cores allows detail to be cast into the components that reduce machining requirements even further.

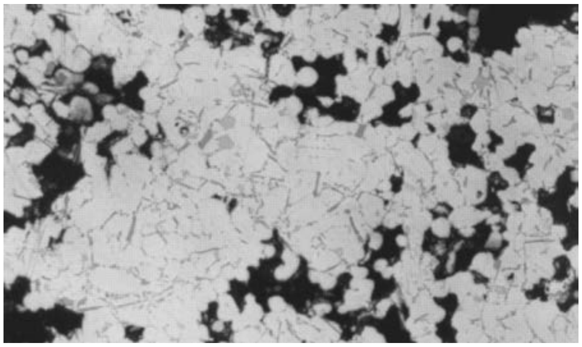

Fig. 1-1a Micrograph of solidification shrinkage in an aluminum casting.

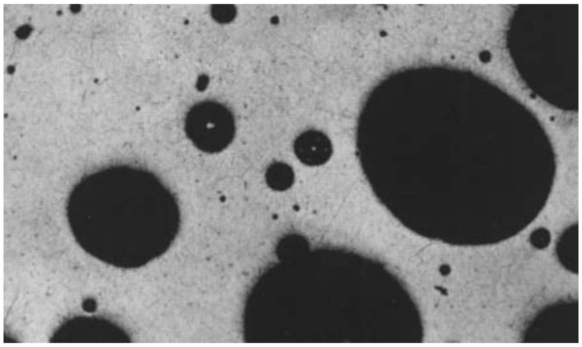

Fig. 1-1b Micrograph of entrapped gas porosity in an aluminum die casting.

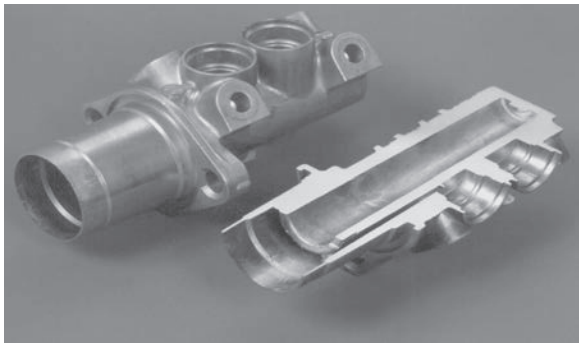

Fig. 1-1c Section through a semi-solid metal cast master brake cylinder, showing the lack of both gas and shrinkage porosity.

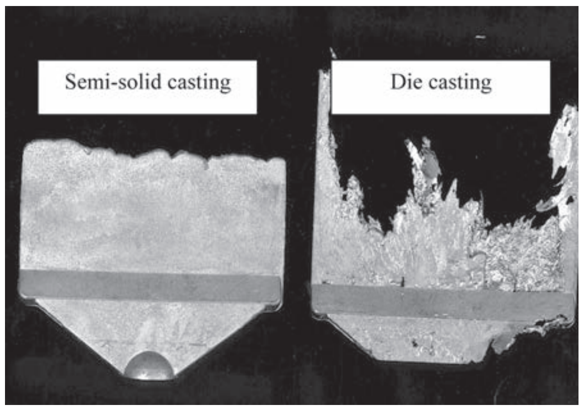

Fig. 1-2 Comparison of the die fill behavior of semi-solid casting and high pressure die casting. Semi-solid presents a calm, slow fill and high pressure results in a fast and turbulent fill with tighter dendritic spacing feeding thinner casting sections.

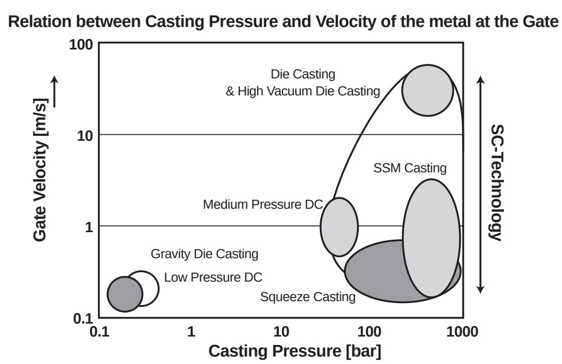

Fig. 1-3 Casting pressure used in the squeeze casting and semi-solid metal casting process.

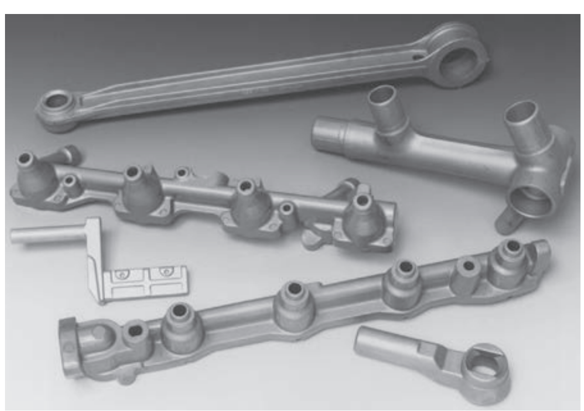

Fig. 1-4 Examples of HIHP cast components, showing the net shape capability of the process.

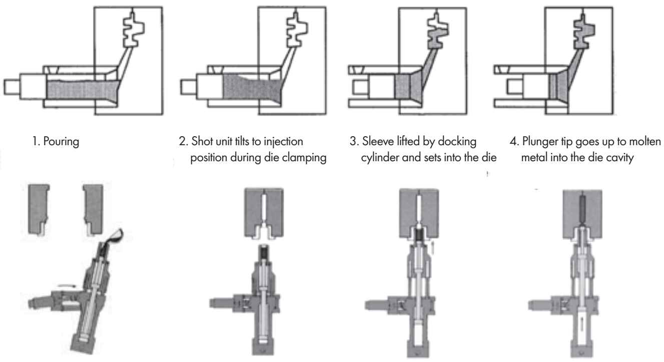

Fig. 1-5a Horizontal injection process used for squeeze casting.

Fig. 1-5b Vertical injection process used for squeeze casting.

1. High Vacuum Die Casting

Although vacuum (assisted) die casting has been used in the die casting industry for many years, a new process generally called high vacuum die casting (or structural die casting) allows the production of aluminum die castings that are being used in structural car body and other safety-critical applications due to better strength, much higher elongation and excellent impact and fatigue resistance. Figure 1 demonstrates the energy absorbing ability, showing a component produced by two welded high vacuum die castings subsequent to a crash test. This ability to absorb energy is quite remarkable for a die casting, and conventional die castings (even those produced using vacuum assist) do not exhibit such behavior.

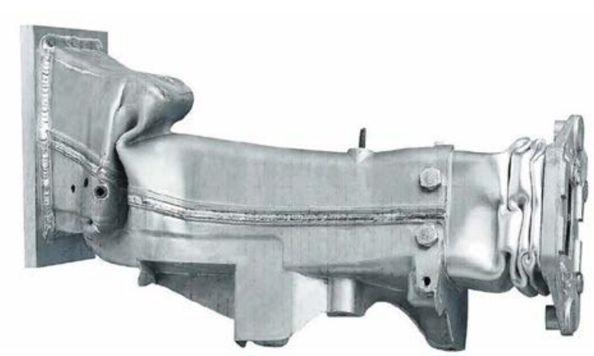

Fig. 1-6 Casting produced by high vacuum die casting subsequent to a crash test[1], demonstrating the ability to absorb energy without cracking.

The high vacuum die casting process maintains the fast injection speed used by conventional die casting, but powerful vacuum systems reduce the air pressure in the die cavity and shot sleeve to typically less than 50 milli-bar (<1/20 of an atmosphere), so there is little gas remaining in the cavity to become trapped in the castings. The advantages of high vacuum die casting include:

◊ In combination with the use of low-iron aluminum alloys provides excellent ductility and toughness, which allows the castings to be used in structural, safety critical applications.
◊ The use of high vacuum minimizes the amount of entrapped gasses, providing the ability to optimize strength and ductility through heat treatment (without blistering).
◊ High vacuum die casting is capable of producing large, thin-walled (0.08-0.16 inches/2-4 mm) structural castings and such castings are being used to replace steel or aluminum stampings in car body and chassis, as well in other applications.

Along with the use of a powerful vacuum system, there are a number of changes to the process that are necessary to achieve this level of performance. The main aspects of high vacuum die casting include:

- Use of low-iron aluminum die casting alloys to maximize strength and ductility
- Metal treatment and handling to optimize metal quality
- Special die, gating, overflow, vacuum channel, etc. designs
- Powerful vacuum systems, sealed dies and advanced vacuum controls to achieved desired vacuum levels in the cavity
- Controlled thermal treatment of the castings to obtain strength-ductility combinations

Some of these are discussed below in more detail.

1.1 Low-Iron Die Casting Alloys [1]

There a number of aluminum alloys that have been specially designed for the high vacuum die casting process, and the chemical compositions of some of the common alloys are listed in Table 3-2. With the exception of Magsimal 59, all these alloys contain relatively high levels of silicon (between 6.5 and 11.5%), and all contain low levels of iron (≤0.25%), which helps provide high levels of ductility (elongation). Die soldering is minimized through the addition of Mn at levels of 0.25-0.8% (and in some cases Sr).

1.2 Treatment and Handling to Optimize Metal Quality

As high vacuum die castings are normally used in structural applications, much greater care needs to be taken to optimize the quality of the metal (compared to other die casting processes). Therefore, the alloys must be cleaned (fluxed and filtered) and de-gassed using a rotary degassing process. Rotary degassing involves the introduction of an inert gas below the level of the liquid aluminum, and the rotary impeller produces a uniform distribution of small insert gas bubbles throughout the liquid aluminum. Any dissolved gas (hydrogen), along with small impurity inclusions (such as oxides), attach to the bubbles and rise to the surface of the melt, where they are removed[2]. The metal must at all times be treated with utmost care and all cascades avoided (quiescent transfer, repeated filtering, continuous degassing in the holding/dosing furnace are common elements).

1.3 Robust Die, Gating and Overflow Designs

The gating system used with high vacuum die casting is modified from conventional die casting. High vacuum die casting castings are usually produced with a much larger number of gates (as many as 20-50 gates), in contrast to the 3-5 gates commonly used with conventional die castings. For example, a B-pillar high vacuum die casting produced for the Audi A2 has been reported to use 46 gates. Overflows and vacuum gates are equally important to ensure proper evacuation throughout the entire filling process without injecting the metal into the vacuum system. Overflows are also used to maintain proper thermal balance in the die as the thin walled castings introduce much less heat into the die than conventional (thick walled) die castings and die spraying is absolutely minimized and only used for lubrication and not for controlling the thermal balance of the die. Thermal balance of the die is controlled by a much more sophisticated system of heating and cooling channels in the die.

1.4 Powerful vacuum systems

There are a number of proprietary systems used for high vacuum die casting, including the High-Q-Cast process, Vacural and Alcoa Vacuum Die Casting (AVDC). Most elements of such processes are commercially available individually (and can be retrofitted to existing machines) or as a package (e.g. Bühler's STRUCTURAL process for Bühler machines). Each of these processes have in common the use of powerful vacuum systems (one or two stage, with one or several channels) and advanced vacuum controls to quickly reduce the pressure in the cavity and shot sleeve below 50 milli-bar at the beginning of the fast shot. In addition, to minimize vacuum leaks, seals and special die designs are used on all die surfaces/die components, making the dies much more complex than used for conventional die casting.

1.5 Controlled Thermal Treatments

Although the castings can be used in the as-cast condition, the significantly lower levels of entrapped gases allow the castings to be heat treated without blistering. Components can be heat treated after casting to maximize strength, ductility or toughness. The very high freezing rate of thin walled high vacuum die castings allows for much shorter solution heat treatment times than thick walled castings (e.g. produced by permanent mold or sand casting), but the thin walled components can also much more easily distort during quenching and therefore require special (precision air quench) processes and fixtures to avoid or minimize this problem – and they often need to be straightened and brought back into tolerances after T6/7 heat treatments..

Both T5 and T6/7 heat treatments can be performed to optimize mechanical properties. T5 heat treatments involve water quenching directly after the castings have been ejected from the casting die, followed by a low temperature (150-250°C/300-482°F) aging treatment. T6 heat treating involves heating the castings to a temperature close to their melting (solidus) temperature, followed usually by a water quench and a low temperature age. Note that a streamlined T6 heat treatment has been developed for use with the Aural type alloys, which has been named Auraltherm. This is now also commonly being used in combination with most other (previously described) structural alloys. In contrast to traditional solution heat treatment temperatures of around 500°C (930°F) combined with water quenching, the Auraltherm process involves a "partial solution heat treatment" at a slightly lower temperature followed by rapid air cooling. Because high vacuum die castings are typically thin walled, air cooling provides a sufficiently high cooling rate, while minimizing distortion that can occur during water quenching of thin-walled components. Following the quench, the Auraltherm treatment involves a lower temperature aging treatment. For highest ductility this aging is performed at higher temperatures and/or longer time to "over-age" and hence long term stabilize the castings (T7 process).

2. Squeeze Casting

Squeeze casting is a term commonly used today to refer to any process in which a liquid alloy is cast without turbulence and gas entrapment and subsequently held at high pressure throughout the solidification cycle to yield high quality heat treatable components. Squeeze casting originally was developed as a liquid forging process, in which liquid metal was poured into the lower half of a horizontally-parted die set and subsequently closed die forged (this process is now termed “direct squeeze casting”). In contrast, “indirect squeeze casting” describes a process where the liquid alloy is injected into a cavity via large in-gates, which allows the feeding of solidification shrinkage throughout the freezing process.

Today, the term squeeze casting almost universally relates to the “indirect” process utilizing a runner and gating system. Squeeze castings are made on machines and in steel tooling that are, in many respects, like those employed in conventional die casting. Machines and dies are very robust and capable of containing very high molten metal pressures without deflecting or losing dimensional control.

Squeeze casting machines and tools are designed to introduce clean molten metal into the tool in a precise, repeatable, controlled manner, filling the cavity quickly but without turbulence.

In commercial practice today, there are systems employing either vertical or horizontal injection systems, with the parting line of the die orientated either horizontally or vertically. Figures 1-5a & 1-5b illustrate two of the many process variations in use today around the world.

Squeeze castings can be made from the full range of heat treatable (and non-heat treatable too, if desired) alloys utilized in the permanent mold processes. Only the “hot-short” 2XX, 5XX and 7XX alloys, sometimes used in sand and plaster-mold casting, are not suitable for squeeze casting. Squeeze castings are not limited to the higher silicon (higher fluidity) alloys needed for conventional high pressure die casting. Squeeze castings also do not require the high iron impurity level needed in die casting to prevent “soldering” when molten aluminum is “sprayed” into the die – in fact, high iron concentrations are generally undesirable as they will reduce mechanical properties.

Casting cycles are generally somewhat slower than for conventional die casting. Machine utilization, however, is comparable to that of conventional die casting.

Because metal velocities entering the cavity are considerably slower than die casting, disposable internal cores are more readily applied in squeeze casting, although only cores and core washes that can withstand great metal pressures are suitable.

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3. Semi-Solid Metal Casting

Semi-solid casting differs from squeeze casting as, instead of using fully liquid alloys, it uses a “novel” semi-solid slurry as the feed material. However, similar to squeeze casting, most semi-solid processes use high pressure die casting machines to inject the semi-solid slurry into re-usable, hardened steel dies.

The feed material used for semi-solid processing must have a special “globular” microstructure, such as that shown in Figure 1-7a. The primary aluminum particles (the white-colored phase) must be spherical or globular in shape, and surrounded by eutectic (the dark phase). For comparison, Figure 1-7b shows the dendritic microstructure found in conventional castings. When the globular structure shown in Figure 1-7a is within the semi-solid temperature range, the primary aluminum particles will comprise the solid fraction and the eutectic will be liquid. So at the semi-solid casting temperature, the microstructure will consist of a slurry of small globular solid particles dispersed in a liquid. When this mixture is injected into the die, the semi-solid slurry behaves as a viscous liquid. The principle advantage of semi-solid casting is that this high viscosity slurry allows the use of much faster injection velocities before the onset of turbulence. This allows the semi-solid process to produce extremely high quality castings while filling remarkably thin-walled components at high production rates.

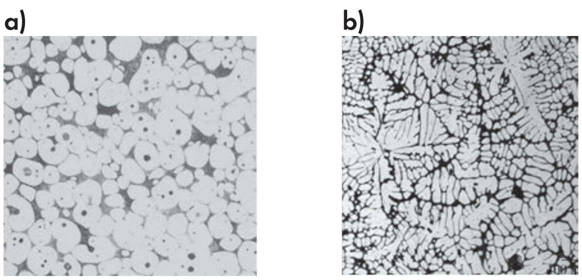

Fig. 1-7 Aluminum alloy 357 microstructures
a) Globular microstructure required for semi-solid processing
b) Conventional cast dendritic microstructure.

Commercial SSM casters are utilizing both horizontal and vertical injection systems, although horizontal injection is more common. SSM casters often use horizontal die casting machines fitted with real-time controlled injection units, which provide the control necessary to avoid turbulence during injection of the semi-solid slurry into the cavity. As with squeeze casting, the metal is typically fed into the cavity through relatively massive runners and gates, which provide paths for the feeding of solidification shrinkage.

SSM castings can be produced from a range of aluminum and magnesium alloys as described below. In addition, cycle rates for SSM castings tend to be faster than both die casting and squeeze casting, as the semi-solid metal can be injected into the cavity at relatively high speeds, and as solidification times are reduced due to the feed material already being 50% solidified. It should be noted that die life for SSM castings should be better than for die casting and significantly better than squeeze casting, as SSM castings are produced at lower casting temperatures.

As noted earlier, there are currently three semi-solid processes in use around the world (thixocasting, rheocasting and thixomolding). These will be described in more detail the following sections.

3.1 Thixocasting

The thixocasting process, which is shown schematically in Figure 1-8, can be considered to consist of three separate stages - the production of a billet feedstock having the special globular microstructure, the re-heating of the billets to the semi-solid casting temperature and the casting of the components.

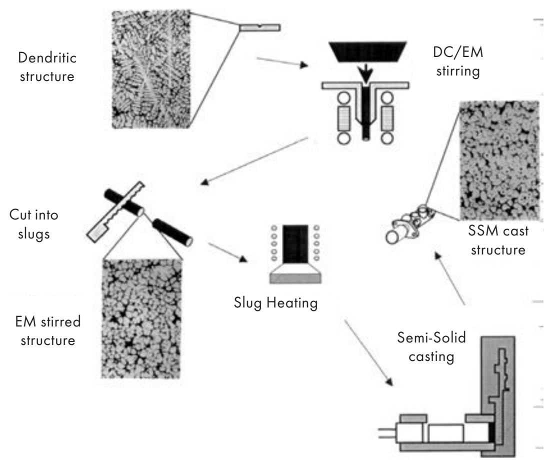

Fig. 1-8 Schematic representation of the thixocasting process.

The feedstock for the thixocasting process is typically produced on a DC casting system equipped with electromagnetic stirrers. As the cylindrically-shaped bars are being cast, the liquid metal is vigorously stirred to prevent the formation of dendrites, instead generating the globular, semi-solid structure. Generally the bars are produced at primary aluminum plants and shipped to the semi-solid caster. Slugs are then cut from the bars, and reheated to the semi-solid casting temperature using induction heating. Figure 1-9 shows the consistency of a re-heated slug, which usually has a solid fraction of 40-50% (50-60% liquid). For alloy 357 this corresponds to a temperature of about 580°C (1076°F). At this temperature, essentially all the eutectic portion of the alloy is liquid.

Fig. 1-9 Consistency of alloy A357 slug at the semi-solid metal temperature.

Once at the semi-solid casting temperature, the slugs are transferred to the shot sleeve of a horizontal die casting machine and injected into the die. Due to the high viscosity of the semi-solid alloys, a greater force is needed to fill the cavity as compared to die casting. Consequently, semi-solid machines generally have a larger capacity shot end than a conventional die casting machine of the same locking force.

Although thixocast parts can be produced from a range of alloys, most of the commercial castings are being produced from heat-treatable aluminum foundry alloys such as A356, 357, 366, A390 and a high strength version of 319.

One of the advantages of thixocasting is the product quality and consistency that results from using pre-cast billets manufactured using the same techniques to control metal quality as are employed to make forging or rolling stock. Thixocasting billets have billet-to-billet and lot-to-lot chemistry, cleanliness and microstructural repeatability comparable to forging and rolling stock, and far more consistent than is achievable when pouring castings from the liquid in single doses. Thus semi-solid components produced by the billet approach tend to have very consistent properties. As noted earlier, the disadvantage associated with thixocasting is its higher manufacturing cost. This arises both from the premium attached to the price of the feedstock, as well as the inability to easily recycle biscuits and runners. Billet is also available from only a few global sources and in a limited number of alloys.

3.2 Rheocasting

Instead of re-heating a pre-cast slug, rheocasting generates the special semi-solid microstructure adjacent to the die casting machine directly from the liquid. A schematic drawing of the rheocasting process is shown in Figure 1-10. The metal is cooled into the semi-solid temperature range while simultaneously generating the semi-solid structure. Once the metal has been cooled to the correct semi-solid temperature, the slurry is transferred to the shot sleeve of a die casting machine, and injected into the die, again using controlled filling to minimize turbulence.

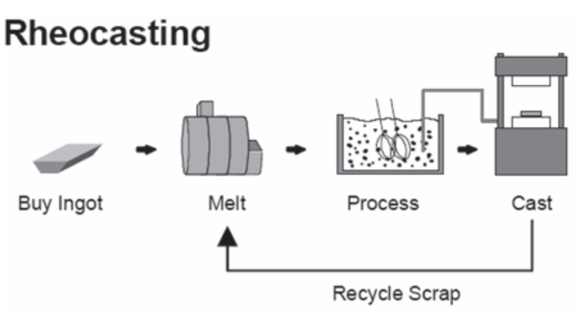

Fig. 1-10 Schematic drawing of rheocasting process.

Rheocasting first entered commercial production in the late 1990's. Today there are a number of different rheocasting processes either in commercial production or under development around the world, many developments of which have been encouraged by the higher cost of thixocasting. These rheocasting or slurry-ready processes generally use one of three different techniques to generate the globular microstructure, either stirring, dendrite fragmentation or pouring from a low superheat to generate numerous solidification nuclei.

The major advantage of rheocasting over thixocasting is that, as the semi-solid feed material is produced at the casting machine by cooling from the liquid, a special feed material is not required. Instead conventional ingot material can be used, eliminating the surcharge associated with the thixoforming billet. Another advantage is that biscuits and runners can now be recycled directly into the casting stream, again reducing cost (see Figure 1-10). However, especially when compared to thixocasting, much greater care must be taken with metal cleanliness when producing parts using rheocasting.

It is worth noting that not all rheocasters are focusing on the production of structural, safety-critical components. Rheocasting provides much greater flexibility for casting lower solid fraction slurries, and some rheocasters are producing castings using solid fractions as low as 15%. As these lower solid fraction slurries will be less viscous, turbulence during die filling can become more of an issue. Consequently, these low solid fraction rheocasting processes are generally being used to produce die casting-like parts having reduced porosity levels (often eliminating the need for impregnation).

Alloys used for rheocasting include not only the foundry-type alloys (A356, 357, 366, A390, high strength 319), but also alloys used more typically for die casting such as 380 and 383.

3.3 Thixomolding

Thixomolding, a process that combines many of the aspects of die casting, semi-solid casting and plastic injection molding, is a semi-solid process for the production of components exclusively from magnesium alloys. It uses a specially designed machine, closer in design to a plastic injection molder than a die casting machine.

The thixomolding process is shown schematically in Figure 1-11. Special magnesium alloy pellets or chips are used as the feed material for the process. Room temperature chips are fed into the back end of a heated steel barrel using a volumetric feeder. The barrel is maintained under an argon atmosphere, to reduce oxidation of the magnesium chips. The barrel is heated in several zones, typically by radiant heaters located on the outside of the barrel. Inside the barrel, rotation of the screw moves the magnesium chips forward as they are heated into the semi-solid temperature range.

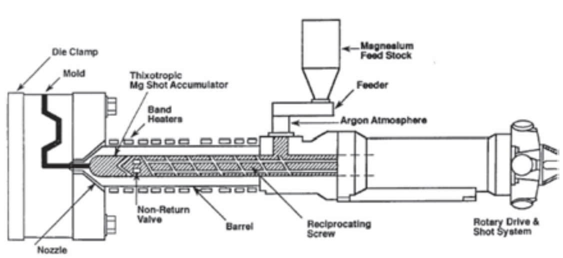

Fig. 1-11 Schematic drawing of thixomolding process.

Once semi-solid, the screw rotation provides the necessary shearing force to break up the dendrites and produce the globular particles required for semi-solid casting. A nominal slurry injection temperature for magnesium alloy AZ91D is 580°C (1076°F), which corresponds to a solid fraction of about 30%. Once the semi-solid slurry reaches the front of the heating zone, it is forced through a non-return valve and into an accumulation zone. When the appropriate amount of slurry is collected in the accumulation zone, the screw moves forward to force the semi-solid slurry into the pre-heated steel die to produce a near-net shape part. Pressure is maintained during solidification to reduce porosity. Once the component has solidified, the screw retracts and the process repeated.

As the semi-solid slurry is fully contained within the barrel of the thixomolding machine, this also allows thixomolders to make parts over a wide range of solid fractions. Thixomolded components are produced with solid fractions as high as 40-50%, or as low as 5%. Typically the thinner walled components will be produced using lower solid fractions to optimize flow length, but obviously at such a low solid fraction the slurry will be more fluid, potentially generating turbulence during die filling. The production of structural components will utilize higher solid fractions (30% or greater) to minimize turbulence and so entrapped gasses.

Thixomolding cannot be used for aluminum alloys due to the semi-solid slurry being contained within a steel barrel and being stirred by a steel augur. Similar to issues preventing the hot chamber die casting of aluminum, the use of semi-solid aluminum in the thixomolding machine would dissolve the steel augur and barrel.

The first thixomolding machine was built in 1991 and thixomolding entered commercial production shortly afterwards. Similar to die casting machines, thixomolding machines are sized based on the clamping force applied to the platens. Thixomolding machines typically range in size from 75 tons to 1600 tons or so.

The main advantages of the thixomolding process are lower porosity, longer mold life (due to the lower casting temperature), more rapid start-up, changeover and shut down of the process, and reduced melt loss. Another advantage is that thixomolding avoids the foundry environment, as the semi-solid magnesium is completely contained within the thixomolding machine. However, cycle rates for a thixomolding machine tend to be slower than for conventional hot chamber die casting. In addition, the chipping process used to produce the feed material for thixomolding adds cost over conventional ingot material.

Thixomolders typically use the same magnesium foundry alloys as hot chamber die casters, such as AZ91, AM50 and AM60.

Mechanical properties of these alloys after high vacuum die casting are listed in Tables 2 - 4.

Note: Thixomolding is a proprietary process licensed by Thixomat Inc.

Summary

Table 1-1 summarizes many of the processing parameters used with squeeze casting and the three semi-solid casting processes, and compares them to conventional high pressure die casting.

Parameter	Die Casting	High Vacuum Die Casting	Squeeze Casting	Thixocasting	Rheocasting	Thixomolding
Feed Material	Liquid	Liquid	Liquid	Semi-solid	Semi-solid	Semi-solid
Gate Size	Thin	Thin	Thick	Thick	Thin or thick	Thin
Injection speed	Fast	Fast	Very Slow	Slow	Slow to fast	Fast
Intensification pressure	Normal	Normal	High	High	Medium to high	Medium to high
Vacuum	<400 millibar	<50 millibar				
Porosity level	High	Low to very low	Low to very low	Very low	Low to very low	Low

Table 1-1 Comparison of process parameters for thixocasting, rheocasting, thixomolding, and conventional high pressure die castings.

4. Comparisons of High Vacuum, Squeeze, SSM and Other Casting Processes

1

The following tables show comparisons of a number of processing characteristics for High Vacuum, Squeeze, SSM and other casting processes. The single digit entries (1,2,3,4 or 5) in the tables are intended to be a qualitative indicator with 1 being most favorable and 5 being least favorable.

Table 1-2a: Product Characteristics – Strength & Integrity Factors

Mass Produciton Process	Solidificaiton Rate (SDAS)	Microporosity	Shrinkage Feeding	Pressure Tightness	Solution Heat Treatable	Alloy Range Applicable	MMC Applicable	Surface Integrity	Weldability	Available Strength	Available Ductility
DIE CAST											
Conventional	5-25	5	4	4	No	4	5	1	5	5	5
Controlled Shot	5-40	4	3	3	Limited	4	3	1	4	4	4
Vacuum	5-25	2	3	3	Limited	4	3	1	4	3	4
High Vacuum	5-25	1	2	1	Yes	3	3	1	1	1	1
SQUEEZE CAST											
Direct	25-78	1	1	1	Yes	3	1	3	1	1	1
Indirect	5-25	1	1	1	Yes	3	2	1	1	1	1
SEMI-SOLID CASTING											
Thixocasting	10-40	1	1	1	Yes	3	1	1	1	1	1
Rheocasting	10-40	1-2	1-3	1-3	Yes	2	1	1	1-3	1	1
Thixomolding	5-15	2-5	3-4	1-4	Yes	4	1	1	3	4	2
SAND PROCESS											
Green	40-100	5	4	4	Yes	1	3	5	2	3	3
Dry	30-80	4	4	4	Yes	1	3	4	2	3	3
Cosworth	25-60	3	3	3	Yes	1	5	4	2	3	3
Lost Foam	50-150	5	4	4	Yes	4	5	5	2	5	5
PERMANENT MOLD											
Gravity, Static	20-60	3	3	3	Yes	2	3	3	2	3	2
Gravity, Tilt	20-60	3	3	3	Yes	2	4	3	2	3	2
Low Pressure	20-60	2	2	2	Yes	3	5	3	2	2	2
Counterpressure	20-60	2	2	2	Yes	3	5	2	2	2	2
Cast Forged	15-40	2	2	2	Yes	4	3	2	2	2	2
High Vacuum	5-25	1	2	1	Yes	3	3	1	1	1	1
FORGING	N/A	1	N/A	1	Yes	5	3	3	1	1	1

Table 1-2b: Product Characteristics – Dimensional & Complexity Factors

	Net Shape Capabilities				Dimensional Tolerance					Surface Finsih
Mass Produciton Process	Part Complexity	Dimensional Repeatability	Machining Allowance	Minimum Walls	Linear	Draft	Across Parting	Thickness	Flatness	Smoothness
DIE CAST										
Conventional	1	1	1	1	1	2	2	2	2	1
Controlled Shot	2	1	2	1	1	2	2	2	2	1
Vacuum	1	1	1	1	1	2	2	2	2	1
High Vacuum	1	1	1	1	1	2	2	1	1	1
SQUEEZE CAST										
Direct	4	2	5	4	3	5	4	5	1	2
Indirect	2	1	3	1	1	2	2	3	2	1
SEMI-SOLID CASTING										
Thixocasting	2	1	1	1	1	1	1	2	2	1
Rheocasting	2	1	1	1	1	1	1	2	2	1
Thixomolding	2	1	1	1	1	1	1	1	2	1
SAND PROCESS										
Green	2	5	5	5	5	3	5	4	4	5
Dry	2	3	3	4						
Cosworth	2	3	3	4	4	3	4	3	3	4
Lost Foam	1	2	3	2	3	1	1	1	5	5
PERMANENT MOLD										
Gravity, Static	3	3	4	3	3	4	4	3	3	3
Gravity, Tilt	3	3	4	3	3	4	4	3	3	3
Low Pressure	3	3	4	3	2	4	3	3	3	3
Counterpressure	3	3	4	3	2	4	3	3	3	3
Cast Forged	5	2	5	4	2	5	4	4	2	2
FORGING	5	2	5	5	2	5	5	5	1	2

Table 1-2c: Product Characteristics – Machine & Tooling Factors										
	Machine		Combined				Tooling			
Mass Produciton Process	Productivity (Cycle Time)	Utilization (Up Time)	Internal Coring	Cast-In Inserts	Materials	Development Time	Life	Cost	Change Flexibility	Multi-Cavity
DIE CAST										
Conventional	2	5	5	1	Tool Steel	3	3	4	5	3
Controlled Shot	2	4	3	2	Tool Steel	3	2	5	5	3
Vacuum	2	5	5	1	Tool Steel	3	3	5	5	3
High Vacuum	1	4	4	1	Tool Steel	2	4	5	5	3
SQUEEZE CAST										
Direct	5	4	5	4	Tool Steel	2	4	4	5	5
Indirect	3	3	3	1	Tool Steel	5	4	5	5	3
SEMI-SOLID CASTING										
Thixocasting	1	1	3	1	Tool Steel	5	1	4	5	3
Rheocasting	1	2	3	1	Tool Steel	5	1	4	5	3
Thixomolding	2	2	3	1	Tool Steel	5	1	4	5	3
SAND PROCESS										
Green	1	1	1	5	Plastic-Steel	1	1	1	1	1
Dry	4	2	1	3	Iron-Steel	2	3	3	2	4
Cosworth	4	2	1	3	Iron-Steel	2	2	2	2	4
Lost Foam	3	2	1	5	Aluminum	4	1	2	2	3
PERMANENT MOLD										
Gravity, Static	4	2	2	4	Iron-Steel	3	4	2	3	3
Gravity, Tilt	4	2	3	4	Iron-Steel	3	4	2	3	4
Low Pressure	5	3	2	3	Iron-Steel	2	4	3	4	3
Counterpressure	5	3	2	3	Tool Steel	3	3	3	4	4
Cast Forged	5	3	5	5	Tool Steel	2	4	4	4	5
FORGING	1	4	5	5	Tool Steel	2	2	4	5	5

Table 1-2d: Product Characteristics – Casting Factors

Mass Produciton Process	Metal Flow	Directed Solidification	°F/Sec Solidifications	Sec Cavity/ Fill Time	KSI Solidifications	°F Die/Mold Temperature	° F Pouring Temperature
DIE CAST							
Conventional	5	4	1	0.04-0.1	10-15	300-450	1175-1250
Controlled Shot	4	4	2	0.05-0.2	6-12	400-600	1225-1300
Vacuum	4	4	1	0.04-0.1	4-8	300-450	1175-1250
High Vacuum	2	2	1	0.03-0.1	4-8	400-600	1175-113
SQUEEZE CAST							
Direct	2	4	3	5-25	15-40	450-600	1300-1350
Indirect	1	1	1	0.5-2	10-20	450-600	1275-1400
SEMI-SOLID CASTING							
Thixocasting	1	1	1	0.1-0.5	10-20	300-600	<1100
Rheocasting	1	1	1	0.05-0.5	10-20	300-600	<1150
Thixomolding	1	1	1	0.04-0.2	5-20	200-600	<1150
SAND PROCESS							
Green	3	4	4	5-25	Atmos.	Ambient	1300-1400
Dry	3	3	4	5-25	Atmos.	Ambient	1300-1350
Cosworth	1	3	3	5-25	Atmos.	Ambient	1300-1350
Lost Foam	2	5	5	5-25	Atmos.		
PERMANENT MOLD							
Gravity, Static	3	3	3	5-25	Atmos.	600-800	1300-1500
Gravity, Tilt	2	2	3	10-30	Atmos.	600-800	1300-1450
Low Pressure	1	2	3	10-60	Atmos.	600-800	1275-1350
Counterpressure	1	2	3	10-60	0.2-1	600-800	1275-1350
Cast Forged	2	4	2	5-25	Atmos.	400-600	1250-1300
FORGING	N/A	N/A	N/A	N/A	N/A	300-600	N/A

Table 1-2e: Economics – Process & Product Cost Factors								
	Process					Product		
Mass Produciton Process	Overall	Equipment	Tooling	Casting	Processing	Raw Material	Component Weight	Near-Net Shape
DIE CAST								
Conventional	1	4	4	1	1	1	2	1
Controlled Shot	3	4	5	3	1	2	2	1
Vacuum	2	4	5	2	1	2	2	1
High Vacuum	3	4	5	2	1	3	1	1
SQUEEZE CAST								
Direct	3	4	4	3	3	2	1	3
Indirect	3	5	5	2	2	2	1	2
SEMI-SOLID CASTING								
Thixocasting	4	5	4	3	1	5	1	1
Rheocasting	2	5	4	2	1	2-3	1	1
Thixomolding	2	5	4	2	1	4	1	1
SAND PROCESS								
Green	1	2	1	1	5	1	5	4
Dry	3	3	2	2	4	2	5	3
Cosworth	2	3	2	2	4	3	4	3
Lost Foam	1	3	2	1	–	–	–	–
PRECISION PROCESS								
Investment	3	3	2	3	2	4	2	1
Plaster	3	2	1	3	4	4	2	1
PERMANENT MOLD								
Gravity, Static	2	1	3	3	4	1	4	3
Gravity, Tilt	2	2	3	3	3	2	4	3
Low Pressure	2	1	3	3	2	2	3	3
Counterpressure	2	2	4	3	2	2	3	3
Cast Forged	4	2	4	3	1	3	3	4
FORGING	4	5	4	4	4	4	1	5

Heat Treatment & Temper Designations for High Vacuum, Squeeze & SSM Casting

Section 2

Examination of the heat treatment of nonferrous alloys reveals a wide variety of processes are employed. The process of precipitation and the hardening that accompanies it are especially important in aluminum alloys, and also in some magnesium and copper alloys.

1.1 Solution Heat Treatment

A prerequisite to precipitation hardening is the ability to heat the alloy to a temperature range wherein the hardening elements are dissolved. This is possible because, for many alloys, a solid solution can dissolve a greater concentration of hardening elements at an elevated temperature than at room temperature. This solid solution structure, containing a higher concentration of hardening elements, is then retained at ambient temperatures by cooling rapidly (for example, water quenching) to prevent the precipitates from forming. At room temperature, this solid solution structure is supersaturated with respect to the hardening elements, and hence is unstable.

1.2 Quenching

This is the second important step in the sequence of heat treating operations. The objective is to preserve the solid solution formed at the solution heat-treating temperature. As a broad generalization, the highest strengths available and the best combinations of strength and toughness are those associated with rapid quenching rates, as achieved by quenching into agitated water. Resistance to corrosion and stress corrosion cracking are other characteristics that are generally improved by the fastest quenching rates. For maximum dimensional stability, some castings are fan cooled or even cooled in still air. In such instances, precipitation-hardening response is limited, resulting in lower strength and hardness.

1.3 Precipitation Heat Treatment

After solution heat treatment and quenching, precipitates can then form. In fact, in some alloys, precipitation can occur spontaneously at room temperature. However, for most alloys, this process is both speeded up and controlled through a controlled elevated temperature “aging” process. This process occurs by raising the temperature of the casting to promote the chemical diffusion process, which allows the supersaturated hardening elements to concentrate and “precipitate” out of the supersaturated solid solution. It is this formation of fine precipitates evenly distributed throughout the matrix that provides the higher strength. Choice of time-temperature cycles for precipitation heat treatment should receive careful consideration. Larger particles of precipitate result from longer times and higher temperatures; however, the larger particles must of necessity be fewer in number with greater distances between them. The objective is to select the cycle that produces optimum precipitate size and distribution pattern. Unfortunately, the cycle required to maximize one property, such as yield strength, is usually different from that required to maximize others, such as elongation or corrosion resistance. Consequently, the cycles used commercially represent compromises that provide the optimum combinations of properties. Parts may be “under-aged” or “over-aged” to achieve specific combinations of strength, ductility, corrosion resistance, and stability. Generally, the hardness and strength will increase and the ductility will decrease at more severe aging parameters. However, with longer aging times, the strength starts to drop and the elongation increases. (Fig. 2-1) This is termed over-aging. The over-aging process is accelerated at higher temperatures.

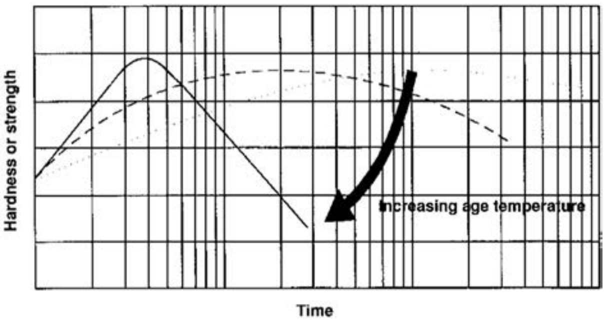

Fig. 2-1 Effect of age hardening temperature for alloy AlSi7Mg(A356).

2. Heat Treatment: Issues & Controls

2.1 Overheating

Nominal commercial solution heat-treating temperature is determined by the composition limits of the alloy, with an allowance for unintentional excessive temperature variations. Care must be exercised to avoid exceeding the solidus temperature. If appreciable eutectic melting occurs as a result of overheating, properties such as tensile strength, ductility, and fracture toughness will be degraded. Materials that exhibit microstructural evidence of incipient melting/overheating are generally considered unacceptable. The lower limit for the solution heat treatment is based on maximizing the amount of hardening elements dissolved in the solid solution.

2.2 Excessive Heating Rate

When high heating rates are employed, the phenomenon of non-equilibrium melting must be considered. This phenomenon occurs when certain phases or compounds are slow to dissolve in the solid solution. When the heating rate is rapid, much of these phases will melt before the diffusion process has time to disperse the compounds into the solution. If this occurs, and the material is quenched before the liquid has had time to equilibrate, it will solidify and form fine eutectic rosettes (incipient melting). Examination of the alloy microstructure should be included as part of the certification process when faster heating rates are used.

2.3 Underheating

When the temperature attained by the parts is appreciably below the normal range, the amount of hardening elements dissolved in the solid solution will be reduced and the strength, after aging, will be somewhat lower than expected.

2.4 Plunger and Die Lubricants

High integrity-high pressure castings, produced by properly run high vacuum, squeeze and SSM casting processes, contain very low levels of porosity. However, selection of plunger and die lubricants for these processes is a critical issue. Incorrect selection and application of plunger and die lubricants may result in residual material in the part that when exposed to the temperatures in solution heat treatment, will break down and form blisters in the heat treated part, especially at the cast surface.

2.5 Solution Heat Treatment Schedule

This is the time at temperature required to dissolve a satisfactory amount of the hardening phases and to achieve good homogeneity within the solid solution. Solution treatment serves two functions in Al-Si alloys, 1) solution of the precipitates and 2) spheroidization of the Si phase, which increases ductility. The time required for spheroidization may be somewhat longer than the time required for solutionizing. Both times are a function of the morphology of the microstructure before heat treatment, and the thickness of the material section. Soak time is not considered to have begun until all the instrumentation on the furnace and the load has stabilized at the desired temperature.

2.6 Quenching

Quench delay times, which are defined as starting when the furnace door begins to open until the load is fully immersed in the quenchant are critical to the resulting mechanical propertiess. The shorter the delay the better the results. Addtionally, residual stresses which can cause cracking or lead to warpage in subsequent machining operations can be generated by non-uniform quenching of thick and thin sections. This tendency can be reduced through special quenchants, such as inversely-soluble polymers that prevent nucleation boiling on casting surfaces.

3. Temper Designations

The temper designations used in the United States for heat-treatable aluminum alloys are part of the system that has been adopted by the American National Standard Institute (ANSI H35.1). Used for all wrought and cast product forms except ingot, the system is based on the sequences of mechanical or thermal treatments, or both, used to produce the various tempers. For the purposes of this document, only the basic temper designations for cast products will be defined.

F, as-cast –
cooled from the cast mold with no subsequent heat treatment.

O, annealed –
medium-temperature thermal treatment intended to soften the casting and relieve stresses; provides lowest residual stresses.

3.1 Major Subdivisions of "T" temper

In T-type designation, the T is always followed by a number; each number denotes a specific sequence of basic treatments as described below.

T4, solution heat treated –
thermal treatment just below the solidus temperature intended to bring soluble phases into solid solutions; for a short time after solution heat treating, it provides the "softest" condition, so it is sometimes suitable for machining or forming before aging to full T6 or T7 temper. T4 is a reasonably stable and suitable temper in certain Al-Cu (2XX) or Al-Mg (5XX) alloys, but not stable and not a final temper for the more common high vacuum, squeeze and SSM Al-Si/Mg (3XX) alloys.

T5, artificially aged only–
low temperature thermal treatment generally intended to strengthen and harden the casting; may also improve machinability; also relieves stresses and stabilizes for service at elevated temperatures. In most cases it is necessary to quench the casting immediately upon ejection.

T6, solution heat treated, quenched and artificially aged –
generally produces the highest strength and hardness, combined with reasonable ductility. A modified T6 heat treatment (Auraltherm or similar process) can be used with high vacuum die castings. The Auraltherm process involves a "partial solution heat treatment" at a slightly lower temperature followed by rapid air cooling. A normal aging treatment is used after quenching.

T7, solution heat treated, quenched and over-aged –
provides the highest strength/hardness & ductility combination with stress relief and stability for service at elevated temperatures.

Chemical, Mechanical & Physical Properties of High Vacuum, Squeeze, and Semi-Solid Die Castings

Section
3

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3

** Data presented for these alloys are the results of DOE/CMC/NADCA sponsored research and development.*

+ Data presented for these alloys are from an SAE paper by R. DasGupta (SPX/Contech).

1. Introduction

Alloys selected for high vacuum, squeeze and semi-solid die castings are typically chosen for specific mechanical or physical property requirements. However, castability issues such as mold-ability, tool life, and hot tearing resistance must also be considered. It should be noted that the property data for squeeze and semi-solid castings listed in this specification have not been scrutinized by the manufacturing and user industries to the same degree as other types of castings. Therefore, the data provided in this manual should be considered preliminary. The data for high vacuum die casting alloy properties is taken from alloy producer and user publications. The data supplied in this manual have been collected from various sources to provide typical values for the various alloys and HIHP casting processes.

Because of normal processing parameters, especially solidified under high pressure and/or in absence of air, high vacuum, squeeze, and SSM die casting typically contains significantly less micro porosity (both hydrogen and microshrinkage types) than is normally observed in permanent mold. This results in somewhat higher properties and especially higher fatigue resistance.

1.1 High Vacuum Die Casting

The steel welded assemblies that many of these castings replace, are significantly heavier. The high vacuum levels are associated with the requirements to heat treat the castings to optimize the properties achievable as production solutions.

In the high vacuum casting processes, the properties sought after are:

- High ultimate strength
- High elongation consistent with many body-in-white components
- Attachment complexity embedded in the design

Most commonly used high vacuum die casting alloys can be categorized within 2 main alloy families, the typical 3xx series (Al-Si-Mg) alloys and the Al-Mg-Si type alloys. They all have in common that the typically high levels of Fe (to beat die soldering) of traditional die casting alloys is reduced to below 0.25% and replaced by Mn and in some cases also a small addition of Sr. Successful tests have also been done with 7xx series alloys (Al-Zn-Mg type) alloys which offer very attractive property packages. Die life strongly depends on the alloy composition as well as process parameters. The Al-Si-Mg type alloys offer the easiest processability and part design freedom (large, intricate, complex, thin walled) and are therefore the most commonly used ones. They are either used in F or T5 temper or in T6/7 temper for highest elongation and crash performance.

1.2 Squeeze Casting

For squeeze castings, two main casting characteristics are sought and they are similar to typical requirements for permanent mold castings:

- Good fluidity or mold filling ability
- Resistance to hot tearing and hot cracking.

Alloys most generally used in squeeze casting commercial applications include A356, 357, 380 and A390. These alloys all contain sufficient silicon and other elements to have good fluidity and resistance to hot tearing. Aluminum alloys that are less suitable for squeeze casting are the casting alloys in the 2xx, 5xx & 7xx series, which are much more sensitive to hot tearing and generally have poor mold filling ability.

1.3 Semi-Solid Casting

In semi-solid casting (SSM), resistance to hot tearing is also desirable, but the concept of fluidity is less important due to the unique way the materials are processed.

The most common aluminum alloys produced by semi-solid casting are A356 and 357. Other aluminum alloys produced by semi-solid casting include A390, 319, 319S (a modified high strength version of the conventional 319 composition), 380, and 355. In experimental trials, other aluminum alloys have been produced by semi-solid casting, such as the casting alloy 206, and wrought alloys from the 2xxx, 6xxx and 7xxx series. However, these are more sensitive to hot tearing and have generally poorer mold filling ability.

The most common magnesium alloys produced by semi-solid casting are similar to the die casting alloys, AZ91, AM50 and AM60. These alloys have excellent mold filling capability, good hot tearing resistance, and good mechanical properties after casting.

Because SSM material is handled in its "Semi-Solid" state, hypereutectic Al-Si alloys and particulate - reinforced MMC's are less likely to segregate during forming. These material also make good SSM candidates.

2.1 Cross Referencing of Aluminum Alloy Designations

Table 3-1: Cross Reference of Aluminum Alloy Designations							
Commercial	**A356**	**357**	**355**	**319**	**319S**	**A390**	**380**
AA	A356.0	357.0	355.0	319.0		A390.0	380.0
UNS	A13560	A03570	A03550	A03190		A13900	A03800

2.2 High Vacuum Die Casting

2.2.1 Chemical Composition for High Vacuum Casting

Table 3-2: Chemical Composition of Some of the Aluminum-based Alloys Commonly Used for High Vacuum Die Casting

Alloy Name	Si	Fe	Cu	Mn	Mg	Zn	Ti	Other
Aural 2	9.5-11.5	0.16-0.22	0.03	0.4-0.6	0.1-0.4	0.03	0.08	Sr: 0.01-0.018
Aural 3	9.5-11.5	0.16-0.22	0.03	0.4-0.6	0.4-0.6	0.03	0.08	Sr: 0.01-0.018
Aural 5	6.5-9.5	0.16-0.22	0.03	0.4-0.6	0.1-0.6	0.03	0.08	Sr: 0.01-0.018
Castasil 37	8.5-10.5	0.15	0.05	0.35-0.6	0.06	0.07	0.1	Mo 0.3, Zr 0.3, Sr
Magsimal 59	1.8-2.6	0.2	0.03	0.5-0.8	5.0-6.0	0.07	0.20	Be
Mercalloy 367	8.5-9.5	0.25	0.25	0.25-0.35	0.30-0.50	0.10	0.20	Sr: 0.05-0.07
Mercalloy 368	8.5-9.5	0.25	0.25	0.25-0.35	0.10-0.30	0.0	0.20	Sr: 0.05-0.07
Silafont 36	9.5-11.5	0.15	0.03	0.8	0.1-0.5	0.08	0.04-0.15	Sr

High vacuum die casting is injected at high speeds like in conventional die casting, so die soldering is a major issue due to the affinity of aluminum to iron (die steel) during injection. In conventional die casting alloys this is avoided through the high Fe content (around 1%) in typical alloys. In order to achieve high ductility it is necessary to lower the Fe content to below 0.25% so the Fe is replaced by Mn at levels of 0.25% to 0.8% and in some alloys (with the lower end of the Mn range) through the addition of Sr at 500-700ppm.

2.2.2 Mechanical Properties of High Vacuum Die Casting - F -Temper

Table 3-3: Mechanical Properties of High Vacuum Die Castings in the F-Temper (as cast)

Property	Aural 2	Aural 3	Castasil 37*	Magsimal 59**	Mercalloy 367	Mercalloy 368	Silafont 36
Yield Strength ksi MPa	17-22 (120-150)	19-23 (130-160)	12-16 (80-110)	17-21 (120-145)	17-19 (112-131)	18-20 (125-140)	17-22 (120-150)
UTS ksi MPa	36-45 (250-310)	36-45 (250-310)	29-36 (200-250)	32-38 (220-260)	38-40 (260-275)	38-40 (260-276)	36-42 (250-290)
Elongation (%)	5-10	4-8	10-14	8-12	8	10-12	5-11

* Mechanical properties for Castasil 37 based on .197-.276 in (5-7 mm) thick casting.

** Mechanical properties for Magsimal 59 based on .236-.472 in (6-12 mm) thick casting.

2.2.3 Mechanical Properties of High Vacuum Die Casting - T5 -Temper

Table 3-4: Mechanical Properties of High Vacuum Die Castings Heat Treated to the T5 - Temper

Property	Aural 2	Aural 3	Mercalloy 367	Silafont 36
Yield Strength ksi MPa	22-28 (150-190)	28-35 (190-240)	25-30 (170-205)	23-36 (155-245)
UTS ksi MPa	39-44 (270-300)	44-49 (300-340)	43-45 (295-310)	40-49 (275-340)
Elongation (%)	6.5-9	4-6.5	5.0-9.0	4-9

2.2.4 Mechanical Properties of High Vacuum Die Casting - T6/7 -Temper

Table 3-5: Mechanical Properties of High Vacuum Die Castings Heat Treated to the T6/7 - Temper

Property	Aural 2	Aural 3	Mercalloy 367	Mercalloy 368	Silafont 36
Heat Treatment	Auraltherm - 2 (T7)	Auraltherm - 3 (T7)	T6	T6	T6
Yield Strength ksi MPa	17-20 (120-140)	20-32 (140-220)	33-35 (230-245)	27-29 (185-200)	30-41 (210-280)
UTS ksi MPa	29-32 (200-220)	31-41 (210-280)	41-45 (285-310)	41-43 (280-295)	42-49 (290-340)
Elongation (%)	14-18	6-14	8-10	14-16	7-12

2.3 Squeeze Casting

Squeeze castings are generally used after heat treating to the T6 temper, although they are occasionally used in the F-temper (as-cast). Unlike semi-solid castings, squeeze castings are not used after heat treating to the T5 temper, as castings made from fully liquid alloys generally have low ductilities in the T5 temper.

2.3.1 Chemical Composition for Squeeze Casting and Semi-Solid Casting

Table 3-6: Detailed Chemical Composition of Aluminum Alloys for Squeeze and Semi-Solid Casting

Element*	A356	357	355	319	319S**	A390	380
Silicon (Si)	6.5-7.5	6.5-7.5	4.5-5.5	5.5-6.5	5.5-6.5	16.0-18.0	7.5-9.5
Iron (Fe)	0.20	0.15	0.60	1.0	0.15	0.50	2.0
Copper (Cu)	0.20	0.50	1.0-1.5	3.0-4.0	2.5-3.5	4.0-5.0	3.0-4.0
Manganese (Mn)	0.10	0.03	0.50	0.50	0.03	0.10	0.50
Magnesium (Mg)	0.25-0.45	0.45-0.60	0.40-0.60	0.10	0.30-0.40	0.45-0.65	0.10
Nickel (Ni)				0.35	0.03		0.50
Zinc (Zn)	0.10	0.05	0.35	1.0	0.05	0.10	3.0
Lead (Pb)+ Tin (Sn)					0.03		0.35
Titanium (Ti)	0.20	0.20	0.25	0.25	0.20	0.20	
Strontium (Sr)					0.01-0.05		
Other (each)	0.05	0.05	0.05		0.03	0.10	
Other (total)	0.15	0.15	0.15	0.50	0.10	0.20	0.50
Aluminum (Al)	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.

*Wt% **319S may be obtained from SAG

2.3.2 Mechanical Properties of Squeeze Castings - F- Temper

Table 3-7: Mechanical Properties of Squeeze Castings in the F-Temper (as cast)

Property	380
Yield Strength ksi (MPa)	23 (160)
UTS ksi (MPa)	38 (262)
Elongation %	2
Impact Strength ft-lbs (J)	1.5 (2)
Young's Modulus psi x 10^6 (GPa)	10.3 (71)

2.3.3 Mechanical Properties of Squeeze Castings - T6-Temper

Table 3-8: Mechanical Properties of Squeeze Castings Heat Treated to the T6-Temper

Property	A356	357	390
Yield Strength ksi (MPa)	33 (228)	36 (248)	N/A
UTS ksi (MPa)	44 (303)	48 (331)	54 (372)
Elongation %	12	9	<1
Hardness BHN	90		140
Impact Strength ft-lbs (J)	12 (16)	9 (12)	
Fatigue Strength ksi (MPa)	14 (97)		
Young's Modulus psi x 10^6 (GPa)	10.5 (72)	10.5 (72)	11.8 (81)

2.4 Semi-Solid Casting Properties

Alloys used in the Semi-Solid process are noted in table 3-2.4.1 above.
Semi-Ssolid castings are most typically used in the T5-temper although they can also be used as cast (F-temper) or after heat treating to the T6 temper.

2.4.1 Processing Information for Thixocasting and Rheocasting - T5 Temper

Typical T5 heat treatment conditions for thixocast and rheocast aluminumalloys are listed in Table 3-9. For the T5-temper, the castings must be water quenched as soon as possible and no longer than 15-30 seconds after removal from the casting die, and then aged using conditions such as those listed in Table 3-9. Rapid ejection and immediate quenching is encouraged in order to achieve significantly improved properties over the F temper.

Table 3-9: Processing Information for T5-Temper of Thixocasting and Rheocasting

Alloy	Typical Aging Conditions
A356	6-12 hrs @ 320°F (160°C)
357	6 hrs @ 338°F (170°C)
355	10 hrs @ 338°F (170°C)

3

2.4.2 Processing Information for Thixocasting and Rheocasting - T6 Temper

Typical T6 heat treatment conditions for thixocast and rheocast aluminum alloys are listed in Table 3-10. When heat treating to the T6-temper, it is not critical whether the castings are air cooled or water quenched after removal from the casting die. However, the castings must be quenched into water within 15-30 seconds after removal from the solution heat treatment furnace.

Table 3-10: Processing Information for T6-Temper of Thixocasting and Rheocasting

Alloy	Solution Heat Treatment Conditions	Typical Aging Conditions
A356	4-10 hrs @ 1000°F (540°C)	3-6 hrs @ 320°F (160°C)
357	10 hrs @ 1000°F (540°C)	6 hrs @ 338°F (170°C)
319	4 hrs @ 930°F (500°C)	4 hrs @ 338°F (170°C)
319S	6 hrs @ 930°F (500°C)	10 hrs @ 338°F (170°C)
A390	6 hrs @ 930°F (500°C)	6 hrs @ 338°F (170°C)
380	8 hrs @ 940°F (505°C)	3 hrs @ 310°F (155°C)

2.4.3 Mechanical Properties of Thixocast Aluminum Alloys Heat Treated to T5 Temper

Table 3-11: Mechanical Properties of Thixocastings Heat Treated to the T5-Temper

Property	A356	357	355
Yield Strength ksi (MPa)	26 (179)	29 (200)	33 (228)
UTS ksi (MPa)	36 (248)	41 (283)	46 (317)
Elongation %	10	8	7
Hardness BHN	89	90	
Fatigue Strength ksi (MPa)	13.5 (93)		
Young's Modulus psi x 10^6 (GPa)	10.5 (72)	10.5 (72)	10.2 (70)

2.4.4 Mechanical Properties of Thixocast Aluminum Alloys Heat Treated to T6 Temper

Table 3-12: Mechanical Properties of Thixocastings Heat Treated to the T6-Temper

Property	A356	357	319S	A390
Yield Strength ksi (MPa)	33 (228)	41 (283)	46 (317)	N/A
UTS ksi (MPa)	44 (303)	50 (345)	58 (400)	50 (345)
Elongation %	12	9	5	<0.2
Hardness BHN			119	
Impact Strength ft-lbs (J)	14 (97)	8 (55)	14 (97)	
Fracture Toughness, K_Q ksi√in		20	20.5	
Fatigue Strength ksi (MPa)			23.8* (164)*	
Young's Modulus psi x 10^6 (GPa)	10.5 (72)	10.5 (72)		11.8 (81)

*10^7 cycles

2.4.5 Mechanical Properties of Rheocast Aluminum Alloys in the F-Temper

Table 3-13: Mechanical Properties of Rheocastings in the F-Temper (as cast)		
Property	**319**	**A356**
Yield Strength ksi (MPa)	19 (131)	16 (110)
UTS ksi (MPa)	34 (234)	35 (241)
Elongation %	4	13

2.4.6 Mechanical Properties of Rheocast Aluminum Alloys Heat Treated to the T5 Temper

Table 3-14: Mechanical Properties of Rheocastings Heat Treated to the T5-Temper	
Property	**A356**
Yield Strength ksi (MPa)	26 (179)
UTS ksi (MPa)	39 (269)
Elongation %	7
Young's Modulus psi x 10^6 (GPa)	10.5 (72)

2.4.7 Mechanical Properties of Rheocast Aluminum Alloys Heat Treated to the T6 Temper

Table 3-15: Mechanical Properties of Rheocastings Heat Treated to the T-6 Temper			
Property	**A356**	**357**	**319**
Yield Strength ksi (MPa)	34 (234)	42 (290)	22 (152)
UTS ksi (MPa)	45 (310)	50 (345)	37 (255)
Elongation %	13	7	6
Young's Modulus psi x 10^6 (GPa)	10.5 (72)	10.5 (72)	10.7 (74)

2.5 Physical Properties of Aluminum Alloys Commonly Used for Squeeze Casting & Semi-Solid Casting

The values shown below in Table 3-16 are taken from the NADCA Product Specification Standards for High Pressure Die Casting and the Metals Handbook for castings produced by die casting, sand, or permanent mold casting. However, these values should be representative of values for squeeze and semi-solid castings.

Table 3-16: Physical Properties of Squeeze and Semi-Solid Aluminum Alloys

Element	A356	357	355	319	A390	380
Density lbs/in3 (g/cm3)	0.097 (2.69)	0.097 (2.69)	0.098 (2.71)	0.101 (2.80)	0.099 (2.74)	0.098 (2.71)
Melting Range °F (°C)	1030-1140 (555-615)	1030-1140 (555-615)	1010-1150 (545-620)	960-1125 (515-605)	940-1200 (505-650)	1000-1100 (540-595)
Specific Heat BTU/lb°F (J/kg°C)	0.230 (963)	0.230 (963)	0.230 (963)	0.230 (963)		0.230 (963)
Coeff. Of Thermal Expansion μ in/in°F (μ m/m°K)	11.9 (21.6)	12.0 (21.8)	12.4 (22.5)	11.9 (21.6)	10.0 (18.0)	12.2 (22.0)
Poisson's Ratio	0.33		0.33	0.33		0.33

3.1 Cross Referencing of Magnesium Alloy Designations

Most thixomolding components are made from three magnesium alloys, AZ91D, AM-60 and AM-60.

Table 3-17: Cross Reference of Magnesium Alloy Designation

Commercial	AZ91D	AM-50	AM-60
UNS	M11916		M10600
DIN 1729			3.5662.05
JIS H 2222 & H 5303	MDI1D		MDI2A

3.2 Chemical Composition of Magnesium Alloys for Thixomolding

Table 3-18: Chemical Composition of Magnesium Alloys Used for Thixomolding

Element*	AZ91D	AM-50	AM-60
Aluminum (Al)	8.3-9.7	4.4-5.4	5.5-6.5
Zinc (Zn)	0.35-1.0	0.22 max	0.22 max
Manganese (Mn)	0.15-0.50†	0.26-0.6†	0.24-0.6†
Silicon (Si)	0.10 max	0.10 max	0.10 max
Iron (Fe)	0.005†	0.004†	0.005†
Copper (Cu), Max	0.030	0.010	0.010
Nickel (Ni), Max	0.002	0.002	0.002
Others Total	0.02	0.02	0.02
Magnesium (Mg)	Balance	Balance	Balance

*Wt%

†If either of the minimum manganese limit or the maximum iron limit is not met, then the iron/manganese ratio shall not exceed 0.032 for AZ91D, 0.015 for AM-50 and 0.021 for AM-60

3.3 Processing Information for Thixomolded Magnesium Components

Most thixomolded components are used in the F-temper.

3.4 Mechanical Properties of Thixomolded Magnesium Components

Table 3-19: Mechanical Properties of Thixomold Castings

Property	AZ91D	AM-50	AM-60
Yield Strength ksi (MPa)	23 (159)	18 (124)	19 (131)
UTS ksi (MPa)	34 (234)	32 (220)	32 (220)
Elongation %	3-6	6-13	6-9
Hardness BHN	63		65
Shear Strength ksi (MPa)	20 (138)		
Impact Strength ft-lbs (J)	6.6 (8.9)		6.2 (8.4)
Fatigue Strength ksi (MPa)	14 (97)		10-13 (69-90)
Young's Modulus psi x 10^6 (GPa)	6.5 (45)	6.5 (45)	6.5 (45)

3.5 Physical Properties of Magnesium Thixomolded Components

Table 3-20: Physical Properties of Thixomold Magnesium Alloys

Property	AZ91D	AM-50	AM-60
Density lbs/in^3 (g/cm^3)	0.066 (1.81)	0.064 (1.78)	0.065 (1.79)
Melting Range °F (°C)	875-1105 (470-595)	1010-1150 (543-620)	1005-1140 (540-615)
Specific Heat BTU/lb °F (J/kg°C)	0.25 (1.05)	0.25 (1.05)	0.25 (1.05)
Coeff. Of Thermal Expansion μ in/in°F (μ m/m°K)	13.8 (25.0)	14.4 (26.0)	14.2 (25.6)
Thermal Conductivity BTU/ft hr °F (W/m °K)	42 (72)	36 (62)	36 (62)
Electrical Resistivity (μΩcm)	(14.1)	(12.5)	(12.5)
Poisson's Ratio	0.35	0.35	0.35

3

Table 3-21: Typical Properties for Cast Aluminum Alloys Producd by the Squeeze and SSM Processes

		Squeeze Cast				SSM Cast			
						Thixocast			
		380-F	A356-T6	357-T6	390-T6	355-T5	A356-T5	357-T5	319S-T6
Yield Strength	**ksi**	23	33	36	N/A	33	26	29	46
	(MPa)	(160)	(228)	(248)	N/A	(228)	(179)	(200)	(317)
Ultimate Tensile Strength	**ksi**	38	44	48	54	46	36	41	58
	(MPa)	(262)	(303)	(331)	(372)	(317)	(248)	(283)	(400)
Elongation	**%**	2	12	9	<1	7	10	8	5
Hardness	**HBN**		90		140		89	90	119
Impact Strength	**ft-lbs**	1.5	12	9			13.5		14
	(J)	(2)	(16)	(12)			(93)		(97)
Fatigue Strength	**ksi**		14						23.8*
	(MPa)		(97)						(164*)
Young's Modulus	**psi x 10^6**	10.3	10.5	10.5	11.8	10.2	10.5	10.5	10.2
	(GPa)	(71)	(72)	(72)	(81)	(70)	(72)	(72)	(70)
Density	**lbs/in³**	0.098	0.097	0.097	0.098	0.098	0.097	0.097	
	(g/cm³)	(2.71)	(2.69)	(2.69)	(2.73)	(2.71)	(2.69)	(2.69)	
Melting Range	**°F**	1000-1100	1030-1140	1030-1140	950-1200	1010-1150	1030-1140	1030-1140	
	(°C)	(540-595)	(555-615)	(555-615)	(510-650)	(545-620)	(555-615)	(555-615)	
Specific Heat	**BTU/lb°F**	0.230	0.230	0.230		0.230	0.230	0.230	
	(J/kg°C)	(963)	(963)	(963)		(963)	(963)	(963)	
Coeff of Thermal Exp.	**µ in/in°F**	12.2	11.9	12.0	10	12.4	11.9	12.0	
	(µ m/m°K)	(22.0)	(21.6)	(21.8)	(18.0)	(22.5)	(21.6)	(21.8)	
Poisson's Ratio		0.33	0.33			0.33	0.33		

*10^7 cycles

SSM Cast								
Thixocast				Rheocast				
A356-T6	357-T6	A390-T6	319-F	A356-F	A356-T5	319-T6	A356-T6	357-T6
33 (228)	41 (283)	N/A N/A	19 (131)	16 (110)	26 (179)	22 (152)	34 (234)	42 (290)
44 (303)	50 (345)	50 (345)	34 (234)	35 (241)	39 (269)	37 (255)	45 (310)	40 (345)
12	9	<0.2	4	13	7	6	13	7
14 (97)	8 (55)							
10.5 (72)	10.5 (72)	11.8 (81)			10.5 (72)	10.7 (74)	10.5 (72)	10.5 (72)
0.097 (2.69)	0.097 (2.69)	0.099 (2.74)	0.101 (2.8)	0.097 (2.69)	0.097 (2.69)	0.101 (2.8)	0.097 (2.69)	0.097 (2.69)
1030-1140 (555-615)	1030-1140 (555-615)	940-1200 (505-650)	960-1125 (615-605)	1030-1140 (555-615)	1030-1140 (555-615)	960-1125 (515-605)	1030-1140 (555-615)	1030-1140 (555-615)
0.230 (963)	0.230 (963)		0.230 (963)	0.230 (963)	0.230 (963)	0.230 (963)	0.230 (963)	0.230 (963)
11.9 (21.6)	12.0 (21.8)	10.0 (18.0)	11.9 (21.6)	11.9 (21.6)	11.9 (21.6)	11.9 (21.6)	11.9 (21.6)	12.0 (21.8)
0.33			0.33	0.33	0.33	0.33	0.33	

3

The data contained in this section represents actual measured values obtained on specimens removed from select production casting configurations. This data is presented in addition to the typical properties shown in the previous sections in order to provide additional information on the capability of various squeeze and semi-solid metal cast alloys. Since there are more alloys shown in this section than those most commonly squeeze and semi-solid metal cast, an expanded chemical composition table is displayed at the end of this section for ease of reference.

Squeeze Cast 356-T61

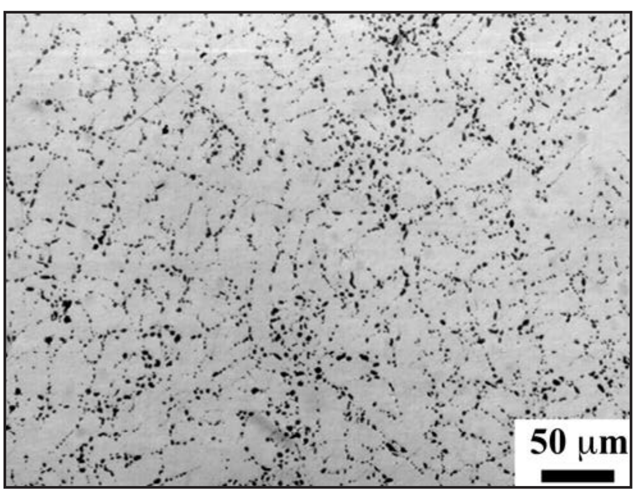
Alloy Chemistry:

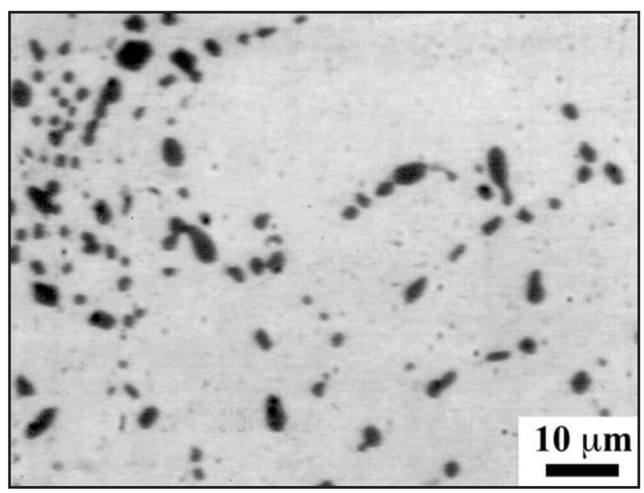
7.8%Si	0.33%Mg	0.22%Fe	0.14%Ti

Component & Test Sample Description:
Test samples were taken from the center of a 0.375 inch think plate of a large 356 squeeze casting. This plate section was roughly halfway between a heavy section and the gate.

Heat Treatment:
Samples solutionized for 8 hours at 1000°F (538°C) and then quenched into 150°F (65°C) water. Samples were then allowed to incubate at room temperature for no less than 24 hours and were then artificially aged for 8 hours at 310°F (154°C).

Microstructure:

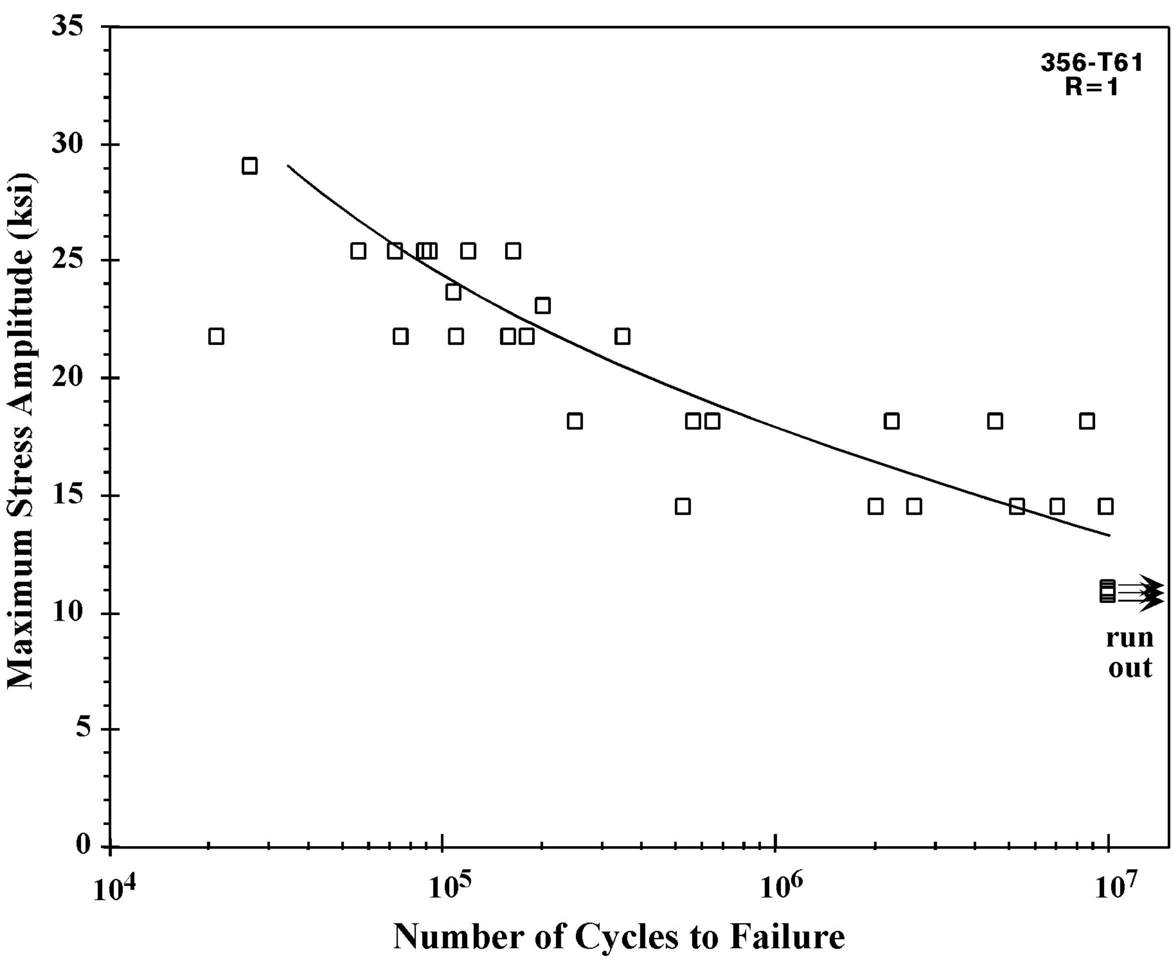




Comments:
Because of the extensive liquid feeding that occurred parallel to the axis of the tensile samples, a number of eutectic rich feed channels resulted, which although they are typically about 50 to 100 μm in diameter, some are up to 350 μm in diameter. The axis of the tensile samples was parallel to the axis of this feeding.

The samples also contained a minor volume fraction of β-FeSiAl intermetallic plates. Such high Fe content has resulted in lower elongation to failure values.

Properties			
Tensile	**Round tensile bars with 0.25″ x 0.25″ guage cross section and 1.0″ gauge length**		**Average ± Standard Deviation**
	Yield Stress	(MPa)	231.7± 5.5
		(ksi)	33.6 ± 0.8
	UTS	(MPa)	371.2 ± 1.4
		(ksi)	46.0 ± 0.2
	Elongation to Failure (%)		11.9 ± 1.9
	Minimum Elongation (%)		5.3
	Reduction in Area (%)		14.2
Hardness	Vickers Hardness		113 ± 2
	Rockwell B		
Microstructure	Secondary dendrite arm spacing (μm)		24
	Average silicon particle diameter (μm)		26



Squeeze Cast A356-T61

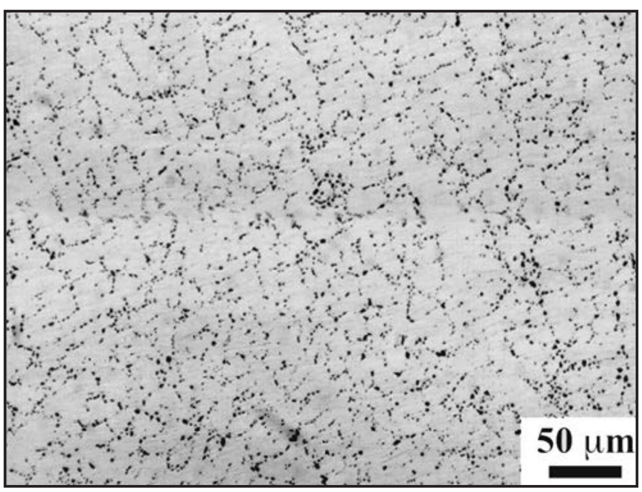
Alloy Chemistry:

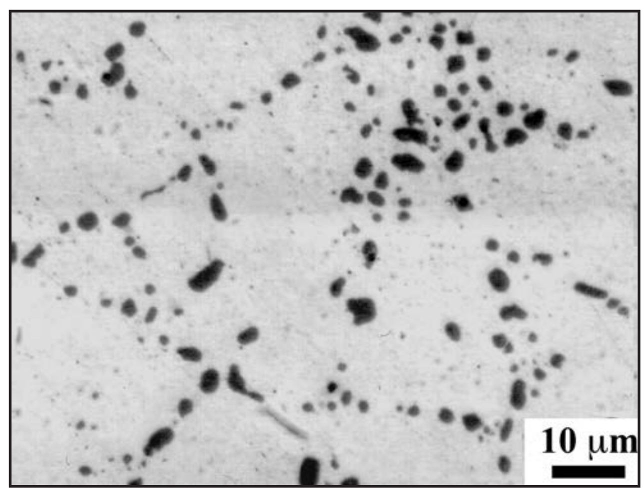
6.8%Si	0.37%Mg	0.11%Fe	0.019%Sr

Component & Test Sample Description:
Test samples were taken from the edge of a 0.5" thick web of a blocky A356 squeeze cast part. Since the samples were at the end of the web there was very little fluid flow in this section of the casting late in the solidification sequence.

Heat Treatment:
Samples solutionized for 8 hours at 1000°F (538°C) and then quenched into 150°F (65°C) water. Samples were then allowed to incubate at room temperature for no less than 24 hours and were then artificially aged for 8 hours at 310°F (154°C).

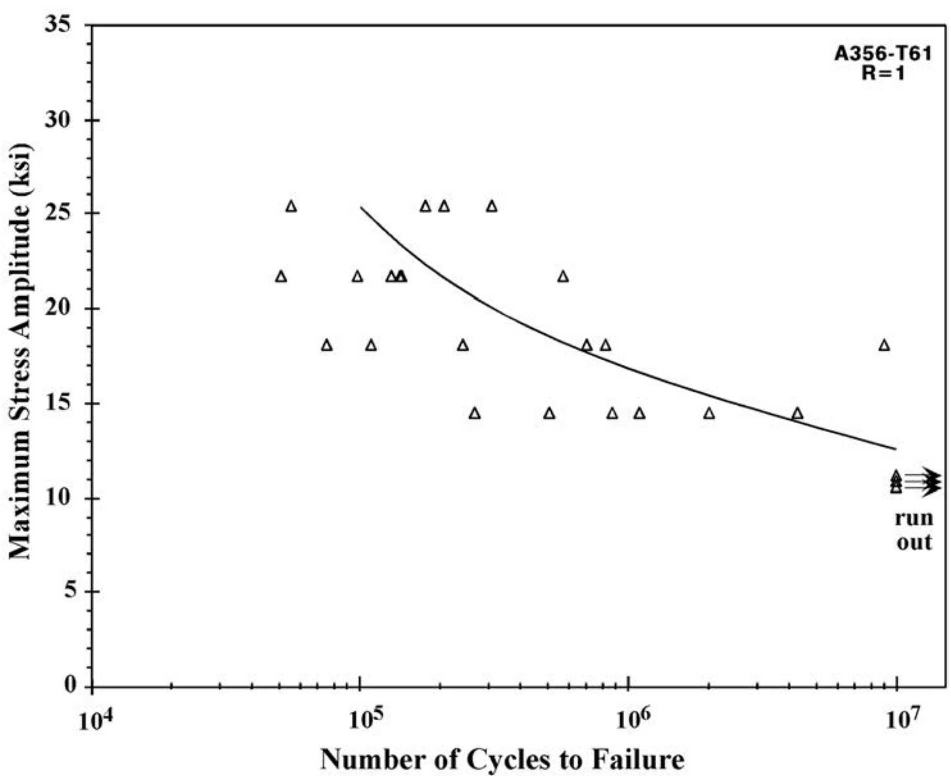
Microstructure:





Properties			
	Round tensile bars with 0.25″diameter and 1.0″ long guage length		**Average ± Standard Deviation**
Tensile	Yield Stress	(MPa)	246.8 ± 11.7
		(ksi)	35.8 ± 1.7
	UTS	(MPa)	299.9 ± 6.9
		(ksi)	43.5 ± 1.0
	Elongation to Failure (%)		6.6 ± 2.0
	Minimum Elongation (%)		2.6
	Reduction in Area (%)		8.5
Hardness	Vickers Hardness		117 ± 4
	Rockwell B		
Microstructure	Secondary dendrite arm spacing (µm)		
	Average silicon particle diameter (µm)		

3



Squeeze Cast B356-T61

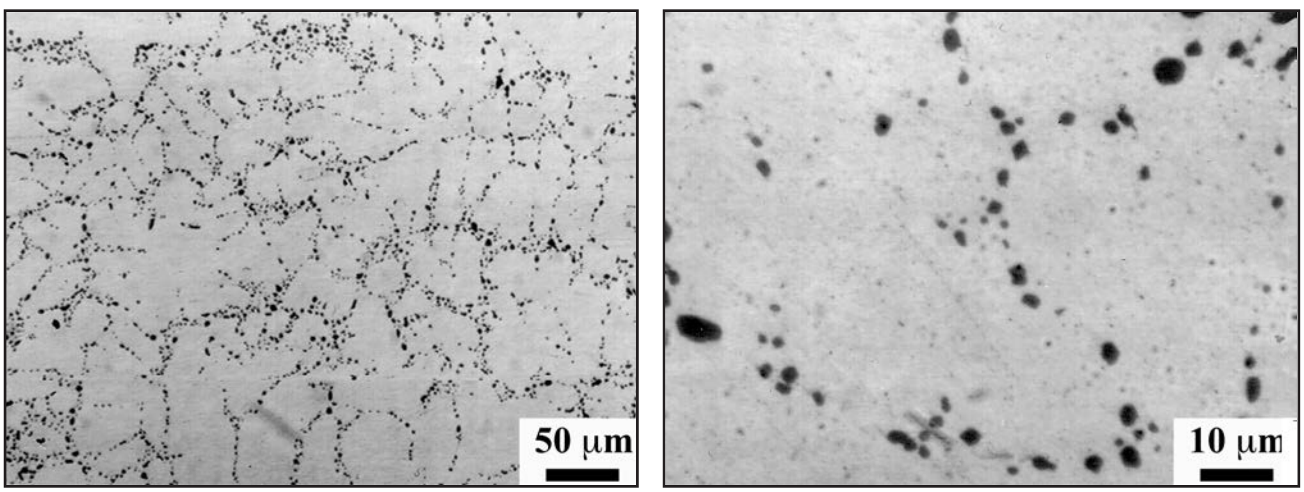
Alloy Chemistry:

6.4%Si	0.35%Mg	0.08%Fe	0.130%Ti	0.004%Sr

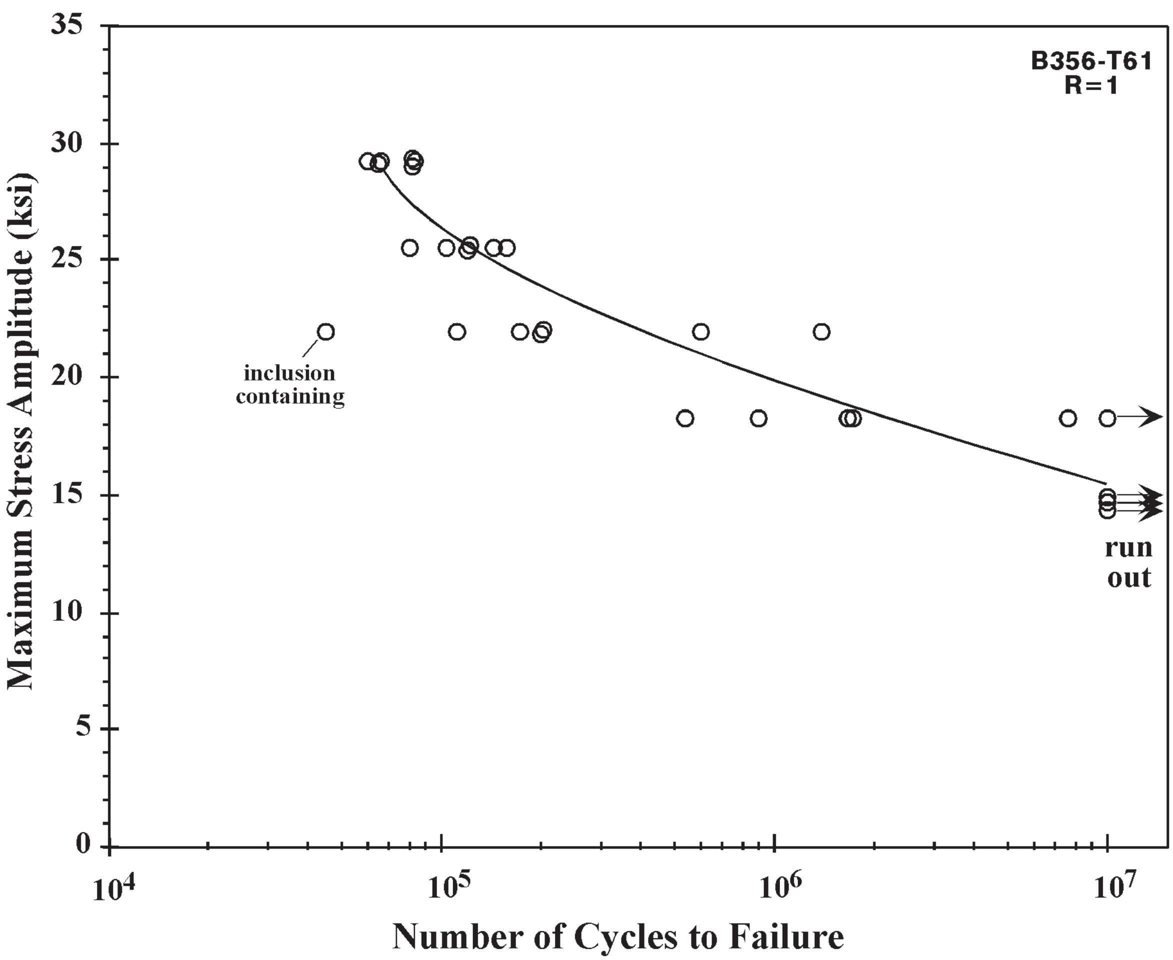
Component & Test Sample Description:
Test samples were taken from a U-shaped bar with cross-section 1.75 inches wide with a 0.9 inch thick of a moderately sized B356 squeeze cast part. This section lies several inches from the end of the bar and any metal feeding during the squeeze casting process would occur parallel to the axis of the tensile of fatigue sample.

Heat Treatment:
Samples solutionized for 8 hours at 1000°F (538°C) and then quenched into 150°F (65°C) water. Samples were then allowed to incubate at room temperature for no less than 24 hours and were then artificially aged for 8 hours at 310°F (154°C).

Microstructure:



Properties			
Tensile	**Round tensile bars with 0.25"diameter and 1.0" long gage length**		**Average ± Standard Deviation**
	Yield Stress	(MPa)	222.7 ± 7.6
		(ksi)	32.3 ± 1.1
	UTS	(MPa)	302.7 ± 6.2
		(ksi)	43.9 ± 0.9
	Elongation to Failure (%)		17.6 ± 1.8
	Minimum Elongation (%)		14.6
	Reduction in Area (%)		24.26 ± 4.5
Hardness	Vickers Hardness		102 ± 6
	Rockwell B		
Microstructure	Secondary dendrite arm spacing (µm)		24
	Average silicon particle diameter (µm)		2.6



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Squeeze Cast 356MOD-T6 (Modified chemistry with ~0.25% Mg; ~0.5% Fe)			
Properties			
Tensile	**Round tensile bars with 0.25"diameter and 1.0" long guage length**		**Average ± Standard Deviation**
	Yield Stress	(MPa)	222.7 ± 7.6
		(ksi)	32.3 ± 1.1
	UTS	(MPa)	302.7 ± 6.2
		(ksi)	43.9 ± 0.9
	Elongation to Failure (%)		17.6 ± 1.8
	Minimum Elongation (%)		14.6
	Reduction in Area (%)		24.26 ± 4.5
Hardness	Vickers Hardness		102 ± 6
	Rockwell B		
Microstructure	Secondary dendrite arm spacing (μm)		24
	Average silicon particle diameter (μm)		2.6

Squeeze Cast 356MOD-T6 (Modified chemistry with ~0.25% Mg; ~0.5% Fe and heat treated to SPX Contech Modified T6)			
Properties			
Tensile	**Round tensile bars with 0.25"diameter and 1.0" long guage length**		**Average ± Standard Deviation**
	Yield Stress	(MPa)	225 - 276
		(ksi)	37.0 - 40.0
	UTS	(MPa)	303 - 331
		(ksi)	44.0 - 48.0
	Elongation to Failure (%)		3.0 - 5.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B		50 - 65
Microstructure	Average silicon particle diameter (μm)		

3

Squeeze Cast A356.2-T6			
Properties			
Tensile	**Round tensile bars with 0.25"diameter and 1.0" long guage length**		**Range**
	Yield Stress	(MPa)	145 - 165
		(ksi)	21.0 - 24.0
	UTS	(MPa)	255 - 276
		(ksi)	37.0 - 40.0
	Elongation to Failure (%)		13.0 - 17.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B		40 - 56
Microstructure	Average silicon particle diameter (μm)		

Squeeze Cast 356.2-T6MOD (SPX Contech Modified T6)			
Properties			
Tensile	**Round tensile bars with 0.25"diameter and 1.0" long guage length**		**Range**
	Yield Stress	(MPa)	221 - 234
		(ksi)	32.0 - 34.0
	UTS	(MPa)	296 - 310
		(ksi)	43.0 - 45.0
	Elongation to Failure (%)		10.0 - 14.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B		48 - 63
Microstructure	Average silicon particle diameter (μm)		

Squeeze Cast 357-T6			
Properties			
Tensile	**Round tensile bars with 0.25”diameter and 1.0” long guage length**		**Range**
	Yield Stress	(MPa)	241 - 262
		(ksi)	35.0 - 38.0
	UTS	(MPa)	324 - 338
		(ksi)	47.0 - 49.0
	Elongation to Failure (%)		8.0 - 10.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B		52 - 68
Microstructure	Average silicon particle diameter (μm)		

Squeeze Cast 383MOD-F (SPX Contech Modified Chemistry)			
Properties			
Tensile	**Round tensile bars with 0.25”diameter and 1.0” long guage length**		**Range**
	Yield Stress	(MPa)	145 - 159
		(ksi)	21.0 - 23.0
	UTS	(MPa)	269 - 290
		(ksi)	39.0 - 42.0
	Elongation to Failure (%)		2.8 - 3.5
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B		50 - 65
Microstructure	Average silicon particle diameter (μm)		

3

Squeeze Cast 383MOD-T4 (SPX Contech Modified Chemsitry)			
Properties			
Tensile	**Round tensile bars with 0.25"diameter and 1.0" long guage length**		**Range**
	Yield Stress	(MPa)	234 - 255
		(ksi)	34.0 - 37.0
	UTS	(MPa)	359 - 386
		(ksi)	52.0 - 56.0
	Elongation to Failure (%)		5.0 - 7.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B		55 - 70
Microstructure	Average silicon particle diameter (μm)		

Squeeze Cast 383MOD-T5 (SPX Contech Modified Chemistry)			
Properties			
Tensile	**Round tensile bars with 0.25"diameter and 1.0" long guage length**		**Range**
	Yield Stress	(MPa)	255 - 276
		(ksi)	37.0 - 40.0
	UTS	(MPa)	283 - 317
		(ksi)	41.0 - 46.0
	Elongation to Failure (%)		1.5 - 3.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B		60 - 70
Microstructure	Average silicon particle diameter (μm)		

Squeeze Cast 383MOD-T6 (SPX Contech Modified Chemistry)			
Properties			
Tensile	**Round tensile bars with 0.25"diameter and 1.0" long guage length**		**Range**
	Yield Stress	(MPa)	296 - 317
		(ksi)	43.0 - 46.0
	UTS	(MPa)	379 - 421
		(ksi)	55.0 - 61.0
	Elongation to Failure (%)		3.0 - 5.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B		73 - 84
Microstructure	Average silicon particle diameter (μm)		

Semi-Solid Metal Cast 319-F			
Properties			
Tensile	**Flat bars with 0.005" x 0.353" gauge section and 2.0" long guage length removed from the casting**		**Range**
	Yield Stress	(MPa)	132 - 146
		(ksi)	19.1 - 21.1
	UTS	(MPa)	244 - 267
		(ksi)	35.4 - 38.7
	Elongation to Failure (%)		3.1 - 6.2
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B		
Microstructure	Average silicon particle diameter (μm)		

Semi-Solid Metal Cast 319-T4			
Properties			
Tensile	**Flat bars with 0.005″ x 0.353″ gauge section and 2.0″ long gauge length removed from the casting**		**Range**
	Yield Stress	(MPa)	172 - 185
		(ksi)	25.0 - 26.9
	UTS	(MPa)	290 - 343
		(ksi)	42.0 - 49.7
	Elongation to Failure (%)		5.5 - 14.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B*		50 - 57
	Brinell (BHN)		89.3 - 96.7
Microstructure	Average silicon particle diameter (μm)		
* Hardness values converted from Brinell per ASTEM E140-97.			

Semi-Solid Metal Cast 319-T5			
Properties			
Tensile	**Flat bars with 0.005″ x 0.353″ gauge section and 2.0″ long gauge length removed from the casting**		**Range**
	Yield Stress	(MPa)	227 - 248
		(ksi)	32.9 - 36.0
	UTS	(MPa)	285 - 327
		(ksi)	41.3 - 47.4
	Elongation to Failure (%)		1.4 - 5.3
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B*		70 - 73
	Brinell (BHN)		111.5 - 116.5
Microstructure	Average silicon particle diameter (μm)		
* Hardness values converted from Brinell per ASTEM E140-97.			

Semi-Solid Metal Cast 319-T6			
Properties			
Tensile	**Flat bars with 0.005″ x 0.353″ gauge section and 2.0″ long gauge length removed from the casting**		**Range**
	Yield Stress	(MPa)	284 - 296
		(ksi)	41.2 - 42.9
	UTS	(MPa)	345 - 387
		(ksi)	50.0 - 56.1
	Elongation to Failure (%)		3.0 - 7.3
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B*		74 - 79
	Brinell (BHN)		113.5 - 124.5
Microstructure	Average silicon particle diameter (μm)		
* Hardness values converted from Brinell per ASTEM E140-97.			

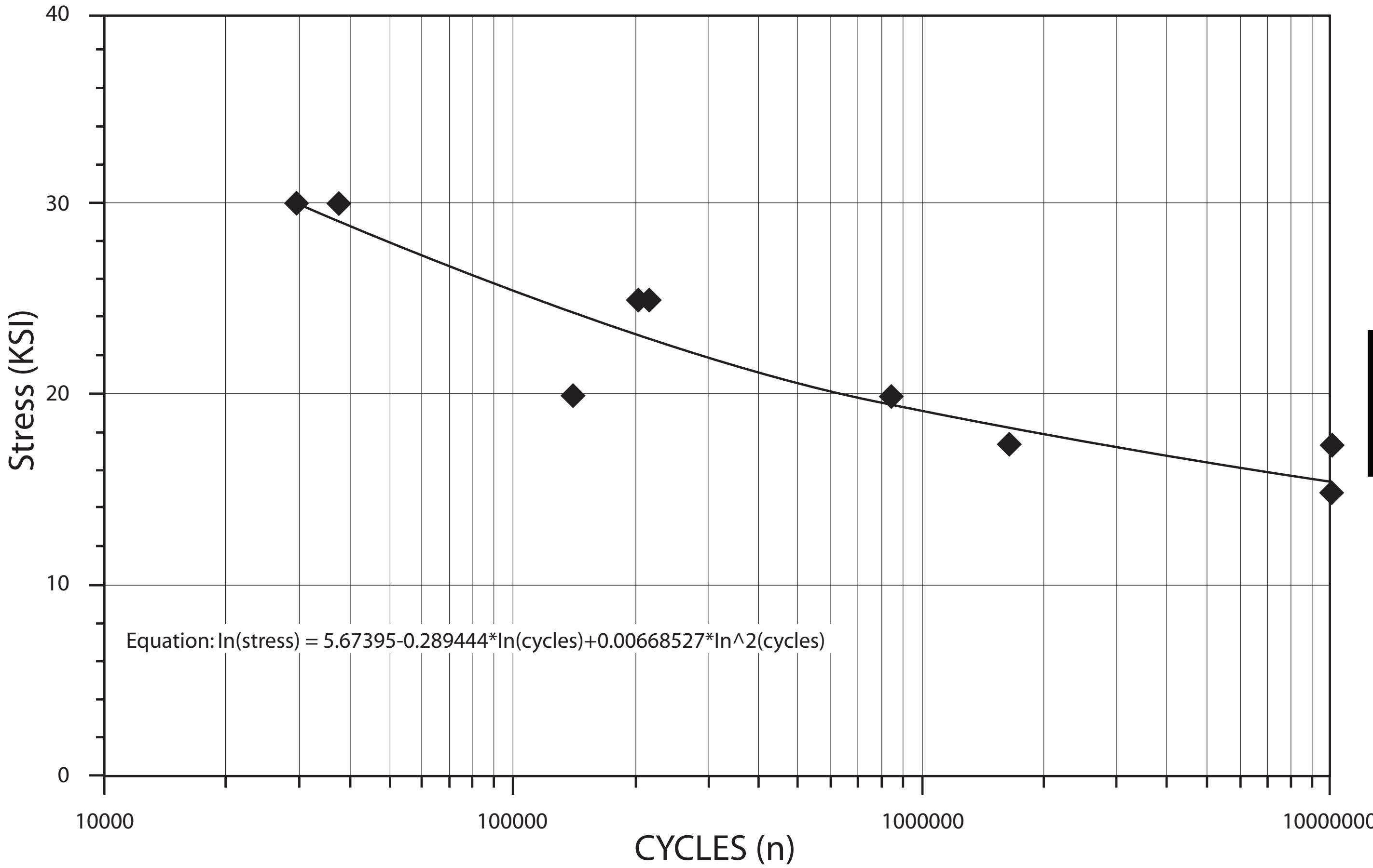
Semi-Solid Metal Cast 356-T5			
Properties			
Tensile	**Round Tensile bars with 0.505″ gauge diameter and 2.0″ long gauge length removed from the casting**		**Range**
	Yield Stress	(MPa)	152 - 221
		(ksi)	22.0 - 32.0
	UTS	(MPa)	214 - 295
		(ksi)	31.0 - 42.8
	Elongation to Failure (%)		3.0 - 14.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B*		40 - 49
	Brinell (BHN)		80.6 - 87.5
Microstructure	Average silicon particle diameter (μm)		
* Hardness values converted from Brinell per ASTEM E140-97.			

3

Semi-Solid Metal Cast 356-T6			
Properties			
	Round tensile bars with 0.505″ gauge diameter and 2.0″ long gauge length removed from the casting		**Range**
Tensile	Yield Stress	(MPa)	152 - 245
		(ksi)	22.0 - 35.5
	UTS	(MPa)	262 - 317
		(ksi)	38.0 - 46.0
	Elongation to Failure (%)		4.5 - 20.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B*		40 - 51
	Brinell (BHN)		80.6 - 89.9
Microstructure	Average silicon particle diameter (μm)		
* Hardness values converted from Brinell per ASTEM E140-97.			

Semi-Solid Metal Cast 357-T5			
Properties			
	Round tensile bars with 0.350″ x 1.4″ gauge diameter and 1.4″ long gauge length removed from the casting		Range
Tensile	Yield Stress	(MPa)	124 - 219
		(ksi)	18.0 - 31.8
	UTS	(MPa)	241 - 289
		(ksi)	35.0 - 41.9
	Elongation to Failure (%)		4.7 - 11.0
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B*		
	Brinell (BHN)		
Microstructure	Average silicon particle diameter (μm)		
* Hardness values converted from Brinell per ASTEM E140-97.			

Semi-Solid Metal Cast 357-T6			
Properties			
Tensile	**Round tensile bars with 0.350" gauge diameter and 1.4" long gauge lengeth from the casting**		**Range**
	Yield Stress	(MPa)	138 - 303
		(ksi)	20.0 - 44.0
	UTS	(MPa)	255 - 339
		(ksi)	37.0 - 49.2
	Elongation to Failure (%)		4.0 - 13.2
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B*		
	Brinell (BHN)		
Microstructure	Average silicon particle diameter (μm)		
* Hardness values converted from Brinell per ASTEM E140-97.			



S-N Curve for SSM 357-T6 Grain Refined Aluminum Alloy

Semi-Solid Metal Cast A357-T61

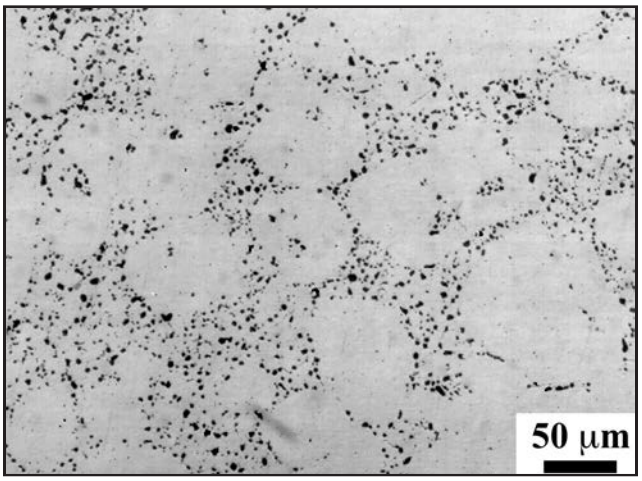
Alloy Chemistry:

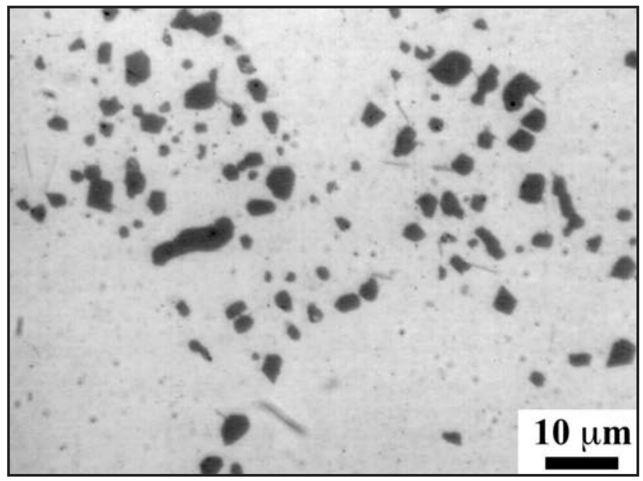
6.8%Si	0.56%Mg	0.10%Fe	0.019%Sr

Component & Test Sample Description:
Test samples were taken from the center of a 0.2 inch think plate of an A357 semi-solid cast part.

Heat Treatment:
Samples solutionized for 8 hours at 1000°F (538°C) and then quenched into 150°F (65°C) water. Samples were then allowed to incubate at room temperature for no less than 24 hours and were then artificially aged for 8 hours at 310°F (154°C).

Microstructure:





Properties			
Tensile	**Flat tensile bars with 0.25″ x 0.25″ gauge cross section and 0.4″ long gauge length**		**Range**
	Yield Stress	(MPa)	243.4 ± 11.7
		(ksi)	25.3 ± 1.7
	UTS	(MPa)	316.5 ± 9.0
		(ksi)	45.9 ± 1.3
	Elongation to Failure (%)		8.4 ± 2.0
	Minimum Elongation (%)		6.5
	Reduction in Area (%)		9.0
Hardness	Vickers Hardness		112 ± 5
	Rockwell B		
Microstructure	Average silicon particle diameter (µm)		

Semi-Solid Metal Cast A357-T62

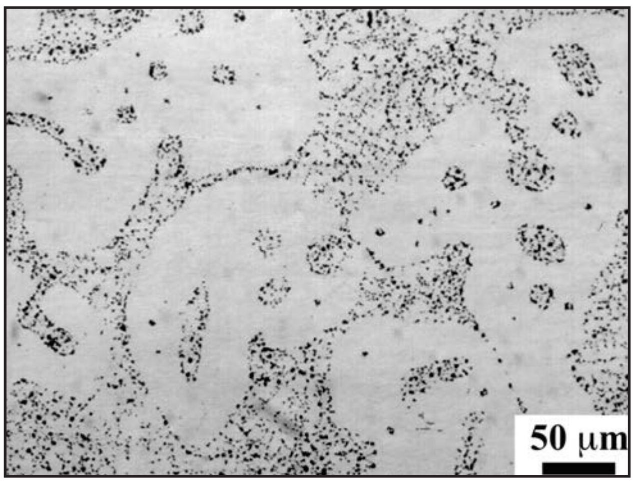
Alloy Chemistry:

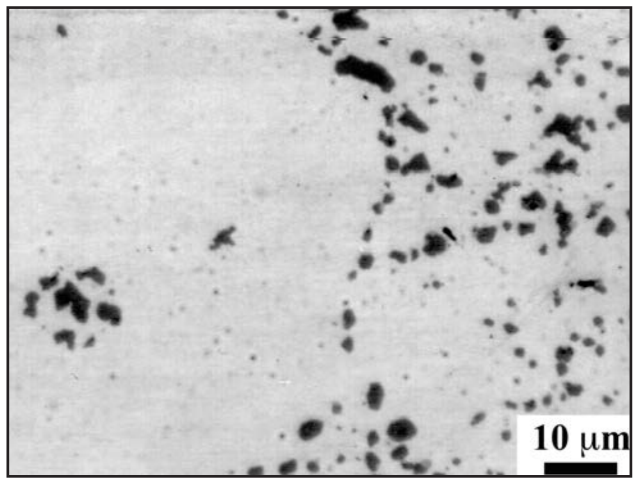
7.6%Si	0.48%Mg	0.19%Fe	0.089%Ti	0.031%Sr

Component & Test Sample Description:
Test samples were taken from the center of a 0.22 inch think wall of a plate shaped section of a small A357 semi-solid cast part.

Heat Treatment:
Samples solutionized for 8 hours at 1000°F (538°C) and then quenched into 150°F (65°C) water. Samples were then allowed to incubate at room temperature for no less than 24 hours and were then artificially aged for 8 hours at 310°F (154°C).

Microstructure:





Properties			
	Flat tensile bars with 0.25" x 0.25" gauge across section and 0.4" king gauge length		**Range**
Tensile	Yield Stress	(MPa)	243.4 ± 11.7
		(ksi)	35.3 ± 1.7
	UTS	(MPa)	299.9 ± 6.9
		(ksi)	43.5 ± 1.0
	Elongation to Failure (%)		6.6 ± 2.0
	Minimum Elongation (%)		4.0
	Reduction in Area (%)		8.5
Hardness	Vickers Hardness		124 ± 2
	Rockwell B		
Microstructure	Average silicon particle diameter (µm)		2.4

Semi-Solid Metal Cast 390-T5			
Properties			
Tensile	**Flat bars with 0.005″ x 0.353″ gauge section and 2.0″ long gauge length removed from ta casting**		**Range**
	Yield Stress	(MPa)	225 - 270
		(ksi)	32.6 - 39.2
	UTS	(MPa)	225 - 270
		(ksi)	32.6 - 39.2
	Elongation to Failure (%)		<0.2%
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B*		72- 86
	Brinell (BHN)		115 - 140
Microstructure	Average silicon particle diameter (μm)		
* Hardness values converted from Brinell per ASTEM E140-97.			

Semi-Solid Metal Cast 390-T6			
Properties			
Tensile	**Flat bars with 0.005″ x 0.353″ gauge section and 2.0″ long gauge length removed from ta casting**		**Range**
	Yield Stress	(MPa)	341 - 385
		(ksi)	49.5 - 55.9
	UTS	(MPa)	341 - 385
		(ksi)	49.5 - 55.9
	Elongation to Failure (%)		<1.0%
	Minimum Elongation (%)		
	Reduction in Area (%)		
Hardness	Vickers Hardness		
	Rockwell B*		86 - 92
	Brinell (BHN)		140 - 165
Microstructure	Average silicon particle diameter (μm)		
* Hardness values converted from Brinell per ASTEM E140-97.			

Engineering & Design: Tolerancing

SECTION 4

Section Contents

Engineering & Design: Tolerancing

Tolerance in any part is a three-dimensional characteristic. Many different types of tolerance will be discussed throughout. Most feature tolerances will have Linear Tolerance in combination with Projected Area Tolerance to give an overall feature "volumetric" tolerance like Parting Line, Moving Die Component (MDC) and Angularity Tolerances.

Projected Area is the area of a specific feature projected into a plane. For parting line and parting line shift the Projected Area is the open area of the die cavity in the parting line plane. For example, if a die half was laid down and filled with liquid, the surface of the liquid at the parting line is the Projected Area. For the MDC, the Projected Area is determined using the same method as for a parting line. See the applicable figures in the appropriate sections for Projected Area.

Linear Tolerance is calculated from a line perpendicular to any feature. The Parting Line line is the total depth of molten material on both die halves, which is perpendicular to the parting line plane. The MDC line is the length of the core slide which is perpendicular to the head of the core slide. Length of a core slide is determined from the point where the core first engages the die to its full insertion point.

Projected Area Tolerance plus Linear Tolerance equals feature tolerance (tolerance of the volume of the part).

See Volumetric Tolerance diagram on the facing page.

Frequently Asked Questions (FAQ)

1) What is the difference between Standard and Precision Tolerances?
   See pages 4-3 and 44, Standard and Precision Tolerances.
2) What is a Parting Line Shift?
   See pages 4-19 and 4-20, Parting Line Shift.
3) If my casting requires machining, how should the casting be dimensioned?
   See page 4-40 and 4-41, Machining Stock Allowances.
4) How large should a cast-in hole be if threads need to be tapped or formed in the casting?
   See page 4-34 and 4-35, Cored Holes for Cut Threads. Also see pages 4-36 and 4-37, Cored Holes for Formed Threads.
5) What type of draft should be used on exterior and interior walls?
   See pages 4-21 through 4-24, Draft Requirements.
6) What type of flatness tolerance can be expected on a cast surface?
   See pages 4-29 and 4-30, Flatness Requirements.

1 Introduction

Die casting requires a specific degree of precision for the end product to meet the requirements of form, fit and function. However there is a cost associated with increased precision.

Some of the costs associated with a higher degree of tolerance include:

- *Decreased die life due to wear that puts die dimensions outside of specified high precision tolerance*
- *More frequent die repair or replacement to maintain a high precision tolerance*
- *More frequent shutdown (shorter production runs) to repair or replace dies*
- *More frequent part or die inspections to ensure high precision tolerance is maintained*
- *Potential for higher scrap rate for not maintaining specified high precision tolerance*

A good casting design will take into account not only the precision required to meet the requirements of form, fit and function, but will also take into account maximizing tolerance to achieve a longer die life and longer production runs with less inspections. This will result in less potential for scrap and more acceptable parts because the tolerance range for acceptable parts has increased.

In section 4 tolerance will be specified in two values. Standard Tolerance is the lesser degree of precision that will meet most applications of form, fit and function. It is specified in thousandths of an inch (0.001) or hundredths of a millimeter (0.01). Degree of variation from design specified values is larger than that of Precision Tolerance as shown in graphical representation at the end of section 4.

Precision Tolerance is a higher degree of precision used for special applications where form, fit and function are adversely affected by minor variations from design specifications. Precision Tolerance is also specified in thousandths of an inch or hundredths of a millimeter. However, its variation from design specified values is less than that of Standard Tolerances.

Examples of tolerance application may be an engine casting that uses Standard Tolerance. Form, fit and function are not critical since moving parts will be encased in sleeves that are cast into place. Variations in size will be filled with cast metal.

Standard Tolerance meets the criteria for this application as part of the design. However a gas line fitting may require a higher degree of precision so that mating parts fit together to prevent leaks. Precision gas fittings may cost more to produce because of the higher degree of precision that must be maintained.

Degree of precision depends on the applications of form, fit and function which resides with the design engineer's expectation of part performance.

Cast components can be specified and produced to an excellent surface finish, close dimensional tolerances and to minimum draft, among other characteristics.

All of the capabilities of the casting process, specified to maximum degree, will rarely, if ever, be required in one cast part. For the most economical production, the design engineer or specifier should attempt to avoid such requirements in a single component.

It is important for the product designer and engineer to understand precisely how today's die casting process can be specified in accordance with the capabilities of the die casting industry.

2 Section Objectives

The Engineering and Design Sections of this document are prepared to aid product specifiers in achieving the most cost-effective results through net-shape and near-net-shape casting production. They present both English and Metric values on the same page.

Section 4 presents standard/precision tolerances and other specifications for die cast parts ranging from a fraction of an inch (several millimeters) to several feet (meter) in size. Material weight ranges from a fraction of an ounce (several milligrams) to tens of pounds (kilograms).

Sizes are for reference only. Die casters should be consulted on the size of casting they can produce.

Section 5 presents Geometric Dimensioning, which provides guidelines for applying tolerances to cast part specifications.

These sections provide information for developing the most economically produced design that meets the specifications of form, fit and function.

3 Standard and Precision Tolerances

As noted in the contents for this section, seven important sets of tolerancing guidelines are presented here as both "Standard" and "Precision" Tolerances:

- *Linear dimensions*
- *Dimensions across parting Lines*
- *Dimensions formed by moving die components (MDC)*
- *Angularity*
- *Draft*
- *Flatness*
- *Cored holes for threads*

The following features are only specified in Standard Tolerance. Unlike the features above, parts that exceed the following tolerances will not meet the requirements of form, fit and function. These features are specified at the maximum tolerance to meet their requirements. These features include:

- *Concentricity*
- *Parting Line Shift*

Volumetric Tolerance for Across Parting Line Features

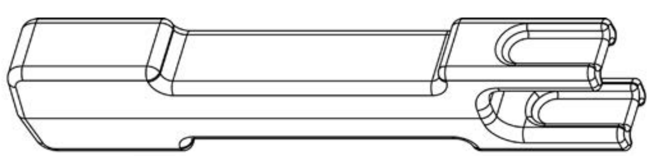
(See diagram on this page.) Parting Line Projected Area is defined by the horizontal center line shown in the figure below. Its dimensions are 1.00 inch wide by (7.50 - 1.50) inches long. The Projected area is (1.00 x 6.00) or 6.00 in. sq. This is the surface area used for features across the parting line. Tolerance is expressed in inches.

Linear Dimension (depth of cavity on both die halves) is 1.40 inches. This is the linear dimension used to determine Linear Tolerance.

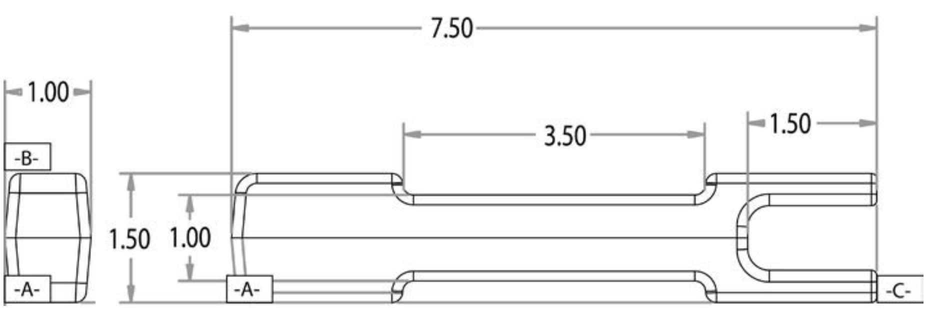
Feature Tolerance is Projected Area Tolerance plus Linear Area Tolerance.

Graphical Representation

Throughout section 4 there is graphical representation of specific feature tolerances. Precision tolerances are generally closer to design specifications than standard tolerances. The x-axis along y-axis at zero indicates actual design specification. Graph lines indicate the maximum allowable deviation from design specification.



Volume = 6.64 in^3



Engineering & Design: Tolerancing

Cpk vs Cp

Demonstrable process capability requirements need to be discussed and agreed upon by the customer and the caster for all new jobs. Cpk is the measurement commonly used to determine if the process can produce the parts within specification. It is common in die casting for the process to yield a high Cp while struggling for Cpk for a few dimensions. This is because the casting may shrink or distort in un-anticipated ways. This can be particularly problematic for large and thin castings.

Standard Tolerances

Standard Tolerances cover expected values consistent with high casting cycle speeds, uninterrupted production, reasonable die life and die maintenance costs, as well as normal inspection, packing and shipping costs.

Such tolerances can normally be achieved by the widely available production capabilities of casters practicing standard methods and procedures. Conformity to these standards by designers assures the most predictable service and lowest cost.

Precision Tolerances

Critical requirements for dimensional accuracy, draft, etc.., beyond the Standard Tolerances presented, can be specified when required.

Precision Tolerances are presented on the page following the Standard Tolerances for the same characteristic. The values shown for Precision Tolerances represent greater casting accuracy. See graphical comparison of Standard and Precision Tolerances throughout section 4. Part precision tolerances involve extra precision in die construction and/or special process controls during production. The use of new technologies and equipment aid in maintaining Precision Tolerance.

While early consultation with the caster can sometimes result in selected special precision requirements being incorporated with little additional cost, such tolerances should be specified only where necessary.

It should be noted that the tolerances shown must, of necessity, be guidelines only—highly dependent on the particular shape, specific features and wall thickness transitions of a given part design. These factors, under the control of the product designer, greatly influence the ability of the casting process to achieve predetermined specifications in the final cast part.

Where a number of critical requirements are combined in a single casting, early caster evaluation of a proposed design is essential. Design modifications for more cost-efficient casting can nearly always be made. Without such feedback, additional costs can usually be expected and the design, as originally planned, may not be producible by die casting.

When specific designs are examined, tolerances even closer than the Precision Tolerances shown can often be held by repeated production sampling and recutting of the die casting die, together with production capability studies. While such steps will result in additional tooling and production costs, the significant savings that can result by eliminating substantial secondary machining and/or finishing operations can prove highly cost effective.

When attempting to hold tolerances closer than Precision Tolerances steel safe practrices should be utilized when building dies and tooling.

Datums Placement

Proper use of dimensioning places all features in space relative to some datum structure. Datums are best when they represent the functional requirements of the final product. All the tolerance recommendations presented in this section are length/size dependent. Therefore, one should take care when choosing the datum features.

- Things to consider when selecting datums
  - Function of the part.
  - Location of critical features relative to the datums
  - Cross parting vs in parting dimensions vs moving die components

4 Production Part Technologies

This section presents advantages and limitations of various production technologies for a simple part such as the one shown in Fig. 4-1. The section that follows presents the die cast alternative and its advantages and limitations.

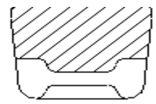


Fig. 4A-1 Proposed component.

Metal Stamping Alternative

This part design, as pictured in Fig. 4-1 and if designed to a minimum thickness without additional complexities, could be considered for volume production by the metal stamping process. Metal stamping lends itself to high-speed production with infrequent die replacement or repair. However, the stamping process can only produce features that are apparent on both sides of a thin part. Indentations on one side of the part appear as ridges on the other side of the part. Critical bends in the metal surface of stamped products become areas of weakness where metal is formed to make the bend. Complex features within the layer of metal are impossible without additional stamped parts and assembly. Thicker parts require higher stamping pressure which compounds metal fatigue at critical bends. This is similar to a large tree snapping in the wind where a sapling will bend. Multiple stamped layers and assembly would exceed the cost of the die cast alternative.

Extrusion Alternative

If the part design required stock depth beyond stamping capabilities, the extrusion process might be a production alternative for creating such a profile—unless complex additional interior features were desirable, such as those shown in Fig. 4-1.

When total costs of a product assembly can be significantly reduced by a more robust part design, as that suggested by Fig. 4-1, the production process which allows such design freedom is the better choice. The extrusion process produces a uniform internal structure in one axis such as a bar or a tube. End features or variations within the axis are impossible. A part, such as the one shown in Fig. 4-1, has design feature variations on all axes therefore extrusion of this part is not possible without multiple operations which would exceed the cost of the die cast alternative.

Machining Alternative

Automated machining could produce product features as shown in Fig. 4-1. Complex features would require additional operations for each piece. This would be very time consuming and would place tremendous wear on production equipment especially during large volume production. As volumes increased, machining would become a very high-cost production option.

Foundry Casting Alternative

Foundry casting plus secondary machining might be an alternative for this part. Foundry casting involves pouring molten metal into a mold. Without the pressure of die, SSM or squeeze casting to force metal into critical paths, around tight turns, and into small features of the mold. Foundry casting can not achieve the detail and precision of die, SSM or squeeze casting. The Foundry casting process is relatively slow in that gravity fills and mold positions take time to achieve.

Extensive secondary machining is required for Foundry castings when close tolerances are required. This is not only costly but time consuming. Foundry casting is usually reserved for large iron castings with very little intricate detail. It is not considered as a high volume process. Net-shape die casting can become the more cost-effective solution, often at low production volumes.

Comment on Theoretical Sharp Corners and Drafted Surfaces

Die castings require draft on surfaces parallel to the pulling direction as well as radii on most sharp corners. This creates an opportunity for features that cannot be directly measured. Other cases may create situations that are impractical to measure. Concave radii generally create a theoretical sharp intersection somewhere inside the casting while convex shapes create a theoretical point in space. Acceptable methods of measuring these features should be discussed and agreed upon with the caster and customer. Keep in mind that 3D scanning technology coupled with GD&T based profile may be the best method to clarify and satisfy the print requirements.

Investment Casting Alternative

At low volumes the investment casting process could be considered to achieve precision tolerances. At higher volumes die casting would be the clear choice.

Powdered Metal Alternative

The powdered metal process offers dimensional accuracy for many parts. It cannot achieve the more complex configurations, detailed features or thinner walls which die casting can easily produce to net or near-net shape.

Plastic Molded Alternative

Plastic injection molding could achieve the designed configuration shown in Fig. 4-1, but if requirements of rigidity, creep resistance, and strength—particularly at elevated temperatures—were important, plastics would be questionable. The longevity of plastic components is normally substantially less than that of metal components. Plastics products are subject to failure modes such as sunlight, radiation, heat and various chemicals. The designer needs to ensure that the application and duration of the end product will meet the customers needs and expectations. Additionally, the preference for use of a recycled raw material as well as the potential for eventual recycling of the product at the end of its useful life would also support a decision for die casting.

5 Die Casting, SSM and Squeeze Cast Part Design

Fig. 4-1A, illustrates a good design practice for die, SSM and squeeze casting production.

Sharp corners have been eliminated and the design has been provided with the proper draft and radii to maximize the potential die life and to aid in filling the die cavity completely under high production cycle speeds.

Typical average wall thicknesses for a cast design range from 0.040 in. (1.016 mm) to 0.200 in. (5.08 mm), depending on alloy, part configuration, part size and application.

Smaller castings with wall sections as thin as 0.020 in. (0.50 mm) can be cast, with die caster consultation. For extremely small zinc parts, miniature die casting technology can be used to cast still thinner walls.

Dimensions are for reference. Some die casters can produce parts that are thicker or thinner than dimensions listed. Consult a die caster to determine their limitations.

Fig. 4-1 will be used elsewhere in this section to present dimensional tolerances, specifically as they relate to part dimensions on the same side of the die half, across the parting line, and those formed by moving die components.

Note: Because dies wear over the course of producing castings, it should be noted that the number of shots on a die prior to repair or replacement will be less for tighter casting tolerances and greater for wider casting tolerances.

Fig. 4-1 will also be used in the Geometric Dimensioning Section to show how datum structure can influence tooling and tolerances.

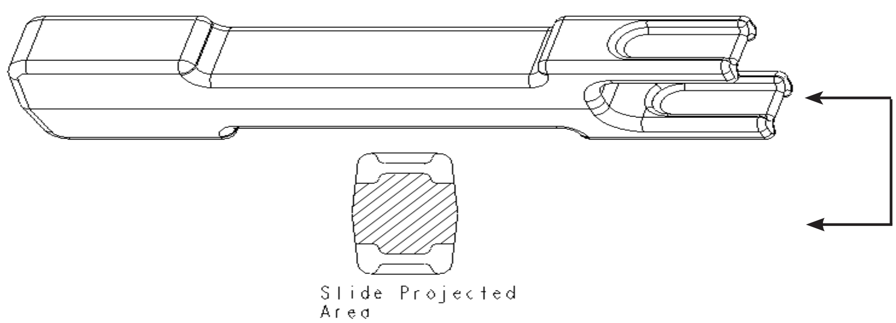


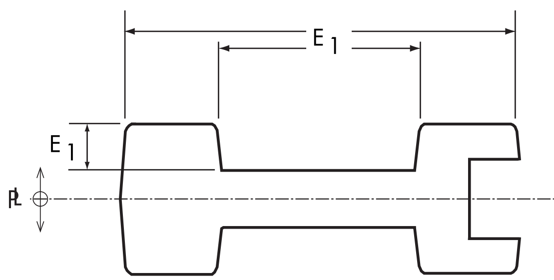
Fig. 4A-1A *Proposed component with added features and design modified for cost-effective die casting production, showing orientation in the die casting die and core slide (moving die component) to cast the additional f*

6 Linear Dimensions: Standard Tolerances

The Standard Tolerance on any of the features labeled in the adjacent drawing, dimension "E_1" will be the value shown in table S-4-1 for dimensions of features formed in the same die part. Tolerance must be increased for dimensions of features formed by the parting line or by moving die parts to allow for movement such as parting line shift or the moving components in the die itself. See tables S-4-2 and S-4-3 for calculating tolerance of moving die components or parting line shift. Linear tolerance is only for fixed components to allow for growth, shrinkage or minor imperfections in the part.

Tolerance is the amount of variation from the part's nominal or design feature.

For example, a 5 inch design specification with ±0.010 tolerance does not require the amount of precision as the same part with a tolerance of ±0.005. The smaller the tolerance number, the more precise the part must be (the higher the precision). Normally, the higher the precision the more it costs to manufacture the part because die wear will affect more precise parts sooner. Production runs will be shorter to allow for increased die maintenance. Therefore the objective is to have as much tolerance as possible without affecting form, fit and function of the part.



*GD&T is required for radii and chamfers

Example:
Aluminum Casting
E_1 = 5.00 in (127 mm)

Standard Tolerance (from Table S-4-1)		
First inch (25.4 mm)		±.010 in (±0.25 mm)
Each additional inch (25.4 mm)	4x	±.001 in (±0.025 mm)
		±.014 in (±0.35 mm)*

**Note that .014 in converts to 0.36 mm. Significant digits and conversions can cause variations in final tolerance.*

Linear dimension tolerance only applies to linear dimensions formed in the same die half with no moving components.

Linear tolerances apply to radii and diameters as well as wall thicknesses.

Table S-4-1 Tolerances for Linear Dimensions (Standard)
In inches, two-place decimals (.xx); In millimeters, single-place decimals (.x)

Length of Dimension "E_1"	Casting Alloys			
	Zinc	Aluminum	Magnesium	Copper
Basic Tolerance up to 1" (25.4mm)	±0.010 (±0.25 mm)	±0.010 (±0.25 mm)	±0.010 (±0.25 mm)	±0.014 (±0.36 mm)
Additional Tolerance for each additional inch over 1" (25.4mm)	±0.001 (±0.025 mm)	±0.001 (±0.025 mm)	±0.001 (±0.025 mm)	±0.003 (±0.076 mm)

Note: Because dies wear over the course of producing castings, it should be noted that the number of shots on a die prior to repair or replacement will be less for tighter casting tolerances and greater for wider casting tolerances.

The values shown represent Standard Tolerances, or normal casting production practice at the most economical level. For greater casting accuracy see Precision Tolerances for this characteristic on the facing page. Be sure to also address the procedures referred to in Section 7, "Quality Assurance," sub-section 3, 4 and 5.

Significant numbers indicate the degree of accuracy in calculating precision. The more significant numbers in a specified tolerance, the greater the accuracy. Significant number is the first non-zero number to the right of the decimal and all numbers to the right of that number. For example, 0.014. The degree of accuracy is specified by the three significant numbers 0, 1, 4. This is not to be confused with tolerance precision. A tolerance limit of 0.007 has a higher degree of precision because it is closer to zero tolerance. Zero tolerance indicates that the part meets design specifications exactly. Linear Standard and Linear Precision tolerances are expressed in thousandths of an inch (.001) or hundredths of a millimeter (.01).

Notes:
Casting configuration and shrink factor may limit some dimension control for achieving a specified precision.

Engineering & Design: Tolerancing

PRECISION TOLERANCES

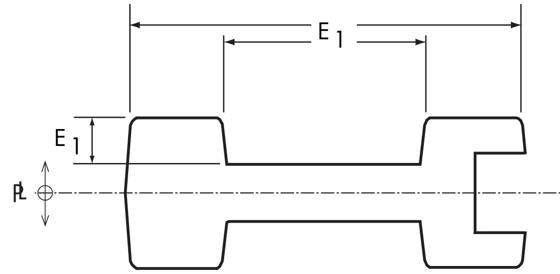
The Precision Tolerance values shown represent greater casting accuracy involving extra precision in die construction and/or special control in production. They should be specified only when and where necessary, since additional costs may be involved. Be sure to also address the procedures referred to in Section 7, "Quality Assurance," sub-section 3, 4 and 5.

Methods for Improving Precision:

1. By repeated sampling and recutting of the die cast tool, along with capability studies, even closer dimensions can be held. However, additional sampling and other costs may be incurred.

Linear Dimensions: Precision Tolerances

Precision Tolerance on any of the features labeled in the adjacent drawing, dimension "E_1" will be the value shown in table P-4-1 for dimensions between features formed in the same die part. Tolerance must be increased for dimensions of features formed by the parting line or by moving die parts to allow for movement such as parting line shift or the moving components in the die itself. See tables P-4-2 and P-4-3 for calculating precision of moving die components or parting line shift. Linear tolerance is only for fixed components to allow for growth, shrinkage or minor imperfections in the part.



**GD&T is required for radii and chamfers*

Example:
Aluminum Casting
E_1 = 5.00 in (127 mm)

Precision Tolerance (from Table P-4-1)

First inch (25.4 mm)		±.002 in (±0.05 mm)
Each additional inch (25.4 mm)	4x	±.001 in (±0.025 mm)
		±.006 in (±0.15 mm)

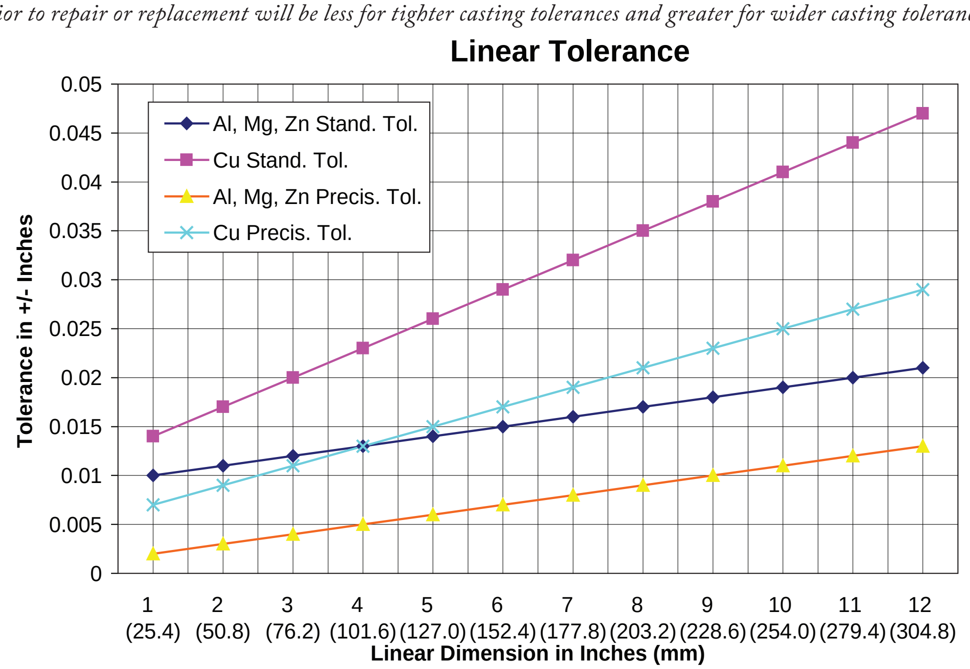
Linear tolerances apply to radii and diameters as well as wall thicknesses.

Linear dimension tolerance only applies to linear dimensions formed in the same die half with no moving components.

Table P-4-1 Tolerances for Linear Dimensions (Precision)
In inches, three-place decimals (.xxx); In millimeters, two-place decimals (.xx)

Length of Dimension "E_1"	Casting Alloys: Zinc	Aluminum	Magnesium	Copper
Basic Tolerance up to 1" (25.4mm)	±0.002 (±0.05 mm)	±0.002 (±0.05 mm)	±0.002 (±0.05 mm)	±0.007 (±0.18 mm)
Additional Tolerance for each additional inch over 1" (25.4mm)	±0.001 (±0.025 mm)	±0.001 (±0.025 mm)	±0.001 (±0.025 mm)	±0.002 (±0.05 mm)

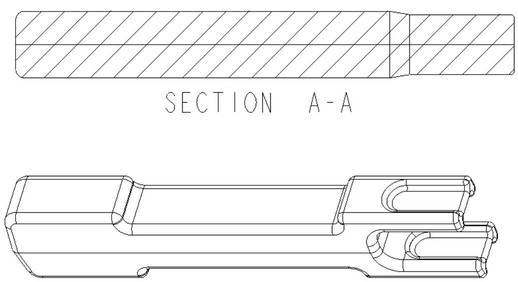
Note: Because dies wear over the course of producing castings, it should be noted that the number of shots on a die prior to repair or replacement will be less for tighter casting tolerances and greater for wider casting tolerances.



7 Parting Line: Standard Tolerances

Parting Line Tolerance is the additional tolerance needed for cross parting line dimensions in order to account for die separation (die blow).. This is not to be confused with Parting Line Shift Tolerance (cavity mismatch) which is the maximum amount die halves shift from side to side in relation to one another.

Parting Line Tolerance is a function of the Projected Area of the part. The Projected Area is a two dimensional area measurement calculated by projecting the three dimensional part onto a plane, which in this case is the cavity surface at the parting line. An easy way to visualize the Projected Area is by what shadow a casting would project onto the cavity surface.



The Parting Line Tolerance is always a plus tolerance since a completely closed die has 0 separation. Excess material and pressure will force the die to open along the parting line plane creating an oversize condition. The excess pressure will cause the part to be thicker than the ideal specification. It is important to understand that Table S-4-2 (Parting Line Tolerance) does not provide the Total Cross Parting Line Tolerance by itself. The Total Cross Parting Line Tolerance for any dimension is the sum of the Linear Tolerance (derived from the part thickness) in addition to the Parting Line Tolerance.

Thus, information from the Parting Line Tolerance table S-4-2 in combination with the formerly discussed Linear Tolerance table S-4-1 give a true representation of Total Cross Parting Line Tolerance. Note that the tolerances in the table apply to a single casting regardless of the number of cavities.

Example: An aluminum die casting has 75 in^2 (483.9 cm^2) of Projected Area on the parting die plane. From table S-4-2, the Parting Line Tolerance is +0.012. This is combined with the total part thickness tolerance from table S-4-1 to obtain the Total Cross Parting Line Tolerance.

The total part thickness including both die halves is 5.00 in. (127 mm) which is measured perpendicular to the parting die plane (dimension "E_2 E_1"). From table S-4-1, the Linear Tolerance is ±0.010 for the first inch and ±0.001 for each of the four additional inches. The Linear Tolerance of ±0.014 inches is combined with the Parting Line Tolerance of +0.012 to yield a Standard Cross Parting Line Tolerance of +0.026/-0.014 in. or in metric terms ±0.35 mm from Linear Tolerance table S-4-1 plus +0.30 mm from Parting Line Tolerance table S-4-2 = +0.65/-0.35 mm.

Table S-4-2 Parting Line Tolerances (Standard) — Added to Linear Tolerances

Projected Area of Die Casting inches^2 (cm^2)	Casting Alloys (Tolerances shown are "plus" values only)			
	Zinc	Aluminum	Magnesium	Copper
up to 10 in^2 (64.5 cm^2)	+0.0045 (+0.114 mm)	+0.0055 (+0.14 mm)	+0.0055 (+0.14 mm)	+0.008 (+0.20 mm)
11 in^2 to 20 in^2 (71.0 cm^2 to 129.0 cm^2)	+0.005 (+0.13 mm)	+0.0065 (+0.165 mm)	+0.0065 (+0.165 mm)	+0.009 (+0.23 mm)
21 in^2 to 50 in^2 (135.5 cm^2 to 322.6 cm^2)	+0.006 (+0.15 mm)	+0.0075 (+0.19 mm)	+0.0075 (+0.19 mm)	+0.010 (+0.25 mm)
51 in^2 to 100 in^2 (329.0 cm^2 to 645.2 cm^2)	+0.009 (+0.23 mm)	+0.012 (+0.30 mm)	+0.012 (+0.30 mm)	—
101 in^2 to 200 in^2 (651.6 cm^2 to 1290.3 cm^2)	+0.012 (+0.30 mm)	+0.018 (+0.46 mm)	+0.018 (+0.46 mm)	—
201 in^2 to 300 in^2 (1296.8 cm^2 to 1935.5 cm^2)	+0.018 (+0.46 mm)	+0.024 (+0.61 mm)	+0.024 (+0.61 mm)	—

For projected area of die casting over 300 in^2 (1935.5 cm^2), consult with your die caster.

STANDARD TOLERANCES

The values shown represent Standard Tolerances, or normal die casting production practice at the most economical level. For greater casting accuracy see Precision Tolerances for this characteristic on the facing page. Be sure to also address the procedures referred to in Section 7, "Quality Assurance," subsection 3, 4 and 5.

Die Shift:

Parting line die shift, unlike parting line separation and moving die component tolerances, is a left/right relationship with possible ± consequences. It can shift in four directions, based on a combination of part features, die construction and operation factors. It can occur at any time and its tolerance consequences should be discussed with the die caster at the design stage to minimize any impact on the final die casting.

Notes:

All values for part dimensions which run across the die parting line are stated as a "plus" tolerance only. The die casting die at a die closed position creates the bottom of the tolerance range, i.e., 0.000 (zero). Due to the nature of the die casting process, dies can separate imperceptibly at the parting line and create only a larger, or "plus" side, tolerance.

Engineering & Design: Tolerancing

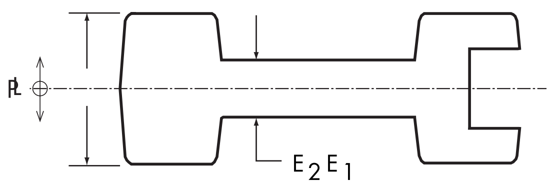
The Precision Tolerance values shown represent greater casting accuracy involving extra precision in die construction and/or special control in production. They should be specified only when and where necessary, since additional costs may be involved. Be sure to also address the procedures referred to in Section 7, "Quality Assurance," subsection 3, 4 and 5.

Methods for Improving Precision:

1. Achieving precision tolerancing often requires welding and recutting the die inserts to more closely match the print dimensions. This practice may reduce the life of the die casting die. This is especially true when specialized die materials, treatments, and/or coatings are necessary to preserve the die life. The potential reduced die life should be discussed and agreed upon prior to correcting tooling to achieve tighter dimensional capability.

Parting Line: Precision Tolerances

Precision Tolerances on dimensions such as "E_2 E_1", which are perpendicular to (across) the die parting line, will be the linear dimension tolerance from table P-4-1 plus the value shown in table P-4-2. The value chosen from the table below depends on the "projected area" of the part, in inches squared or millimeters squared, in the plane of the die parting. Note that the tolerances shown below are "plus side only" and based on a single cavity die casting die.



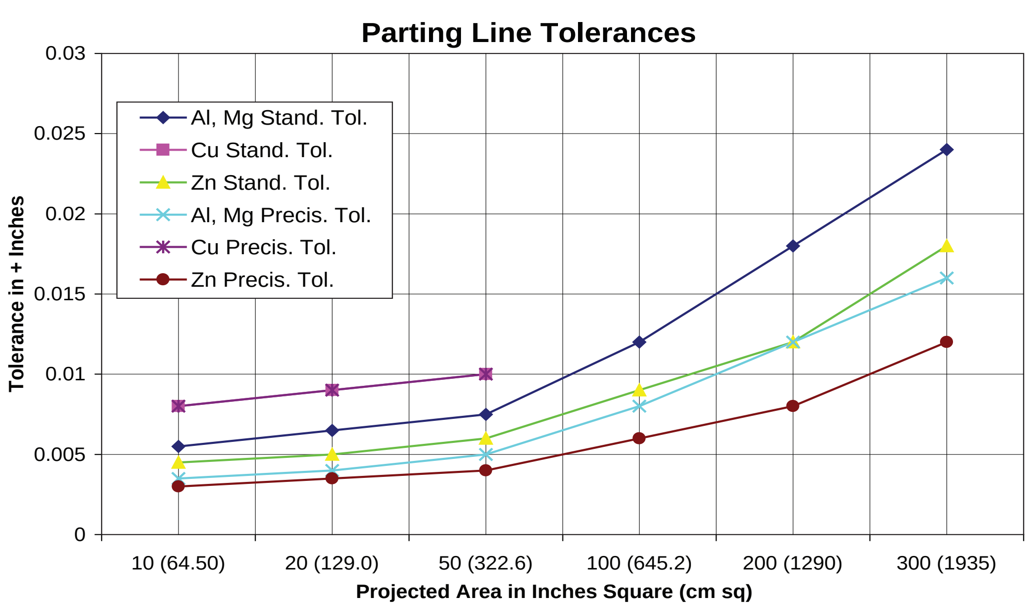
**GD&T is required for radii and chamfers*

Example: An aluminum die casting has 75 in^2 (483.9 cm^2) of Projected Area on the parting die plane. From table P-4-2, Parting Line Tolerance is +0.008. This is combined with the total part thickness tolerance from table P-4-1 to obtain the Total Cross Parting Line Tolerance. Total part thickness including both die halves is 5.000 in. (127 mm) which is measured perpendicular to the parting die plane (dimension "E_2 E_1"). From table P-4-1, the Linear Tolerance is ±0.002 for the first inch and ±0.001 for each of the four additional inches. The Linear Tolerance of ±0.006 is combined with the Parting Line Tolerance of +0.008 to yield a Precision Cross Parting Line Tolerance of +0.014/-0.006 in. or in metric terms (±0.15 mm plus +0.20 mm) = +0.35/-0.15 mm on dimensions that are formed across the parting line.

Table P-4-2 Parting Line Tolerances (Precision) – Added to Linear Tolerances

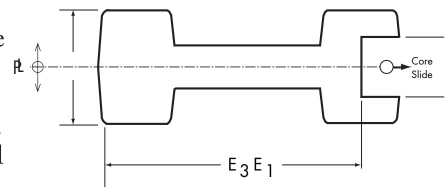
Projected Area of Die Casting inches^2 (cm^2)	Die Casting Alloys (Tolerances shown are "plus" values only)			
	Zinc	Aluminum	Magnesium	Copper
up to 10 in^2 (64.5 cm^2)	+0.003 Ⓐ (+0.076 mm)	+0.0035 (+0.089 mm)	+0.0035 (+0.089 mm)	+0.008 (+0.20 mm)
11 in^2 to 20 in^2 (71.0 cm^2 to 129.0 cm^2)	+0.0035 (+0.089 mm)	+0.004 (+0.102 mm)	+0.004 (+0.102 mm)	+0.009 (+0.23 mm)
21 in^2 to 50 in^2 (135.5 cm^2 to 322.6 cm^2)	+0.004 (+0.102 mm)	+0.005 (+0.153 mm)	+0.005 (+0.153 mm)	+0.010 (+0.25 mm)
51 in^2 to 100 in^2 (329.0 cm^2 to 645.2 cm^2)	+0.006 (+0.153 mm)	+0.008 (+0.203 mm)	+0.008 (+0.203 mm)	—
101 in^2 to 200 in^2 (651.6 cm^2 to 1290.3 cm^2)	+0.008 (+0.203 mm)	+0.012 (+0.305 mm)	+0.012 (+0.305 mm)	—
201 in^2 to 300 in^2 (1296.8 cm^2 to 1935.5 cm^2)	+0.012 (+0.305 mm)	+0.016 (+0.406 mm)	+0.016 (+0.406 mm)	—

For projected area of die casting over 300 in^2 (1935.5 cm^2), consult with your die caster.



8 Moving Die Components (MDC): Standard Tolerances

Moving Die Components Tolerance can affect final part performance similar to Parting Line Tolerance. When the core is fully inserted into the die, the minimum tolerance is zero. As excess material and pressure are exerted in the die, the core can slide out creating an oversized condition. A MDC Tolerance has been developed to ensure minimal impact on form, fit and function by specifying limits to the oversize condition.



**GD&T is required for radii and chamfers*
***All corners should have radii or chamfers*
****Draft should be added to any surface parallel to die/tool movement*

Similar to Parting Line Tolerance, MDC Standard Tolerance is a function of the Moving Die Component (MDC) Tolerance plus Linear Tolerance. Linear Tolerance is calculated based on the length of movement of the core slide along dimension "E_3 E_1". Table S-4-1 is used to determine Linear Tolerance. The linear dimension is not the entire length of "E_3 E_1" but is only the length of the core slide from where the core slide first engages the die to its full insertion position. Linear dimension is normally perpendicular to the Projected Area.

While moving die components have a natural tendency to only add material, there are some situations that can have the opposite effect on the part. For example, long die components can grow thermally larger than typically anticipated. Heavy die components may sag slightly or twist. Typically, these changes can be controlled with shutting die components off against each other. In some cases, this may not be an option. These potential sources of dimensional variation should be discussed early in the process to expand tolerances, modify the datum structure, or modify the casting/die design to minimize issues.

Projected Area is the area of the core head that faces the molten material. MDC Tolerance for moving die components is determined from table S-4-3. The open area (cavity) on the end view of the part in figure 4-1A at the beginning of this section shows the projected area. Projected Area Tolerance plus Linear Tolerance provide MDC Standard Tolerance for the volume of the part. Note that the tolerances in the table apply to a single casting regardless of the number of cavities.

Example: An aluminum casting has 75 in^2 (483.9 cm^2) of Projected Area calculated from the core slide head facing the molten material. From table S-4-3, MDC Tolerance is +0.024. This is combined with the length of the core slide Linear Tolerance from table S-4-1 to obtain the MDC Standard Tolerance. The total core slide length of 5.00 in. (127 mm) is measured from where the core engages the part to full insertion in the plane of dimension "E_3 E_1" to determine Linear Tolerance length. From table S-4-1, the Linear Tolerance is ±0.010 for the first inch and ±0.001 for each of the four additional inches.

The Linear Tolerance of ±0.014 inches is combined with the MDC Tolerance of +0.024 to yield a MDC Standard Tolerance of +0.038/-0.014 in.

MDC Metric Standard Tolerance is +0.96/-0.35 mm = (±0.35 mm) + (+0.61 mm) on dimensions formed by moving die components.

Table S-4-3 MDC Tolerances (Standard) – Added to Linear Tolerances

Projected Area of Die Casting inches^2 (cm^2)	Die Casting Alloys (Tolerances shown are "plus" values only)			
	Zinc	Aluminum	Magnesium	Copper
up to 10 in^2 (64.5 cm^2)	+0.006 (+0.15 mm)	+0.008 (+0.20 mm)	+0.008 (+0.20 mm)	+0.012 (+0.305 mm)
11 in^2 to 20 in^2 (71.0 cm^2 to 129.0 cm^2)	+0.009 (+0.23 mm)	+0.013 (+0.33 mm)	+0.013 (+0.33 mm)	—
21 in^2 to 50 in^2 (135.5 cm^2 to 322.6 cm^2)	+0.013 (+0.33 mm)	+0.019 (+0.48 mm)	+0.019 (+0.48 mm)	—
51 in^2 to 100 in^2 (329.0 cm^2 to 645.2 cm^2)	+0.019 (+0.48 mm)	+0.024 (+0.61 mm)	+0.024 (+0.61 mm)	—
101 in^2 to 200 in^2 (651.6 cm^2 to 1290.3 cm^2)	+0.026 (+0.66 mm)	+0.032 (+0.81 mm)	+0.032 (+0.81 mm)	—
201 in^2 to 300 in^2 (1296.8 cm^2 to 1935.5 cm^2)	+0.032 (+0.81 mm)	+0.040 (+1.0 mm)	+0.040 (+1.0 mm)	—

For projected area of die casting over 300 in^2 (1935.5 cm^2), consult with your die caster.

STANDARD TOLERANCES

The values shown represent Standard Tolerances, or normal die casting production practice at the most economical level. For greater casting accuracy see Precision Tolerances for this characteristic on the facing page. Be sure to also address the procedures referred to in Section 7, "Quality Assurance," subsection 3, 4 and 5.

Die Shift:

Parting line die shift, unlike parting line separation and moving die component tolerances, is a left/right relationship with possible ± consequences. It can shift in four directions, based on a combination of part features, die construction and operation factors. It can occur at any time and its tolerance consequences should be discussed with the die caster at the design stage to minimize any impact on the final die casting.

Notes:
All values for part dimensions which run across the die parting line are stated as a "plus" tolerance only. The die casting die at a die closed position creates the bottom of the tolerance range, i.e., 0.000 (zero). Due to the nature of the die casting process, dies can separate imperceptibly at the parting line and create only a larger, or "plus" side, tolerance.

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P-4-3-18

PRECISION TOLERANCES

Precision Tolerance values shown represent greater casting accuracy involving extra precision in die construction and/or special control in production. They should be specified only when and where necessary, since additional costs may be involved. Be sure to also address the procedures referred to in Section 7, "Quality Assurance," sub-section 3, 4 and 5.

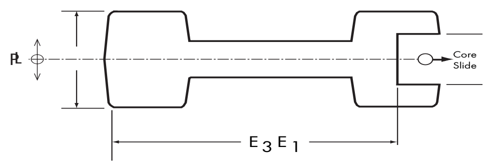
Methods for Improving Precision:

1. By repeated sampling and recutting of the die casting tool, along with production capability studies, even closer dimensions can be held—at additional sampling or other costs.
2. The die casting process may cause variations to occur in parting line separation. Thus, tolerances for dimensions that fall across the parting line on any given part should be checked in multiple locations, i.e., at four corners and on the center line.

Engineering & Design: Tolerancing

Moving Die Components (MDC): Precision Tolerances

Precision Tolerances attainable on die cast dimensions such as "E_3 E_1" formed by a moving die component will be the linear tolerance from table P-4-1 plus the value shown in table P-4-3. Linear Tolerance is the length of the core slide. Projected Area is the area of the head of the core slide facing the molten material. The value chosen from table P-4-3 depends on the Projected Area of the portion of the die casting formed by the moving die component (MDC) perpendicular to the direction of movement. Note that tolerances shown are plus side only.



Example: An aluminum die casting has 75 in^2 (483.9 cm^2) of Projected Area calculated from the core slide head facing the molten material. From table P-4-3, MDC Tolerance is +0.018. This is combined with the length of the core slide Linear Tolerance from table P-4-1 to obtain the MDC Precision Tolerance.

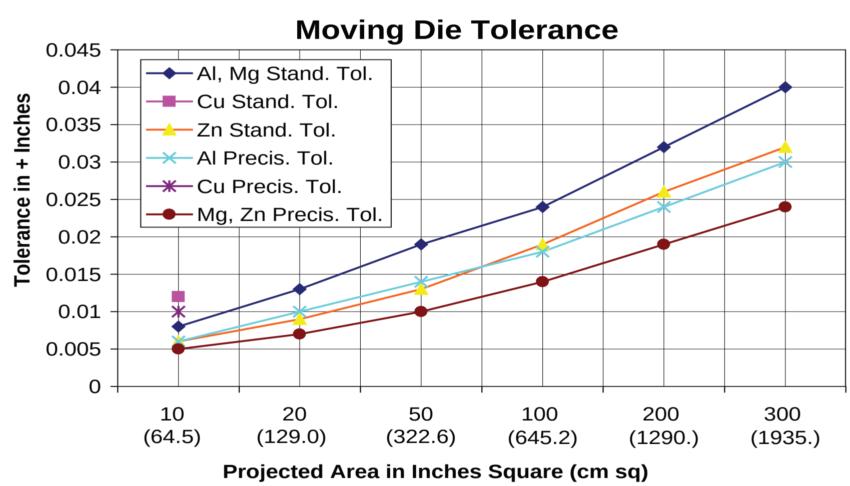
The total core slide length of 5.00 in. (127 mm) is measured from where the core engages the part to full insertion in the plane of dimension "E_3 E_1" to determine Linear Tolerance length from table P-4-1, the Linear Tolerance is ±0.002 for the first inch and ±0.001 for each of the four additional inches. The Linear Tolerance of ±0.006 inches is combined with the MDC Tolerance of +0.018 to yield a MDC Precision Tolerance of +0.024/-0.006 in.

MDC Metric Precision Tolerance is +0.607/-0.15 mm = (±0.15 mm) +(+0.457 mm) on dimensions formed by MDC.

Table P-4-3 MDC Tolerances (Precision) — Added to Linear Tolerances

Projected Area of Die Casting inches^2 (cm^2)	Die Casting Alloys (Tolerances shown are "plus" values only)			
	Zinc	Aluminum	Magnesium	Copper
up to 10 in^2 (64.5 cm^2)	+0.005 Ⓐ (+0.127 mm)	+0.006 (+0.152 mm)	+0.005 (+0.127 mm)	+0.010 (+0.254 mm)
11 in^2 to 20 in^2 (71.0 cm^2 to 129.0 cm^2)	+0.007 (+0.178 mm)	+0.010 (+0.254 mm)	+0.007 (+0.178 mm)	—
21 in^2 to 50 in^2 (135.5 cm^2 to 322.6 cm^2)	+0.010 (+0.254 mm)	+0.014 (+0.356 mm)	+0.010 (+0.254 mm)	—
51 in^2 to 100 in^2 (329.0 cm^2 to 645.2 cm^2)	+0.014 (+0.356 mm)	+0.018 (+0.457 mm)	+0.014 (+0.356 mm)	—
101 in^2 to 200 in^2 (651.6 cm^2 to 1290.3 cm^2)	+0.019 (+0.483 mm)	+0.024 (+0.61 mm)	+0.019 (+0.483 mm)	—
201 in^2 to 300 in^2 (1296.8 cm^2 to 1935.5 cm^2)	+0.024 (+0.61 mm)	+0.030 (+0.762 mm)	+0.024 (+0.61 mm)	—

For projected area of die casting over 300 in^2 (1935.5 cm^2), consult with your die caster.



STANDARD /PRECISION TOLERANCES

Standard Tolerances shown represent normal die casting production practice at the most economical level. Precision Tolerance values shown represent greater casting accuracy involving extra precision in die construction and/or special control in production. They should be specified only when and where necessary, since additional costs may be involved.

9 Angularity Tolerances (Plane surfaces): Standard & Precision Tolerances

Angularity refers to the angular departure from the designed relationship between elements of the die casting. Angularity includes, but is not limited to, flatness, parallelism and perpendicularity. The angular accuracy of a die casting is affected by numerous factors including size of the die casting, the strength and rigidity of the die casting and die parts under conditions of high heat and pressure, position of moving die components, and distortion during handling of the die casting. Angularity is not a stand alone tolerance. Angularity Tolerance is added to other part feature tolerances. For example, if determining tolerance for angular features at the Parting Line, Parting Line Tolerance and Angularity Tolerance would be added to yield total part tolerance.

Angularity is calculated from the following tables based on the surface length that is impacted by angularity and where the surface is located.

There are four tables for calculating Standard and Precision Angularity Tolerance.

- Table S/P-4-4 provides Angularity Tolerance for features in the same die half.
- Table S/P-4-4B provides Angularity Tolerance for features that cross the parting line.
- Table S/P-4-4C provides Angularity Tolerance for MDC features that are in the same die half.
- Table S/P-4-4D provides Angularity Tolerance for multiple MDC features or MDC features that cross the parting line. The more MDCs involved, the more tolerance is necessary hence multiple tables.

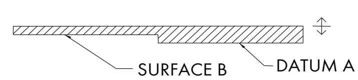
To extend die life a profile tolerance should be utilized when possible.

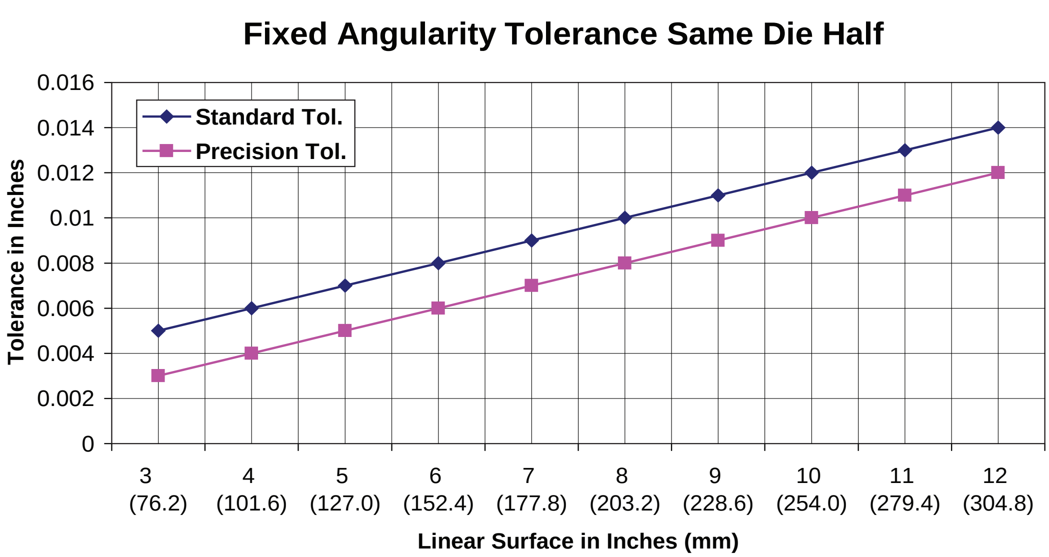
Applicability of Standard

This standard may be applied to plane surfaces of die castings for all alloys. Its tolerances are to be considered in addition to those provided by other standards.

Angularity Tolerances - All Alloys

Tolerances required vary with the length of the surface of the die casting and the relative location of these surfaces in the casting die.

Type	Surfaces 3″ (76.2 mm) or less	Each 1″ (25.4 mm) over 3″ (76.2 mm)	
Standard	.005 (.13 mm)	.001 (.025 mm)	
Precision	.003 (.08 mm)	.001 (.025 mm)	



Engineering & Design: Tolerancing

Precision Tolerance values shown represent greater casting accuracy involving extra precision in die construction and/or special control in production. They should be specified only when and where necessary, since additional costs may be involved.

Methods for Improving Precision:

1. By repeated sampling and recutting of the die casting tool, along with production capability studies, even closer dimensions can be held—at additional sampling or other costs.
2. The die casting process may cause variations to occur in parting line separation. Thus, tolerances for dimensions that fall across the parting line on any given part should be checked in multiple locations, i.e., at four corners and on the center line.

Angularity Tolerances (Plane surfaces): Standard & Precision Tolerances

Same Die Half

Example: Standard Tolerances — Surface -B- and the datum plane -A- are formed by the same die half. If surface -B- is 5" (127 mm) long it will be parallel to the datum plane -A- within .007 (.18 mm). [.005 (.13 mm) for the first 3" (76.2 mm) and .002 (.05 mm) for the additional length.]

Example: Precision Tolerances — Surface -B- and the datum plane -A- are formed by the same die half. If surface -B- is 5" (127 mm) long it will be parallel to the datum plane -A- within .005 (.13 mm). [.003 (.08 mm) for the first 3" (76.2 mm) and .002 (.05 mm) for the additional length.]

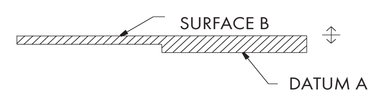
Across Parting Line

Example: For Standard Tolerances — Surface -B- and the datum plane -A- are formed in opposite die sections. If surface -B- is 7" (177.8 mm) long it will be parallel to the datum plane -A- within .014 (.36 mm).

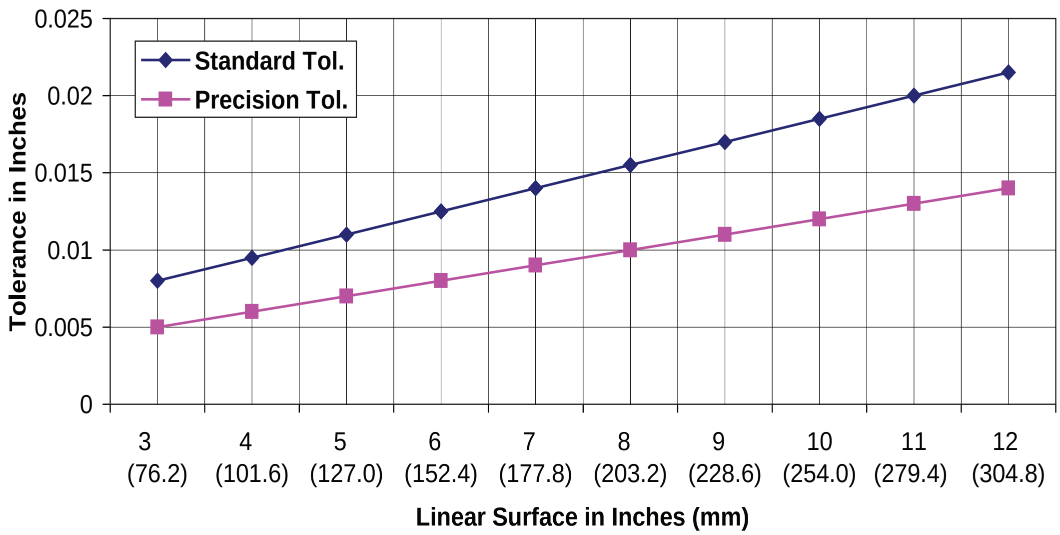
[.008 (.20 mm) for the first 3" (76.2 mm) and .006 (.15 mm) for the additional length.]

Example: For Precision Tolerances — Surface -B- and the datum plane -A- are formed in opposite die sections. If surface -B- is 7" (177.8 mm) long it will be parallel to the datum plane -A- within .009 (.23 mm).

[.005(.13 mm) for the first 3" (76.2 mm) and .004 (.10 mm) for the additional length.]

Type	Surfaces 3" (76.2 mm) or less	Each 1" (25.4 mm) over 3" (76.2 mm)	
Standard	.008 (.20 mm)	.0015 (.038 mm)	
Precision	.005 (.13 mm)	.001 (.025 mm)	

Fixed Angularity Tolerance Across PL



Angularity Tolerances (Plane surfaces): Standard & Precision Tolerances

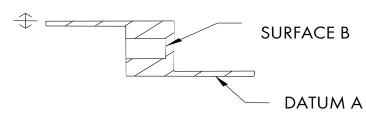
Example: For Standard Tolerances — Surface -B- is formed by a moving die member in the same die section as datum plane -A-. If surface -B- is 5” (127 mm) long it will be perpendicular to the datum plane -A- within .011 (.28 mm).

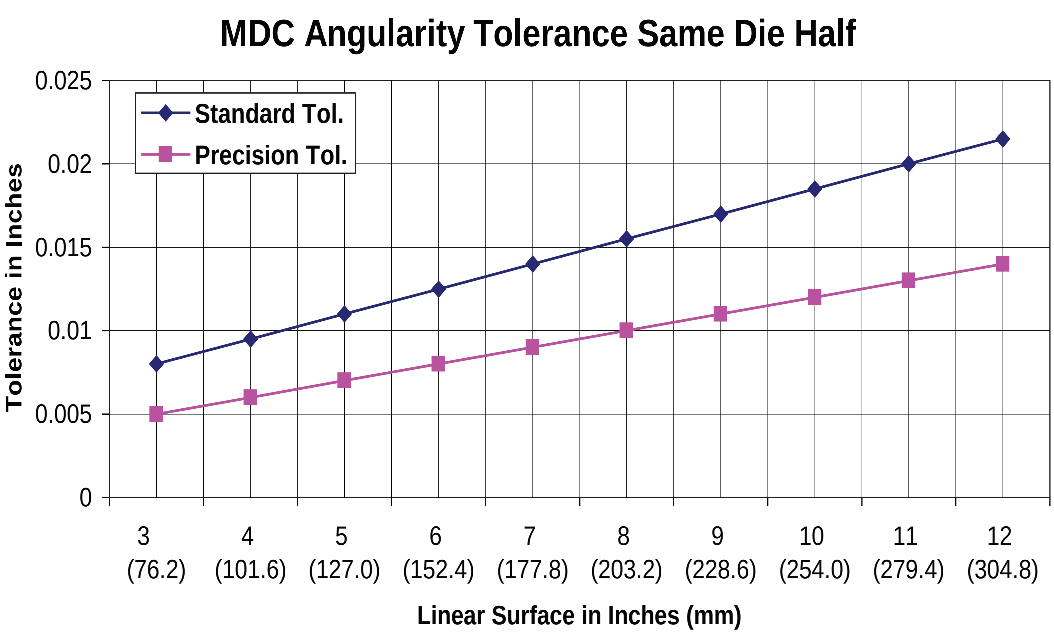
[.008 (.20 mm) for the first 3” (76.2 mm) and .003 (.08 mm) for the additional length.]

Example: For Precision Tolerances — Surface -B- and the datum plane -A- are formed in opposite die sections. If surface -B- is 7” (177.8 mm) long it will be parallel to the datum plane -A- within .009 (.23 mm).

[.005(.13 mm) for the first 3” (76.2 mm) and .004 (.10 mm) for the additional length.]

Type	Surfaces 3” (76.2 mm) or less	Each 1” (25.4 mm) over 3” (76.2 mm)
Standard	.008 (.20 mm)	.0015 (.038 mm)
Precision	.005 (.13 mm)	.001 (.025 mm)





STANDARD /PRECISION TOLERANCES

Standard Tolerances shown represent normal die casting production practice at the most economical level.

Precision Tolerance values shown represent greater casting accuracy involving extra precision in die construction and/or special control in production. They should be specified only when and where necessary, since additional costs may be involved.

Standard Tolerances shown represent normal die casting production practice at the most economical level.

Precision Tolerance values shown represent greater casting accuracy involving extra precision in die construction and/or special control in production. They should be specified only when and where necessary, since additional costs may be involved.

Engineering & Design: Tolerancing

Angularity Tolerances (Plane surfaces): Standard & Precision Tolerances

Example: For Standard Tolerances — Surface -B- is formed by a moving die member and the datum plane -A- is formed by the opposite die section. If surface -B- is 5” (127 mm) long it will be perpendicular to the datum plane -A- within .017 (.43 mm). [.011 (.28 mm) for the first 3” (76.2 mm) and .006 (.15 mm) for the additional length.]

Surfaces -B- and -C- are formed by two moving die members. If surface -B- is used as the datum plane and surface -B- is 5” (127 mm) long, surface -C- will be parallel to surface -B- within .017 (.43 mm).

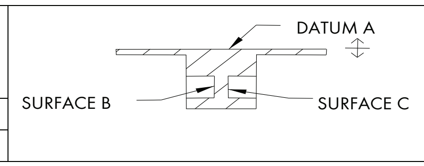
[.011 (.28 mm) for the first 3” (76.2 mm) and .006 (.15 mm) for the additional length.]

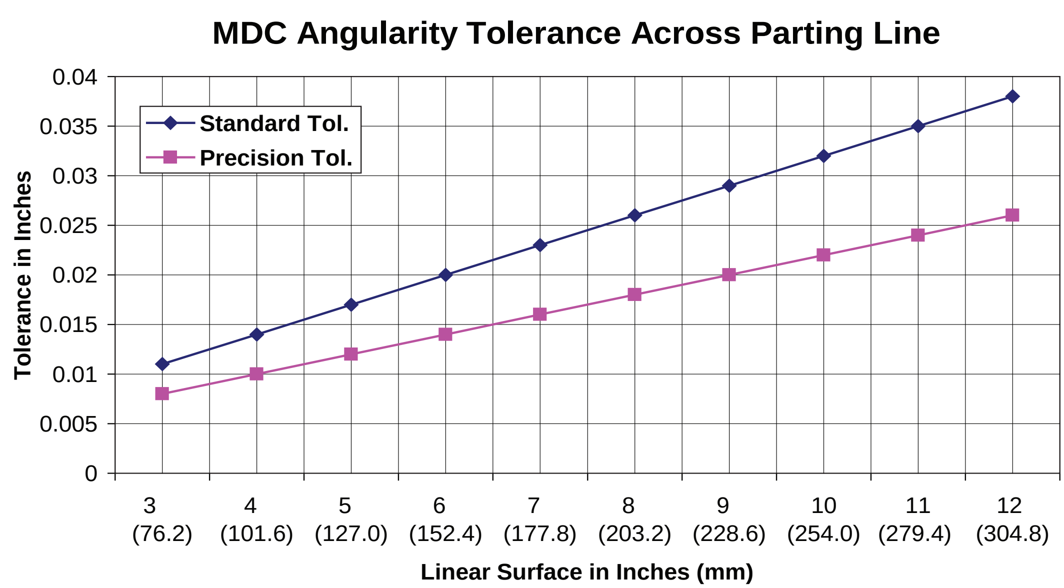
Example: For Precision Tolerances — Surface -B- is formed by a moving die member and the datum plane -A- is formed by the opposite die section. If surface -B- is 5” (127 mm) long it will be perpendicular to the datum plane -A- within .012 (.30 mm). [.008 (.20 mm) for the first 3” (76.2 mm) and .004 (.10 mm) for the additional length.]

Surfaces -B- and -C- are formed by two moving die members. If surface -B- is used as the datum plane and surface -B- is 5” (127 mm) long, surface -C- will be parallel to surface -B- within .012 (.30 mm).

[.008 (.20 mm) for the first 3” (76.2 mm) and .004 (.10 mm) for the additional length.]

Type	Surfaces 3” (76.2 mm) or less	Each 1” (25.4 mm) over 3” (76.2 mm)
Standard	.011 (.28 mm)	.003 (.076 mm)
Precision	.008 (.20 mm)	.002 (.05 mm)





10 Concentricity Tolerances: Varying Degrees of Standard Tolerance

The concentricity of cylindrical surfaces is affected by the design of the die casting. Factors, such as casting size, wall thickness, shape, and complexity each have an effect on the concentricity of the measured surface. The tolerances shown below best apply to castings that are designed with uniformity of shape and wall thickness.

It should be noted that concentricity does not necessarily denote circularity (roundness). Part features can be considered concentric and still demonstrate an out of roundness condition. See section 5.11, Runout vs. Concentricity, in Geometric Dimensioning & Tolerancing for further explanation.

Concentricity Tolerance is added to other tolerances to determine maximum tolerance for the feature. For example, a concentric part that may cross the parting line, the tolerance would be the Concentricity Tolerance added to Parting Line Tolerance to give overall part tolerance. Note that the tolerances in the table apply to a single casting regardless of the number of cavities.

One Die Section

Concentricity Tolerance in a fixed relationship in one die section is calculated by selecting the largest feature diameter, (Diameter A) and calculating the tolerance from Table S-4-5A using the chosen diameter. See information in the side column regarding selecting diameters for oval features. Selected diameter directly impacts degree of precision.

Example: Tolerance in One Die Section — An oval feature has a minimum diameter of 7 inches and a maximum diameter of 8 inches identified by the largest oval in the drawing below. This feature must fit into a hole with a high degree of precision. The minimum diameter (Diameter A) is chosen to give the highest degree of precision. From Table S-4-5A, the basic tolerance for the first 3 inches is 0.008 inches (0.20 mm). 0.002 inches (0.05 mm) is added for each of the additional 4 inches to yield a total Concentricity Tolerance of +0.016 inches (+0.40 mm) for the 7" diameter.

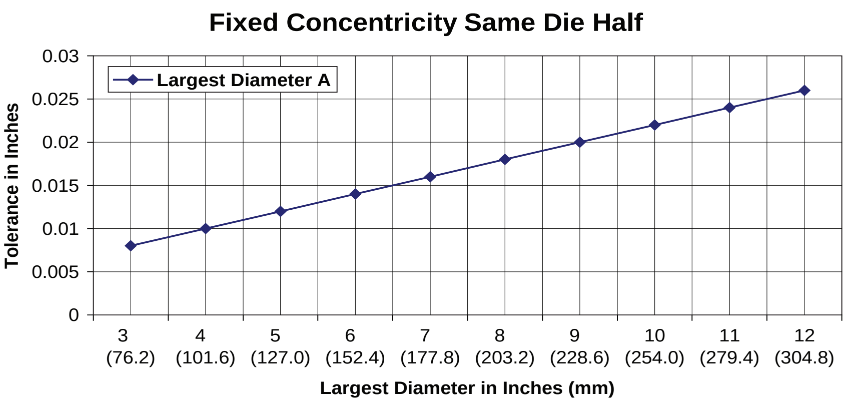
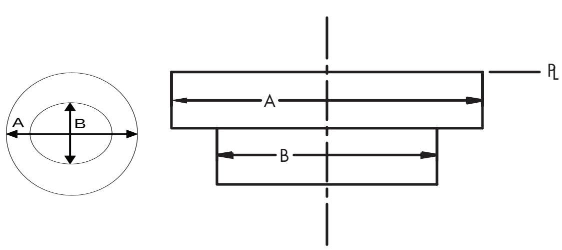


Table S-4-5A: Concentricity Tolerance - Same Die Half (Add to other tolerances)



Surfaces in Fixed Relationship in One Die Section	
Diameter of Largest Diameter (A)	Tolerance (T.I.R.) inches (mm)
Basic Tolerance up to 3" (76.2mm)	.008 (.20 mm)
Additional Tolerance for each additional inch (25.4 mm) over 3" (76.2mm)	+.002 (.05 mm)

Concentricity is defined as a feature having a common center and is usually round, circular or oval. Half the diameter is the center of the feature.

Standard and Precision Tolerance are not specified for Concentricity Tolerance since tolerance is determined from diameter.

As noted in the Concentricity Tolerance description, concentricity does not denote roundness. The feature may be oval and still be concentric. Therefore tolerance precision may be variable depending where diameter is measured.

If minimum diameter is chosen, the calculated tolerance from the table will be less indicating a higher degree of precision.
If maximum diameter is chosen, then calculated tolerance will be more indicating a more "standard" degree of precision.

Diameters chosen between minimum and maximum will determine varying degrees of precision.

Engineering & Design: Tolerancing

Concentricity Tolerances: Varying Degrees of Standard Tolerance

Concentricity is defined as a feature having a common center and is usually round, circular or oval. Half the diameter is the center of the feature.

Standard and Precision Tolerance are not specified for Concentricity Tolerance since tolerance is determined from calculated area.

As noted in the Concentricity Tolerance description, concentricity does not denote roundness. The feature may be oval and still be concentric. Concentricity Tolerance precision is determined from chosen area and how the area is calculated.

Concentric Area Calculation

Round Features are those with equal diameter (D) regardless of where measured. Their area is calculated by:

$(3.14) \times [(1/2\ D)^2]$

Oval Feature areas are determined by averaging the minimum and maximum diameters and then using the same formula as that for Round Features.

Opposite Die Halves

When concentric features are in opposite die halves, the area of the cavity at the parting line determines Concentricity Tolerance. If two concentric features meet at the parting line, it is the area of the larger feature that determines Concentricity Tolerance from table S-4-5B. See the side column for determining the area of a concentric feature. As noted in the side column, degree of precision is determined from the calculated area when crossing the parting line.

If there is a cavity at the parting line between concentric features that are located in opposite die halves such as area C on the figure below, area of the cavity determines Concentricity Tolerance from table S-4-5B.

Total part tolerance is the combination of Concentricity Tolerance plus other feature tolerances for the part.

Example: Tolerance in One Die Section — An oval feature has a minimum diameter of 6 inches and a maximum diameter of 8 inches identified as Diameter A. Diameter B is 5 inches. However, the area of cavity C is 9 by 9 inches. If concentric features meet at the parting line through the squared area C, Concentricity Tolerance is determined from table S-4-5B by the 9 by 9 area which is 81 inches square. From table S-4-5B the Concentricity Tolerance is +.012 inches (+.30 mm).

If concentric features meet at the parting line directly, the area of the larger oval is used to determine the Concentricity Tolerance from table S-4-5B. For example, if the minimum diameter is 6 inches and the maximum diameter is 8 inches, the average diameter is 7 inches. Using the Concentricity Area Calculation formula in the side column, the area is determined to be 38.5 inches square therefore the Concentricity Tolerance is +.008 inches (+.20 mm).

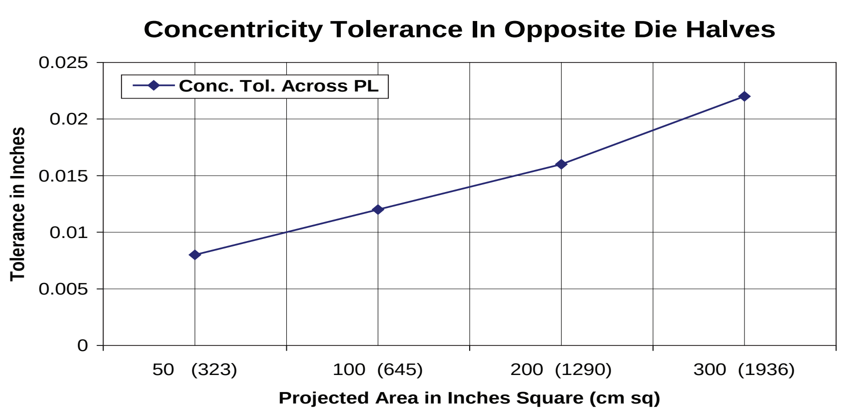
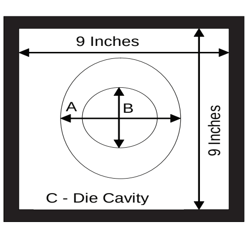
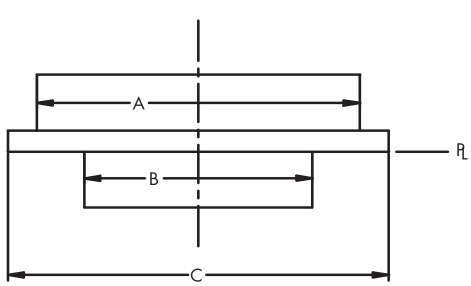


Table S-4-5B: Concentricity Tolerance - Opposite Die Halves (Add to other tolerances)





Surfaces formed by Opposite Halves o Die (single cavity)	
Projected Area (C) of casting	Additional Toleran inches (mm)
Up to 50 in^2 (323 cm^2)	+ .008 (.20 mm)
51 in^2 to 100 in^2 (329 cm^2 to 645 cm^2)	+ .012 (.30 mm)
101 in^2 to 200 in^2 (652 cm^2 to 1290 cm^2)	+ .016 (.41 mm)
201 in^2 to 300 in^2 (1297 cm^2 to 1936 cm^2)	+ .022 (.56 mm)

STANDARD TOLERANCES

Parting Line Shift Tolerances are specified as standard tolerances, only. If a higher degree of precision is required, the caster should be consulted for possible steps that can be taken.

Parting Line Shift Tolerance is only specified in Standard Tolerance because this is the lowest limit to meet the requirements of form, fit and function at the most economical value. Parting line variation has a compounding affect on feature tolerances across the parting line.

Parting Line Shift: Standard Tolerance

Parting line shift or die shift is a dimensional variation resulting from mismatch between the two die halves. The shift is a left/right type relationship that can occur in any direction parallel to the parting line of the two die halves. It has consequences to dimensions unlike parting line separation and moving die component tolerances. Parting line shift will influence dimensions that are measured across the parting line including concentricity of features formed by opposite die halves, and datum structures with datums in opposite die halves. Parting line shift compounds the affects of other tolerances measured across the parting line plane. Parting line shift can cause a part not to meet the requirements of form, fit and function.

Dies are designed and built with alignment systems to minimize parting line shift. However, effectiveness of alignment systems in minimizing parting line shift will depend on temperature variations, die construction, type of die and wear.

Variations in temperature between the two die halves of the die occur during the die's run. With die steel changing size with temperature variation, the two die halves will change size with respect to each other. To accommodate these changes in size, the alignment systems are designed with clearance to eliminate binding during opening and closing of the die. This clearance is necessary for the operation of the die but will allow a certain amount of parting line shift. One side of the die may be heated or cooled to compensate for temperature variation between die halves. One method to compensate for temperature variation is in the design and gating of the die. Another method is to apply additional die lube between shots to cool the hotter die half. Minimizing temperature variation between die halves allows for a more precise alignment system which will limit temperature induced parting line shift.

Moveable components (slides) within a die can also lead to parting line shift. Mechanical locks used to hold the slide in place during the injection of the metal can introduce a force that induces a parting line shift in the direction of the pull of the slide.

The type of die will also affect parting line shift. Due to their design for inter-changeability, unit dies will inherently experience greater parting line shift than full size dies. If parting line shift is deemed critical during part design, a full size die should be considered rather than a unit die.

Steps can be taken during the part design stage to minimize the impact of parting line shift. Datum structures should be set with all of the datum features in one half of the die. If this is not possible, additional tolerance may need to be added (see Geometric Dimensioning, Section 5). Another consideration during part design is to adjust parting lines so those features where mismatch is critical are cast in one half of the die.

Steps can also be taken during the die design to minimize parting line shift. Interlocks and guide blocks can be added to dies to improve alignment, but result in a higher maintenance tool. Placement of the cavities in the die can also be used to minimize the effect of mismatch between the two die halves.

Die wear and alignment system wear may impact parting line shift. As components wear, there is increasing lateral movement that will directly impact parting line shift. The method for decreasing wear induced parting line shift is to minimize moving parts when designing a die system, provide good cooling and lubrication, and have a good preventive maintenance program.

It is important to note that parting line shift can occur at any time and its tolerance consequences should be discussed with the die caster at the design stage to minimize its impact on the final die casting.

There are two components to calculate the affect of parting line shift on a part. The first component is to determine Linear Tolerance. Linear Tolerance is obtained from table S/P-4-1 which was discussed earlier in this section. The second component is to determine Parting Line Shift Tolerance. Cavity area at the parting line is used to determine Projected Area Tolerance from table S-4-6.

Parting Line Shift Tolerance is added to the Linear Tolerance to obtain the volumetric affect of total Parting Line Shift Tolerance on the part.

Parting Line Shift Tolerance is added to other feature tolerances to determine overall part tolerance.

Note that the tolerances in the table apply to a single casting regardless of the number of cavities.

Engineering & Design: Tolerancing

Parting Line Shift: Standard Tolerance

Example: Parting Line Shift Tolerance

The cavity area at the parting line is 75 inches squared. From Table S-4-6, the Projected Area Parting Line Shift Tolerance is ± 0.006 (±0,152 mm). This is added to the Linear Tolerance from table S/P-4-1.

Note: The table represents a step function for additional tolerance based on projected area, whereas the graph represents a linear interpolation between points. A die caster should be contacted to discuss appropriate tolerance for a specific part.

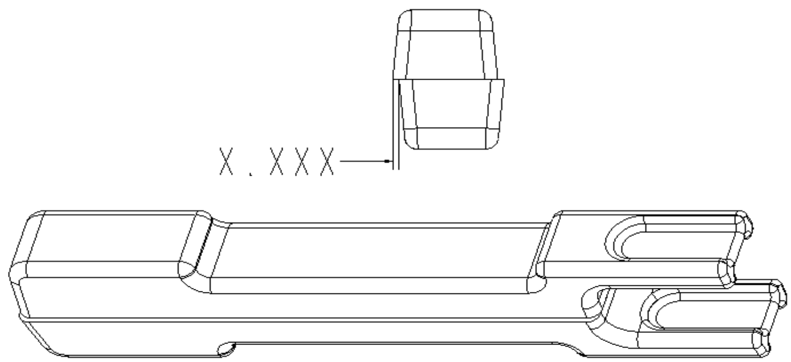
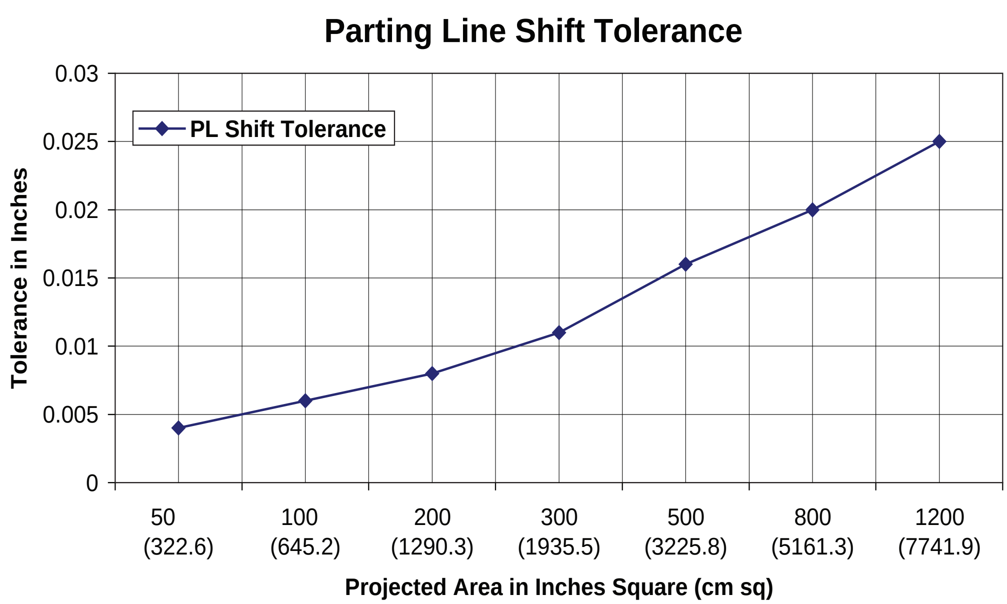


Table S-4-6: Parting Line Shift Tolerance (Excluding unit dies)

Projected Area of Die Casting inches ^{2} (cm ^{2})	Additional Tolerance inches (mm)
up to 50 in ^{2} (322.6 cm ^{2})	±.004 (±.102 mm)
51 in^2 to 100 in^2 (329.0 cm^2 to 645.2 cm^2)	±.006 (±.152 mm)
101 in^2 to 200 in^2 (651.6 cm^2 to 1290.3 cm^2)	±.008 (±.203 mm)
201 in^2 to 300 in^2 (1296.8 cm^2 to 1935.5 cm^2)	±.011 (±.279 mm)
301 in^2 to 500 in^2 (1941.9 cm^2 to 3225.8 cm^2)	±.016 (±.406 mm)
501 in^2 to 800 in^2 (3232.3 cm^2 to 5161.3 cm^2)	±.020 (±.508 mm)
801 in^2 to 1200 in^2 (5167.7 cm^2 to 7741.9 cm^2)	±.025 (±.635 mm)



STANDARD TOLERANCES

The formula for draft shown here represents Standard Tolerance, or normal casting production practice at the most economical level. For Precision Tolerance for draft, see the facing page.

Draft Requirements: Standard Tolerances

Draft is the amount of taper or slope given to cores or other parts of the die cavity to permit easy ejection of the casting.

All die cast surfaces which are normally perpendicular to the parting line of the die require draft (taper) for proper ejection of the casting from the die. This draft requirement, expressed as an angle, is not constant. It will vary with the type of wall or surface specified, the depth of the surface and the alloy selected.

Draft values from the equations, using the illustration and the table below, provides Standard Draft Tolerances for draft on inside surfaces, outside surfaces and holes, achievable under normal production conditions.

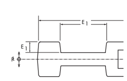
As the formula indicates, draft, expressed as an angle, decreases as the depth of the feature increases. Twice as much draft is recommended for inside walls or surfaces as for outside walls/surfaces. This provision is required because as the alloy solidifies it shrinks onto the die features that form inside surfaces (usually located in the ejector half) and away from features that form outside surfaces (usually located in the cover half). Note also that the resulting draft calculation does not apply to cast lettering, logotypes or engraving. Such elements must be examined individually as to style, size and depth desired. Draft requirements need to be discussed with the die caster prior to die design for satisfactory results.

Draft Example (Standard Tolerances):

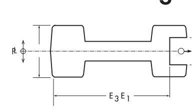
In the case of an inside surface for an aluminum cast part, for which the constant "C" is 30 1/√(in) (19 1/ √ (mm)), the recommended Standard Draft at three depths is:

Depth	Draft Distance	Draft Angle
in. (mm)	in. (mm)	Degrees
0.1 (2.54)	0.010 (0.254)	6″
1.0 (25)	0.033 (0.840)	1.9″
5.0 (127)	0.075 (1.890)	0.85″

Calculation for Draft Distance



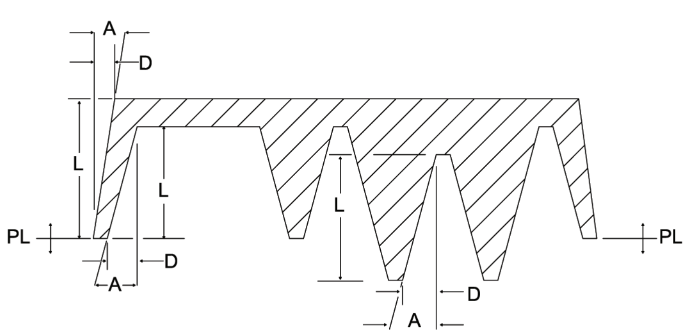
Calculation for Draft Angle



OR $$\frac{57.2738}{C\sqrt{L}}$$

To achieve lesser draft than normal production allows, Precision Tolerances maybe specified (see opposite page).

Where: **D**= Draft in inches
L= Depth or height of feature from the parting line
C= Constant, from table S-4-7, is based on the type of feature and the die casting alloy
A= Draft angle in degrees Draft



Drawing defines draft dimensions for interior and exterior surfaces and total draft for holes (draft is exaggerated for illustration).

Engineering & Design: Tolerancing

Draft Requirements: Standard Tolerances

Table S-4-7: Draft Constants for Calculating Draft and Draft Angle

Values of Constant "C" by Features and Depth (Standard Tolerance)

Alloy	"Inside Wall For Dim. In 1/√in (1/√mm)"	"Outside Wall For Dim. In 1/√in (1/√mm)"	"Hole, Total Draft For Dim. In 1/√in (1/√mm)"
Zinc/ZA	50 (31)	100 (63)	34 (21)
Aluminum	30 (19)	60 (38)	20 (13)
Magnesium	35 (22)	70 (44)	24 (15)
Copper	25 (16)	50 (31)	17 (11)

It is not common practice to specify draft separately for each feature. Draft is normally specified by a general note with exceptions called out for individual features. The formula should be used to establish general draft requirements with any exceptions identified.

For example, an aluminum casting with most features at least 1.0 in. deep can be covered with a general note indicating 2° minimum draft on inside surfaces and 1° minimum on outside surfaces (based on outside surfaces requiring half as much draft).

** For tapped holes cored with removable core pins for subsequent threading see page 4-34 through 4-38.*

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NADCA

P-4-7-18

PRECISION TOLERANCES

Precision Tolerances for draft resulting from the calculations outlined here involve extra precision in die construction and/or special control in production. They should be specified only when necessary. Draft or the lack of draft can greatly affect castability. Early die caster consultation will aid in designing for minimum draft, yet sufficient draft for castability.

Draft Requirements: Precision Tolerances

All cast surfaces normally perpendicular to the parting line of the die require draft (taper) for proper ejection of the casting from the die.
Draft values from the equation at right, using the illustration and the table below, estimate specific Precision Draft Tolerances for draft on inside surfaces, outside surfaces and holes. Precision Draft Tolerances will vary with the type of wall or surface specified, the depth of the wall, and the alloy selected.

As the formula indicates, draft, expressed as an angle, decreases as the depth of the feature increases. See graphical representation on the following pages for various alloys. Twice as much draft is recommended for inside walls or surfaces as for outside walls/surfaces. This provision is required because as the alloy solidifies it shrinks onto the die features that form inside surfaces (usually located in the ejector half) and away from features that form outside surfaces (usually located in the cover half). Note also that the resulting draft calculation does not apply to die cast lettering, logotypes or engraving. Such elements must be examined individually as to style, size and depth desired. Draft requirements need to be discussed with the die caster prior to die design for satisfactory results.

Draft Example (Precision Tolerances):

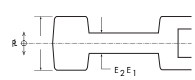
In the case of an inside surface for an aluminum cast part, for which the constant "C" is 40 1/√(in) (25 1/√(mm)) , the recommended Precision Draft at three depths is:

Depth	Draft Distance	Draft Angle
in. (mm)	in. (mm)	Degrees
0.1 (2.54)	0.006 (0.152)	3.6″
1.0 (25.4)	0.020 (.508)	1.1″
2.5 (63.5)	0.032 (0.813)	0.72″

Calculation for Draft Distance

$$A = \frac{\left(\frac{D}{L}\right)}{0.01746}$$

Calculation for Draft Angle

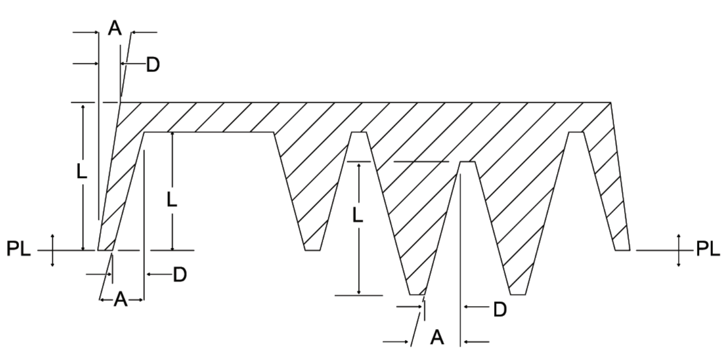


OR

$$\frac{57.2738}{C\sqrt{L}}$$

To achieve lesser draft than normal production allows, Precision Tolerances maybe specified (see opposite page).

Where: **D**= Draft in inches
L= Depth or height of feature from the parting line
C= Constant, from table P-4-7, is based on the type of feature and the die casting alloy
A= Draft angle in degrees Draft



Drawing defines draft dimensions for interior and exterior surfaces and total draft for holes (draft is exaggerated for illustration).

Engineering & Design: Tolerancing

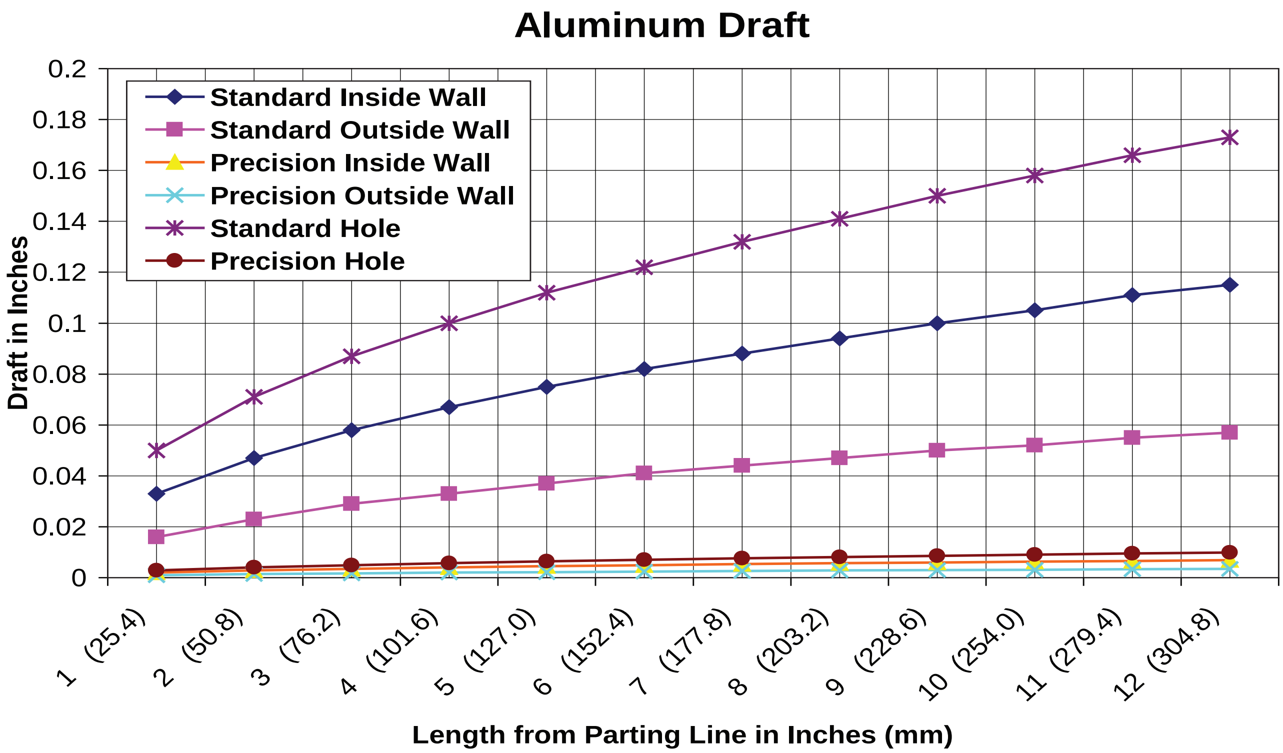
Draft Requirements: Precision Tolerances

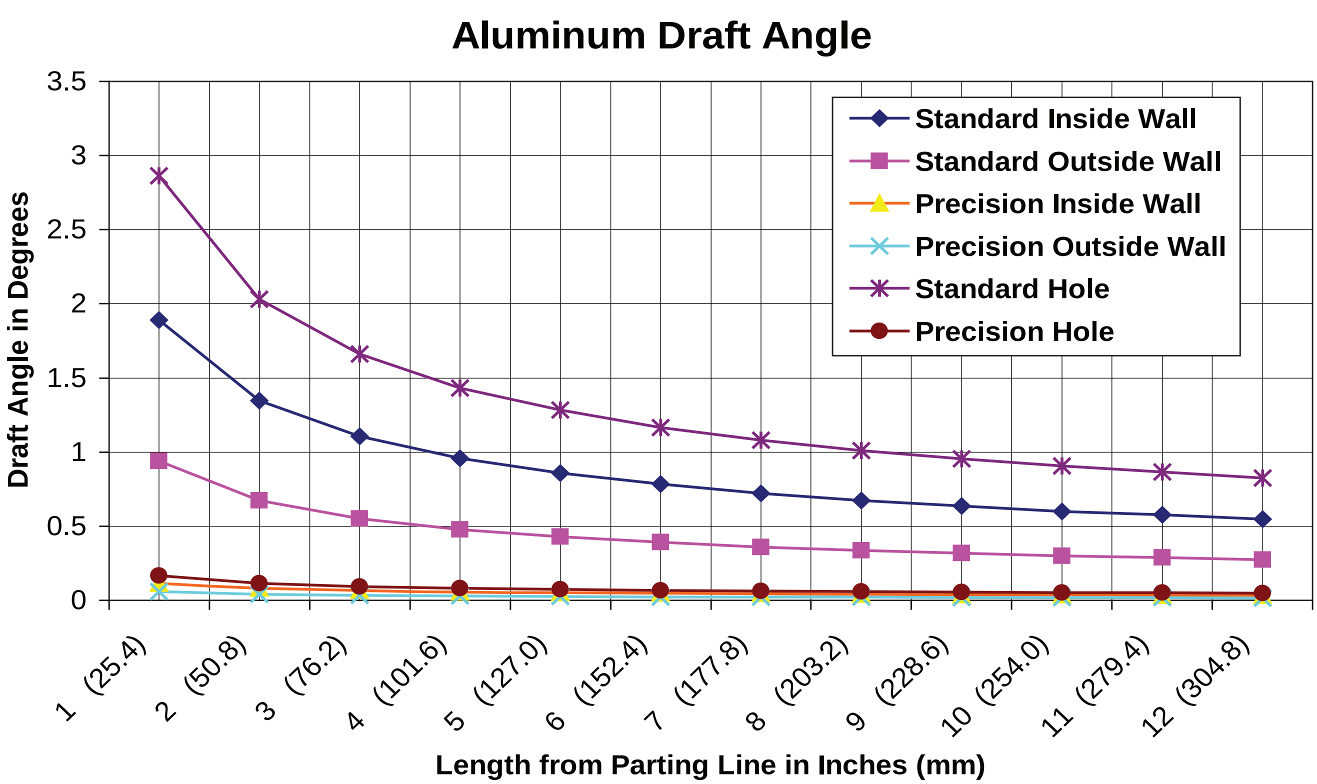
Table P-4-7: Draft Constants for Calculating Draft and Draft Angle

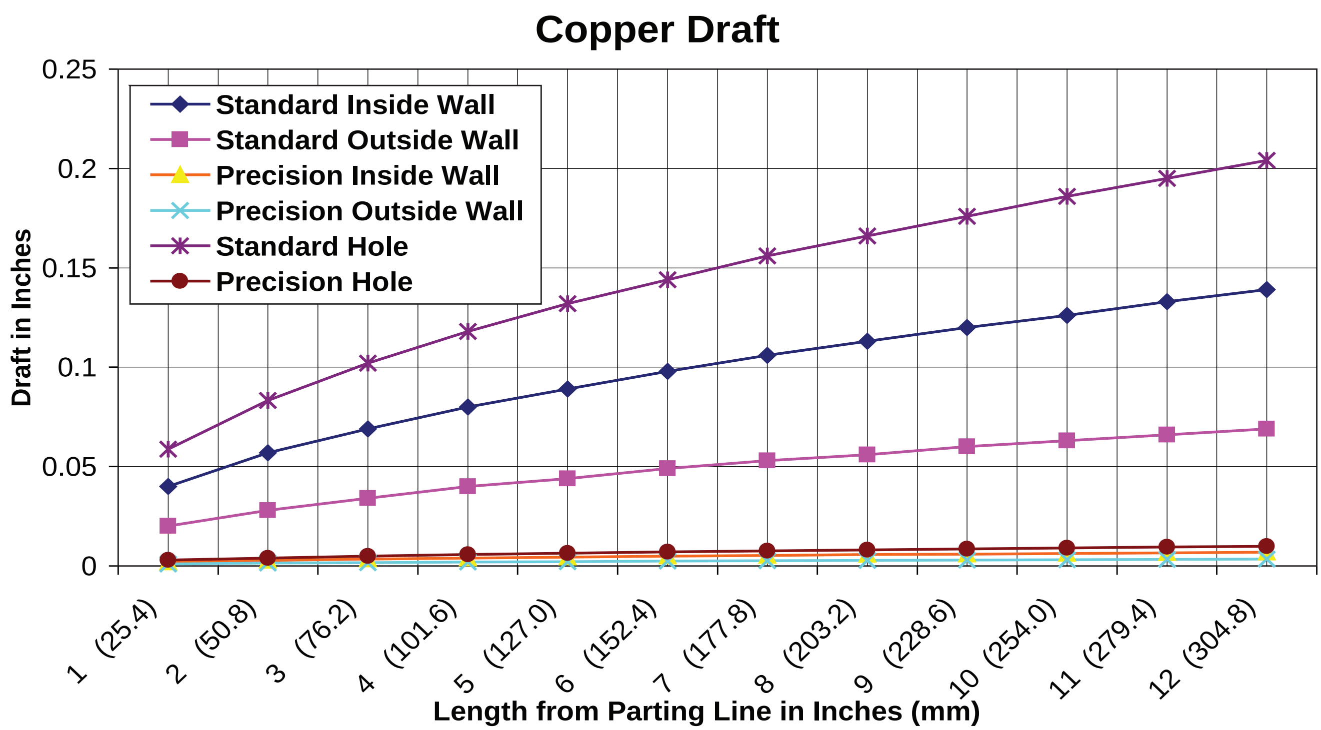
Values of Constant "C" by Features and Depth (Precision Tolerance)			
Alloy	"Inside Wall For Dim. In $1/\sqrt{in}$ ($1/\sqrt{mm}$)"	"Outside Wall For Dim. In $1/\sqrt{in}$ ($1/\sqrt{mm}$)"	"Hole, Total Draft For Dim. In $1/\sqrt{in}$ ($1/\sqrt{mm}$)"
Zinc/ZA	60 (38)	120 (75)	40 (25)
Al/Mg/Cu	40 (25)	80 (50)	28 (18)

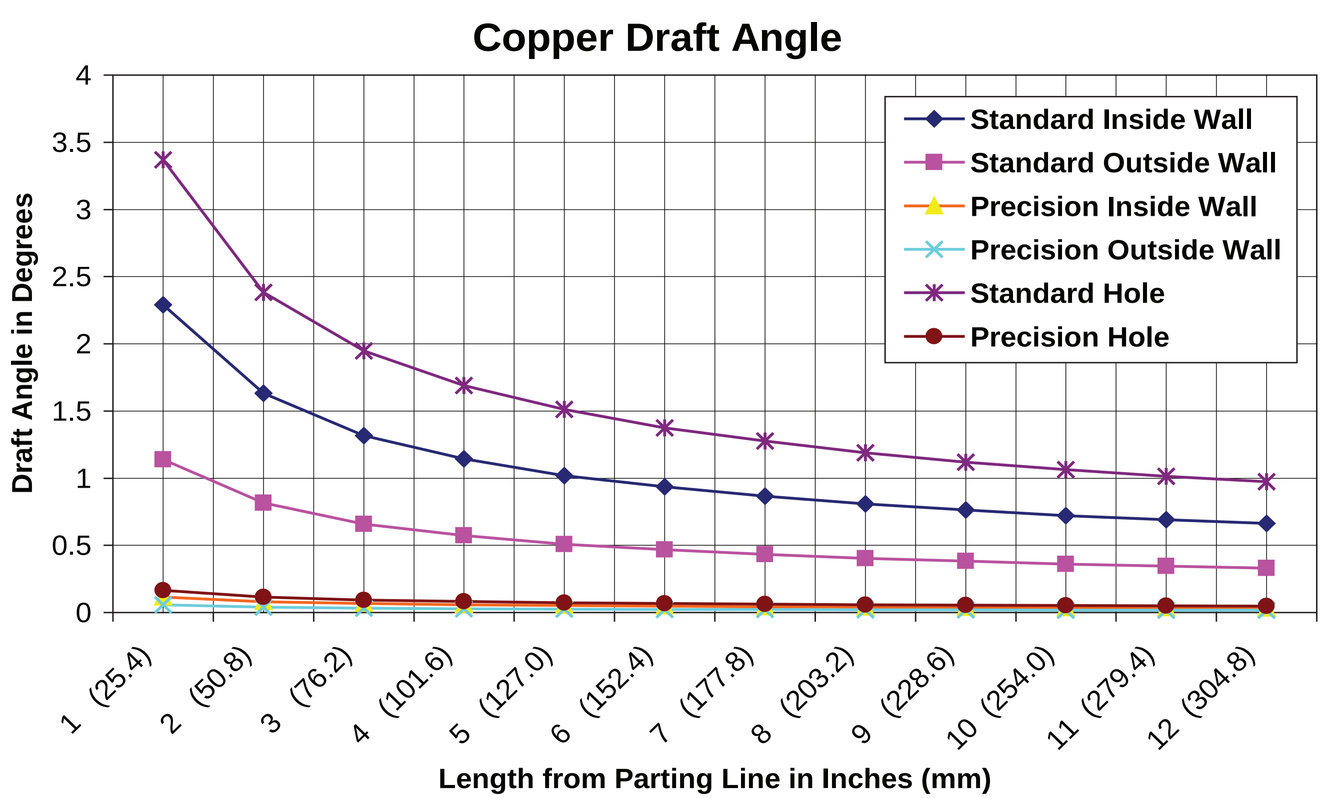
It is not common practice to specify draft separately for each feature. Draft is normally specified by a general note with exceptions called out for individual features. The formula should be used to establish general draft requirements with any exceptions identified.

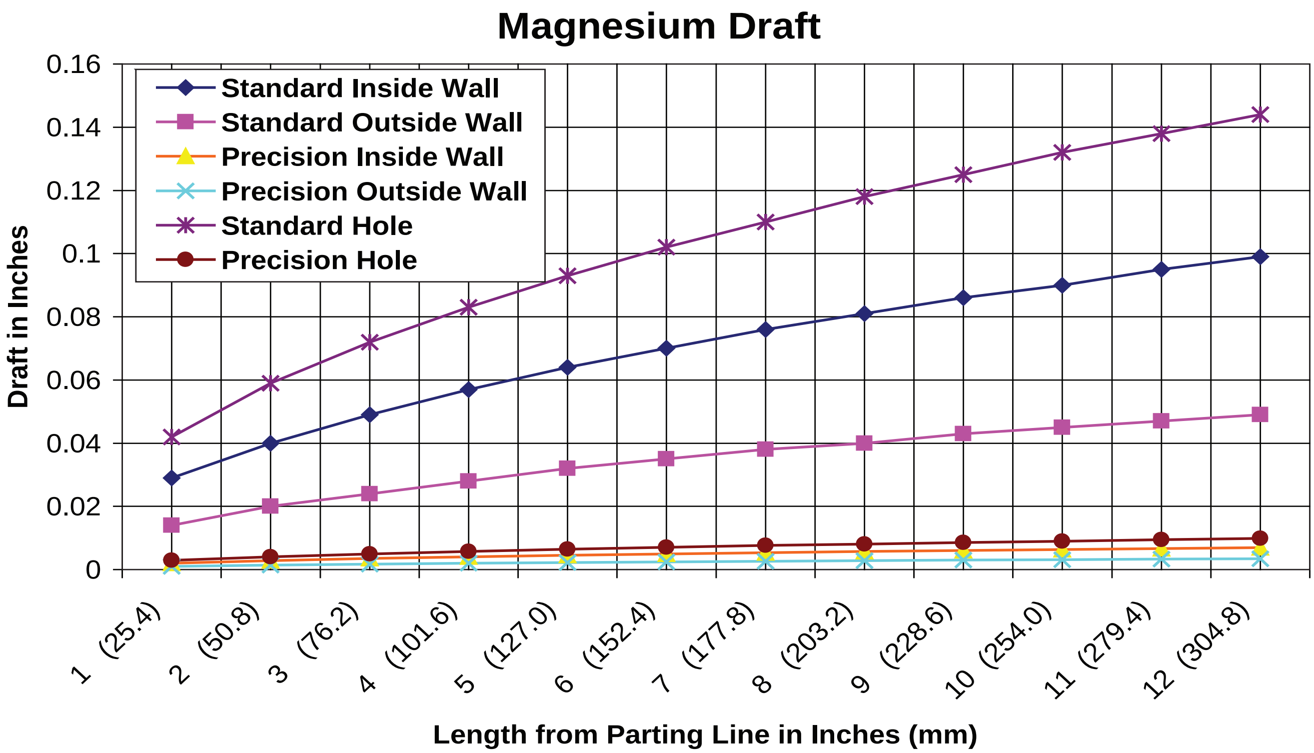
For example, an aluminum casting with most features at least 1.0 in. deep can be covered with a general note indicating 1° minimum draft on inside surfaces and 0.5° minimum on outside surfaces (based on outside surfaces requiring half as much draft).

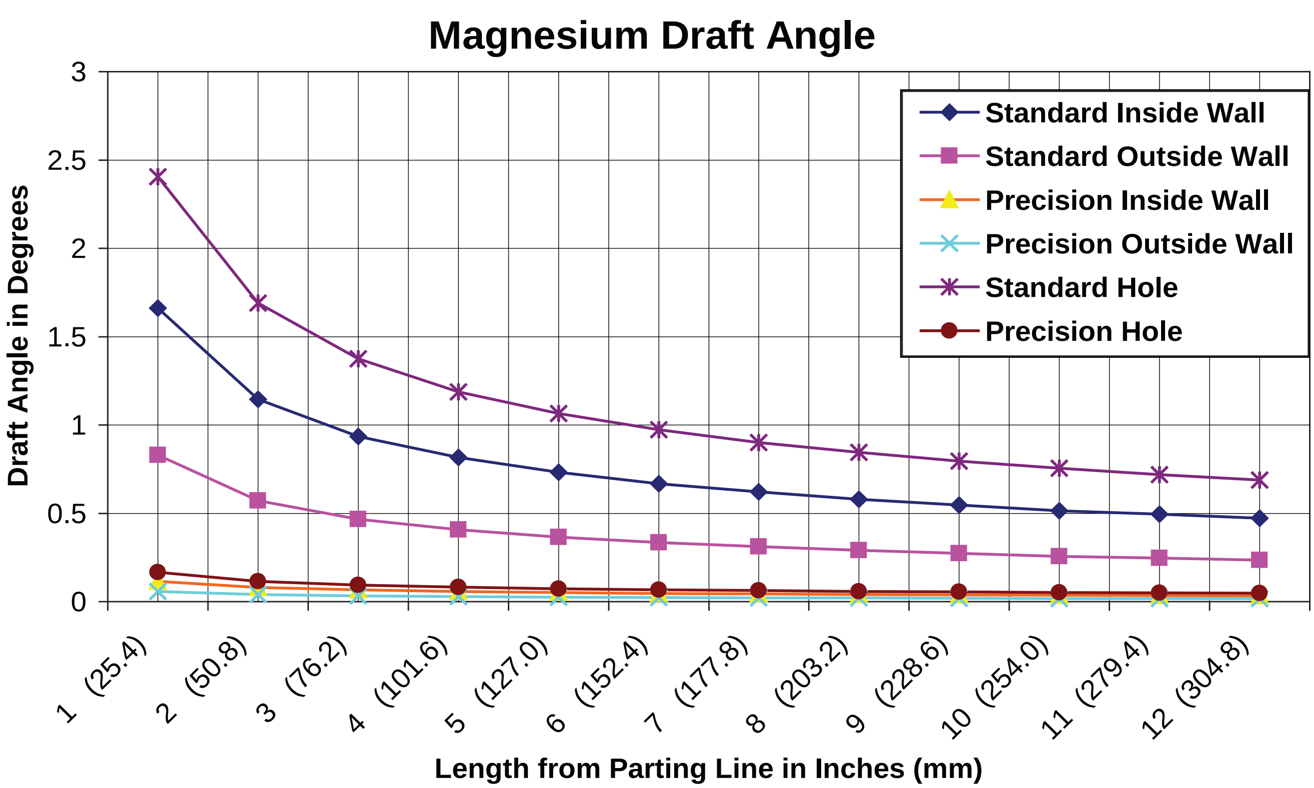

Aluminum Draft
Draft in Inches
Standard Inside Wall
Standard Outside Wall
Precision Inside Wall
Precision Outside Wall
Standard Hole
Precision Hole
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
1 (25.4)
2 (50.8)
3 (76.2)
4 (101.6)
5 (127.0)
6 (152.4)
7 (177.8)
8 (203.2)
9 (228.6)
10 (254.0)
11 (279.4)
12 (304.8)
Length from Parting Line in Inches (mm)


Aluminum Draft Angle
Draft Angle in Degrees
Standard Inside Wall
Standard Outside Wall
Precision Inside Wall
Precision Outside Wall
Standard Hole
Precision Hole
0
0.5
1
1.5
2
2.5
3
3.5
1 (25.4)
2 (50.8)
3 (76.2)
4 (101.6)
5 (127.0)
6 (152.4)
7 (177.8)
8 (203.2)
9 (228.6)
10 (254.0)
11 (279.4)
12 (304.8)
Length from Parting Line in Inches (mm)


Copper Draft
Standard Inside Wall
Standard Outside Wall
Precision Inside Wall
Precision Outside Wall
Standard Hole
Precision Hole
Draft in Inches
0.25
0.2
0.15
0.1
0.05
0
1 (25.4)
2 (50.8)
3 (76.2)
4 (101.6)
5 (127.0)
6 (152.4)
7 (177.8)
8 (203.2)
9 (228.6)
10 (254.0)
11 (279.4)
12 (304.8)
Length from Parting Line in Inches (mm)

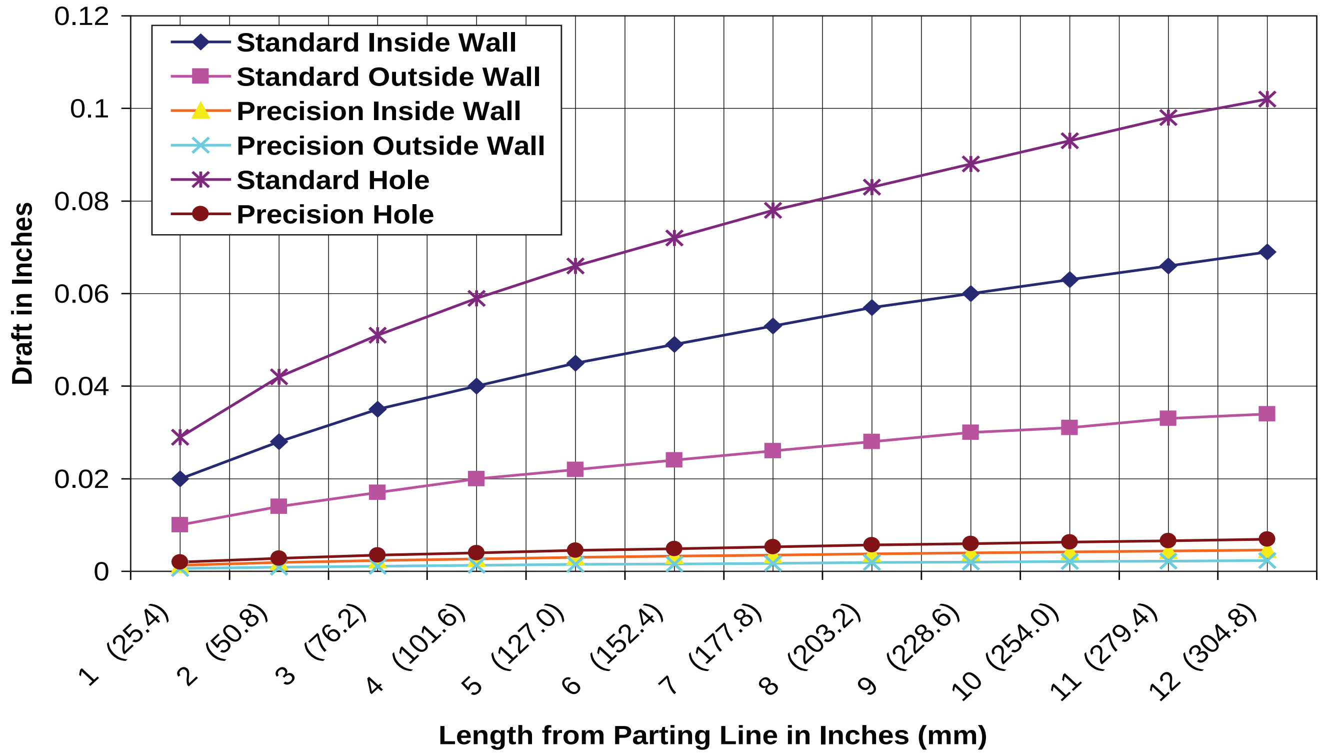

Copper Draft Angle
Standard Inside Wall
Standard Outside Wall
Precision Inside Wall
Precision Outside Wall
Standard Hole
Precision Hole
Draft Angle in Degrees
4
3.5
3
2.5
2
1.5
1
0.5
0
1 (25.4)
2 (50.8)
3 (76.2)
4 (101.6)
5 (127.0)
6 (152.4)
7 (177.8)
8 (203.2)
9 (228.6)
10 (254.0)
11 (279.4)
12 (304.8)
Length from Parting Line in Inches (mm)


Magnesium Draft
Draft in Inches
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Standard Inside Wall
Standard Outside Wall
Precision Inside Wall
Precision Outside Wall
Standard Hole
Precision Hole
1 (25.4)
2 (50.8)
3 (76.2)
4 (101.6)
5 (127.0)
6 (152.4)
7 (177.8)
8 (203.2)
9 (228.6)
10 (254.0)
11 (279.4)
12 (304.8)
Length from Parting Line in Inches (mm)

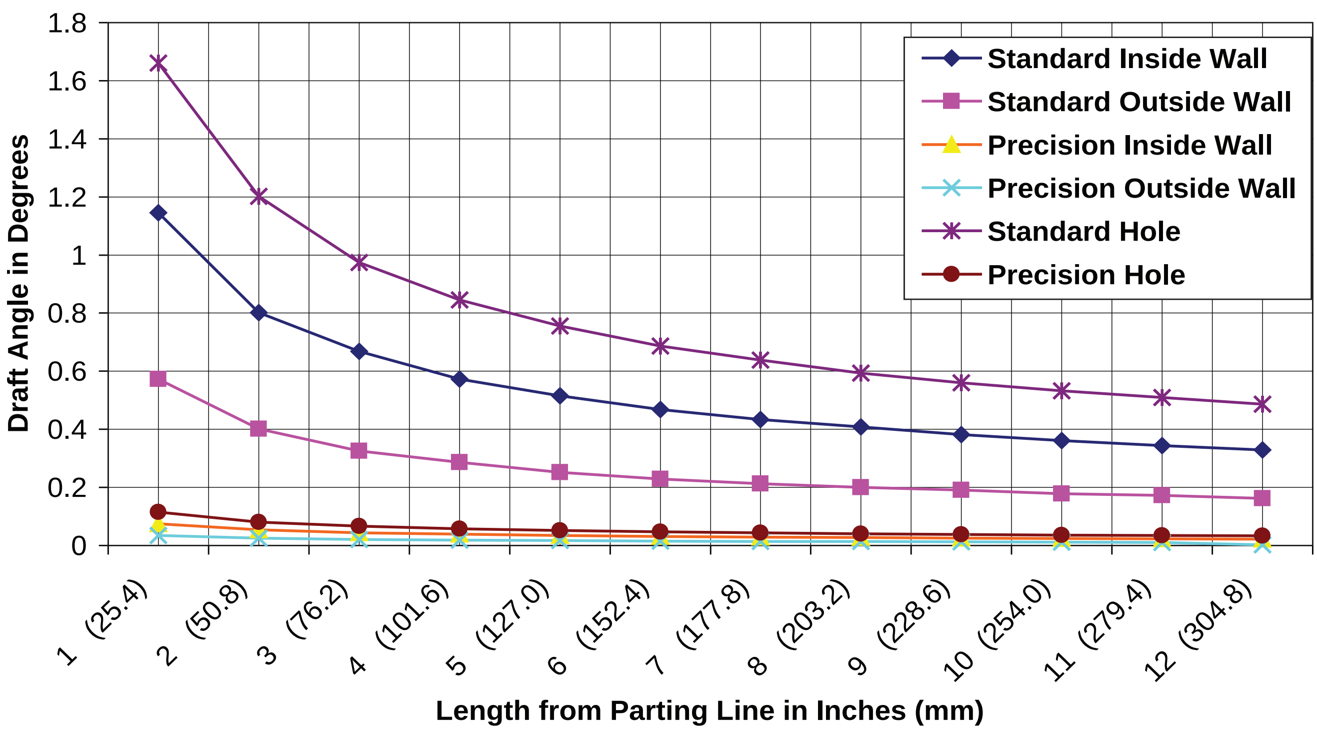

Magnesium Draft Angle
Draft Angle in Degrees
3
2.5
2
1.5
1
0.5
0
Standard Inside Wall
Standard Outside Wall
Precision Inside Wall
Precision Outside Wall
Standard Hole
Precision Hole
1 (25.4)
2 (50.8)
3 (76.2)
4 (101.6)
5 (127.0)
6 (152.4)
7 (177.8)
8 (203.2)
9 (228.6)
10 (254.0)
11 (279.4)
12 (304.8)
Length from Parting Line in Inches (mm)

Engineering & Design: Tolerancing

Zinc Draft



Zinc Draft Angle



Engineering & Design: Tolerancing

Flatness Requirements: Standard Tolerance

Flatness defines surface condition not part thickness. See the flatness explanation on the opposite page.

Standard Tolerance is calculated using the largest dimensions defining the area where the tolerance is to be applied. If flatness is to be determined for a circular surface such as the top of a can, the largest dimension is the diameter of the can. If flatness is to be determined for a rectangular area, the largest dimension is a diagonal.

For greater accuracy, see Precision Tolerances for flatness on the opposite page.

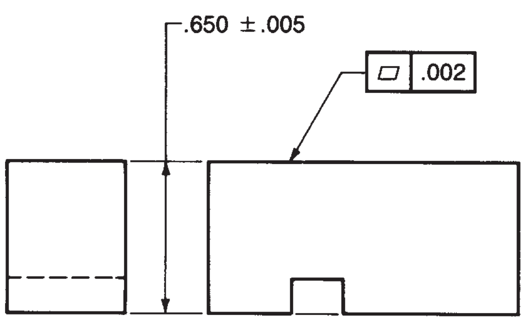
Example: Flatness Tolerance - Diagonal

For a part where the diagonal measures 10 inches (254 mm), the maximum Flatness Standard Tolerance from table S-4-8 is 0.008 inches (0.20 mm) for the first three inches (76.2 mm) plus 0.003 inches (0.08 mm) for each of the additional seven inches for a total Flatness Standard Tolerance of 0.029 inches (0.76 mm).

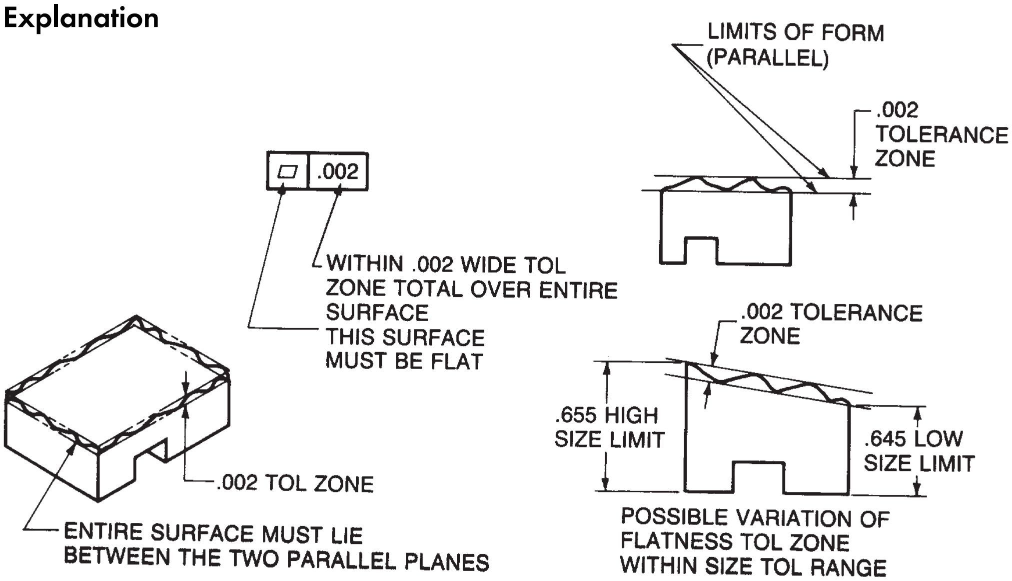
Table S-4-8 Flatness Tolerances, As-Cast: All Alloys

Maximum Dimension of Die Cast Surface	Tolerance inches (mm)
up to 3.00 in. (76.20 mm)	0.008 (0.20 mm)
Additional tolerance, in. (25.4 mm) for each additional in. (25.4 mm)	0.003 (0.08 mm)

Flatness Example



Explanation



STANDARD TOLERANCES

The flatness values shown here represent Standard Tolerances, or normal casting production practice at the most economical level. For greater casting accuracy see Precision Tolerances for this characteristic on the facing page.

Flatness is described in detail in Section 5, Geometric Dimensioning & Tolerancing. Simply put, Flatness Tolerance is the amount of allowable surface variation between two parallel planes which define the tolerance zone. See the figures below.

Flatness of a continuous plane surface on a casting should be measured by a method mutually agreed upon by the designer, die caster and the customer before the start of die design.

Note:
The maximum linear dimension is the diameter of a circular surface or the diagonal of a rectangular surface.

Flatness Design Guidelines:

1. All draft on walls, bosses and fins surrounding and underneath flat surfaces should be standard draft or greater.
2. Large bosses or cross sections can cause sinks and shrinkage distortions and should be avoided directly beneath flat surfaces.
3. Changes in cross section should be gradual and well filleted to avoid stress and shrinkage distortions.
4. Symmetry is important to obtain flatness. Lobes, legs, bosses and variations in wall height can all affect flatness.

Engineering & Design: Tolerancing

Precision Tolerance values for flatness shown represent greater casting accuracy involving extra precision in die construction. They should be specified only when and where necessary since additional cost may be involved.

Notes:
The maximum linear dimension is the diameter of a circular surface or the diagonal of a rectangular surface.

Flatness Design Guidelines:

1. All draft on walls, bosses and fins surrounding and underneath flat surfaces should be standard draft or greater.
2. Large bosses or cross sections can cause sinks and shrinkage distortions and should be avoided directly beneath flat surfaces.
3. Changes in cross section should be gradual and well filleted to avoid stress and shrinkage distortions.
4. Symmetry is important to obtain flatness. Lobes, legs, bosses and variations in wall height can all affect flatness.

Flatness Requirements: Precision Tolerance

The values shown for Precision Tolerance for flatness represent greater casting accuracy involving extra steps in die construction and additional controls in production. They should be specified only when and where necessary since additional costs may be involved.

Even closer tolerances may be held by working with the die caster to identify critical zones of flatness. These areas may be amenable to special die construction to help maintain flatness.

Flatness Explanation

As noted in the explanation diagram, at the bottom of the page, flatness is independent of all other tolerance features including thickness.

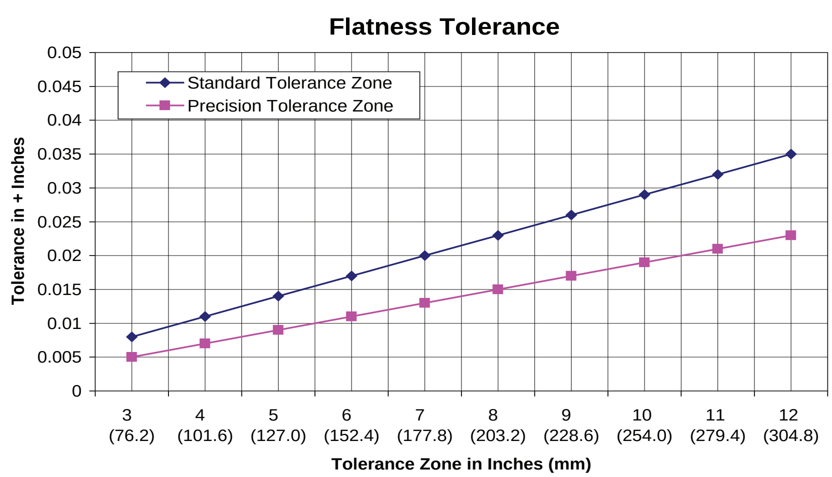
Part thickness has a nominal thickness of 0.300 ±0.010. Flatness Tolerance is 0.005. Therefore at the high limit thickness the part surface flatness can be between 0.305 and 0.310. Nominal thickness flatness can be between .2975 and .3025. Low limit thickness flatness can be between 0.290 and 0.295. Flatness can not range between 0.290 and 0.310. Using both high and low thickness in combination with flatness defeats the purpose for specifying flatness.

Example: Flatness Tolerance - Diagonal

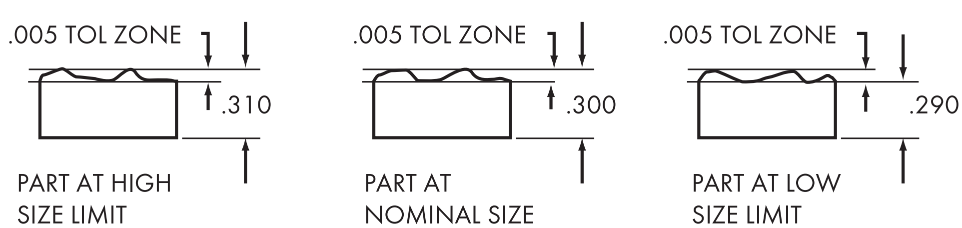
For a part where the diagonal measures 10 inches (254 mm), the maximum Flatness Precision Tolerance from table P-4-8 is 0.005 inches (0.13 mm) for the first three inches (76.2 mm) plus 0.002 inches (0.05 mm) for each of the additional seven inches for a total Flatness Standard Tolerance of 0.019 inches (0.48 mm).

Table P-4-8 Flatness Tolerances, As-Cast: All Alloys

Maximum Dimension of Die Cast Surface	Tolerance inches (mm)
up to 3.00 in. (76.20 mm)	0.005 (0.13 mm)
Additional tolerance, in. (25.4 mm) for each additional in. (25.4 mm)	0.002 (0.05 mm)



Explanation



Design Recommendations: Cored Holes As-Cast

Cored holes in die castings can be categorized according to their function. There are three major classifications.

- Metal savers
- Clearance holes
- Function/locating holes

Each of these functions implies a level of precision. Metal savers require the least precision; function/locating holes require the greatest precision. Leaving clearance holes in-between.

Specifications for cored holes are the combination of form, size and location dimensions and tolerances required to define the hole or opening.

Metal Savers

Metal savers are cored features, round or irregular, blind or through the casting, whose primary purpose is to eliminate or minimize the use of raw material (metal/alloy). The design objective of the metal saver is to reduce material consumption, while maintaining uniform wall thickness, good metal flow characteristics, good die life characteristics with minimal tool maintenance.

In the design of ribs and small metal savers the designer needs to be aware to avoid creating "small" steel conditions in the tool that can be detrimental to tool life.

Design recommendation:

1. Wall thickness
Design for uniform wall thickness around metal savers. Try to maintain wall thickness within ±10% of the most typical wall section.

2. Draft
Use draft constant per NADCA S-4-7 for inside walls. Keep walls as parallel as practical.

3. Radii/fillets
Use as large a radius as possible, consistent with uniform wall thickness. Refer to NADCA guidelines G-6-2. Consider 0.06 inch radius (1.5 mm radius) as a minimum. A generous radius at transitions and section changes will promote efficient metal flow during cavity filling.

Clearance Holes

Clearance holes are cored holes, round or irregular, blind or through the casting, whose primary purpose is to provide clearance for features and components. Clearance implies that location of the feature is important.

Design recommendation:

1. Tolerance
Dimensions locating the cored hole should be per NADCA Standard tolerances; S-4-1 Linear Dimension, S-4-2 Parting Line Dimensions and S-4-3 Moving Die Components.

2. Wall thickness
Design for uniform wall thickness around clearance holes. Try to maintain wall thickness within ±10% of the most typical wall section. If hole is a through hole, allowance should be made for any trim edge per NADCA G-6-5, Commercial Trimming within 0.015 in. (0.4 mm).

3. Draft
Use draft constant per NADCA S-4-7 for inside walls. Keep walls as parallel as practical.

4. Radii/fillets
Use as large a radius as possible, consistent with uniform wall thickness. Refer to NADCA guidelines G-6-2. Consider 0.06 inch radius (1.5 mm radius.) as a minimum. A generous radius at transitions and section changes will promote efficient metal flow during cavity filling.

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For holes with less than a 0.25 inch diameter, wall stock may be a minimum of one half the hole diameter. Unless wall thickness is required for strength. However, Ribbing Should be applied first.

For holes with larger than a 0.25 inch diameter, the wall stock shall be the nominal wall thickness (subject to part design).

These rules can be broken if the product requires more strength. However, ribbing should be attempted first.

Functional/Locating Holes

Functional/locating holes are cored holes whose purpose is to provide for a functional purpose such as threading, inserting and machining or location and alignment for mating parts or secondary operations.

Design recommendation:

1. Tolerance

Dimensions locating the cored hole to be per NADCA Precision tolerances; P-4-1 Linear Dimension, P-4-2 Parting Line Dimensions and P-4-3 Moving Die Components.

2. Wall thickness

Design for uniform wall thickness around functional/locating holes. Try to maintain wall thickness within ±10% of the most typical wall section. If hole is a through hole, allowance should be made for any trim edge per NADCA G-6-5, Commercial Trimming within 0.015 inch (0.4 mm) or if this is not acceptable, a mutually agreed upon requirement.

3. Draft

Use draft constant per NADCA P-4-7 for inside walls. Keep walls as parallel as practical.

4. Radii/fillets

Use as large a radius as possible, consistent with uniform wall thickness. Refer to NADCA guidelines G-6-2. Consider 0.03 inch radius (0.8 mm radius.) as a minimum. A generous radius at transitions and section changes will promote efficient metal flow during cavity filling.

Other Design Considerations

Hole depths

	Diameter of Hole — Inches								
	1/8	5/32	3/16	1/4	3/8	1/2	5/8	3/4	1
Alloy	Maximum Depth — Inches								
Zinc	3/8	9/16	3/4	1	1-1/2	2	3-1/8	4-1/2	6
Aluminum	5/16	1/2	5/8	1	1-1/2	2	3-1/8	4-1/2	6
Magnesium	5/16	1/2	5/8	1	1-1/2	2	3-1/8	4-1/2	6
Copper				1/2	1	1-1/4	2	2-1/2	5

**Depths are recommended maximums and are not necessarily the limits for a specific die caster. Consult a die caster to discuss their capabilities.*

Note:

The depths shown are not applicable under conditions where small diameter cores are widely spaced and, by design, are subject to full shrinkage stress.

Perpendicularity

See Section 5 pages 5-19 and 5-20 Orientations Tolerances.

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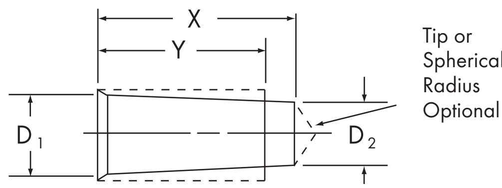
The values shown represent Standard Tolerances, or normal casting production practice at the most economical level. For greater casting accuracy see Precision Tolerances for the characteristic on the facing page.

Engineering & Design: Tolerancing

Cored Holes for Cut Threads: Standard Tolerances

Cored holes for cut threads are cast holes that require threads to be cut (tapped) into the metal. The table below provides the dimensional tolerances for diameter, depth and draft for each specified thread type (Unified and Metric Series). When required, cored holes in Al, Mg, Zn and ZA may be tapped without removing draft. This Standard Tolerance recommendation is based on allowing 85% of full thread depth at the bottom D_2 (small end) of the cored hole and 55% at the top D_1 (large end) of the cored hole. A countersink or radius is also recommended at the top of the cored hole. This provides relief for any displaced material and can also serve to strengthen the core.



Threads extend through the cored hole as by Y. X shows the actual hole depth. As with the countersink at the top of the hole, the extra hole length provides relief for displaced material and allows for full thread engagement. Tolerances below apply to all alloys.

Table S-4-9: Cored Holes for Cut Threads (Standard Tolerances) – Unified Series and Metric Series

Unified Series/ Class	**Hole Diameter** D_1, Max.	D_2, Min.	**Thread Depth** Y, Max.	**Hole Depth** X, Max.
	inches	inches	inches	inches
6-32, UNC/2B, 3B	**0.120**	**0.108**	**0.414**	**0.508**
6-40, UNF/2B	**0.124**	**0.114**	**0.345**	**0.420**
8-32, UNC/2B	**0.146**	**0.134**	**0.492**	**0.586**
8-36, UNF/2B	**0.148**	**0.137**	**0.410**	**0.493**
10-24, UNC/2B	**0.166**	**0.151**	**0.570**	**0.695**
10-32, UNF/2B	**0.172**	**0.160**	**0.475**	**0.569**
12-24, UNC/2B	**0.192**	**0.177**	**0.648**	**0.773**
12-28, UNF/2B	**0.196**	**0.182**	**0.540**	**0.647**
1/4A-20, UNC/1B, 2B	**0.221**	**0.203**	**0.750**	**0.900**
1/4A-28, UNF/1B, 2B	**0.230**	**0.216**	**0.500**	**0.607**
5/16-18, UNC/1B, 2B	**0.280**	**0.260**	**0.781**	**0.948**
5/16-24, UNF/1B, 2B	**0.289**	**0.273**	**0.625**	**0.750**
3/8-16, UNC/1B, 2B	**0.339**	**0.316**	**0.938**	**1.125**
3/8-24, UNF/1B, 2B	**0.351**	**0.336**	**0.656**	**0.781**
7/16-14, UNC/1B, 2B	**0.396**	**0.371**	**1.094**	**1.308**
7/16-20, UNF/1B, 2B	**0.409**	**0.390**	**0.766**	**0.916**
1/2-13, UNC/1B, 2B	**0.455**	**0.428**	**1.250**	**1.481**
1/2-20, UNF/1B, 2B	**0.471**	**0.453**	**0.750**	**0.900**
9/16-12, UNC/1B, 2B	**0.514**	**0.485**	**1.406**	**1.656**
9/16-18, UNF/1B, 2B	**0.530**	**0.510**	**0.844**	**1.010**
5/8-11, UNC/1B, 2B	**0.572**	**0.540**	**1.563**	**1.835**
5/8-18, UNF/1B, 2B	**0.593**	**0.573**	**0.781**	**0.948**
3/4A-10, UNC/1B, 2B	**0.691**	**0.657**	**1.688**	**1.988**
3/4A-16, UNF/1B, 2B	**0.714**	**0.691**	**0.938**	**1.125**
7/8- 9, UNC/1B, 2B	**0.810**	**0.772**	**1.750**	**2.083**
7/8-14, UNF/1B, 2B	**0.833**	**0.808**	**1.094**	**1.308**
1- 8, UNC/1B, 2B	**0.927**	**0.884**	**2.000**	**2.375**
1-12, UNF/1B. 2B	**0.951**	**0.922**	**1.250**	**1.500**

Metric Series Thread Size Ⓐ	**Hole Diameter** D_1, Max.	D_2, Min.	**Thread Depth** Y, Max.	**Hole Depth** X, Max.
	mm	mm	mm	mm
M3.5 X 0.6	3.168	2.923	7.88	9.68
M4 X 0.7	3.608	3.331	9.00	11.10
M5 X 0.8	4.549	4.239	11.25	13.65
M6 X 1	5.430	5.055	13.50	16.50
M8 X 1.25	7.281	6.825	18.00	21.75
f M8 X 1	7.430	7.055	14.00	17.00
M10 X 1.5	9.132	8.595	22.50	27.00
f M10 X 0.75	9.578	9.285	10.00	12.25
f M10 X 1.25	9.281	8.825	20.00	23.75
M12 X 1.75	10.983	10.365	27.00	32.25
f M12 X 1	11.430	11.055	15.00	18.00
f M12 X 1.25	11.281	10.825	18.00	21.75
M14 X 2	12.834	12.135	31.50	37.50
fM14 X 1.5	13.132	12.595	24.50	29.00
f M15 X 1	14.430	14.055	15.00	18.00
M16 X 2	14.834	14.135	32.00	38.00
f M16 X 1.5	15.132	14.595	24.00	28.50
f M17 X 1	16.430	16.055	15.30	18.30
f M18 X 1.5	17.132	16.595	24.30	28.80
M20 X 2.5	18.537	17.675	40.00	47.50
f M20 X 1	19.430	19.055	15.00	18.00
f M20 X 1.5	19.132	18.595	25.00	29.50
f M22 X 1.5	21.132	20.595	25.30	29.80
M24 X 3	22.239	21.215	48.00	57.00
f M24 X 2	22.834	22.135	30.00	36.00
f M25 X 1.5	24.132	23.595	25.00	29.50
f M27 X 2	25.834	25.135	33.75	39.75
M30 X 3.5	27.941	26.754	60.00	70.50

f = Fine Pitch Series

Cored Holes for Cut Threads: Precision Tolerances

PRECISION TOLERANCES

The Precision Tolerance values shown represent greater casting accuracy involving extra precision in die construction and/or special control in production. They should be specified only when and where necessary, since additional cost may be involved.

Cored holes for cut threads are cast holes that require threads to be cut (tapped) into the metal. The table below provides the dimensional tolerances for diameter, depth and draft for each specified thread type (Unified and Metric Series). When required, cored holes in Al, Mg, Zn and ZA may be tapped without removing draft. This Precision Tolerance recommendation is based on allowing 95% of full thread depth at the bottom D_2 (small end) of the cored hole and the maximum minor diameter at the top D_1 (large end) of the cored hole. A countersink or radius is also recommended at the top of the cored hole. This provides relief for any displaced material and can also serve to strengthen the core.

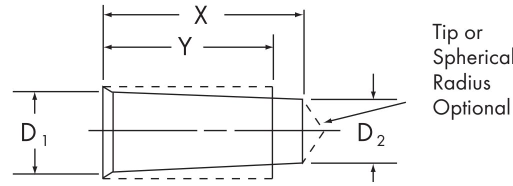


Table P-4-9: Cored Holes for Cut Threads (Precision Tolerances) – Unified Series and Metric Series

Table P-4-9 Cor ed Holes for Cut Threads (Precision Tolerances) — Unified Series and Metric Series

Unified Series/ Class Ⓐ	Hole Diameter D_1, Max. inches	Hole Diameter D_2, Min. inches	Thread Depth Y, Max. inches	Hole Depth X, Max.
0-80, UNF/2B, 3B	*(0.051)*	*(0.047)*	*(0.130)*	*(0.163)*
1-64, UNC/2B, 3B	*(0.062)*	*(0.057)*	*(0.200)*	*(0.250)*
1-72, UNF/2B, 3B	*(0.064)*	*(0.059)*	*(0.160)*	*(0.200)*
2-56, UNC/2B, 3B	*(0.074)*	*(0.068)*	*(0.240)*	*(0.300)*
2-64, UNF/2B, 3B	*(0.075)*	*(0.070)*	*(0.200)*	*(0.250)*
3-48, UNC/2B, 3B	*(0.085)*	*(0.078)*	*(0.280)*	*(0.350)*
3-56, UNF/2B, 3B	*(0.087)*	*(0.081)*	*(0.220)*	*(0.275)*
4A-40, UNC/2B, 3B	*(0.094)*	*(0.086)*	*(0.320)*	*(0.400)*
4A-48, UNF/2B, 3B	*(0.097)*	*(0.091)*	*(0.240)*	*(0.300)*
5-40, UNC/2B, 3B	0.106	0.099	0.280	0.350
5-44, UNF/2B, 3B	0.108	0.102	0.240	0.300
6-32, UNC/2B, 3B	0.114	0.106	0.350	0.438
6-40, UNF/2B	0.119	0.112	0.270	0.338
8-32, UNC/2B	0.139	0.132	0.290	0.363
8-36, UNF/2B	0.142	0.135	0.260	0.325
10-24, UNC/2B	0.156	0.147	0.390	0.488
10-32, UNF/2B	0.164	0.158	0.240	0.300
12-24, UNC/2B	0.181	0.173	0.340	0.425
12-28, UNF/2B	0.186	0.179	0.270	0.338
1/4A-20, UNC/1B, 2B	0.207	0.199	0.370	0.463
1/4A-28, UNF/1B, 2B	0.220	0.213	0.270	0.338
5/16-18, UNC/1B, 2B	0.265	0.255	0.440	0.550
5/16-24, UNF/1B, 2B	0.277	0.270	0.310	0.388
3/8-16, UNC/1B, 2B	0.321	0.311	0.470	0.588
3/8-24, UNF/1B, 2B	0.340	0.332	0.340	0.425
7/16-14, UNC/1B, 2B	0.376	0.364	0.570	0.713
7/16-20, UNF/1B, 2B	0.395	0.386	0.400	0.500
1/2-13, UNC/1B, 2B	0.434	0.421	0.640	0.800
1/2-20, UNF/1B, 2B	0.457	0.449	0.370	0.463
9/16-12, UNC/1B, 2B	0.490	0.477	1.280	1.600
9/16-18, UNF/1B, 2B	0.515	0.505	0.880	1.100
5/8-11, UNC/1B, 2B	0.546	0.532	1.430	1.788
5/8-18, UNF/1B, 2B	0.578	0.568	0.930	1.163
3/4A-10, UNC/1B, 2B	0.663	0.647	1.590	1.988
3/4A-16, UNF/1B, 2B	0.696	0.686	0.950	1.188
7/8- 9, UNC/1B, 2B	0.778	0.761	1.750	2.188
7/8-14, UNF/1B, 2B	0.814	0.802	1.200	1.500
1- 8, UNC/1B, 2B	0.890	0.871	1.900	2.375
1-12, UNF/1B. 2B	0.928	0.914	1.340	1.675

Metric Series Thread Size ⒶⒷ	Hole Diameter D_1, Max. mm	Hole Diameter D_2, Min. mm	Thread Depth Y, Max. mm	Hole Depth X, Max. mm
M1.6 X 0.35	*(1.32)*	*(1.24)*	*(2.40)*	*(3.45)*
M2 X 0.4	*(1.68)*	*(1.59)*	*(3.00)*	*(4.20)*
M2.5 X 0.45	*(2.14)*	*(2.04)*	*(3.75)*	*(5.10)*
M3 X 0.5	*(2.60)*	*(2.49)*	*(4.50)*	*(6.00)*
M3.5 X 0.6	2.99	2.88	5.25	7.05
M4 X 0.7	3.42	3.28	6.00	8.10
M5 X 0.8	4.33	4.17	7.50	9.90
M6 X 1	5.15	4.96	9.00	12.00
M8 X 1.25	6.91	6.70	12.00	15.75
f M8 X 1	7.15	6.96	12.00	15.00
M10 X 1.5	8.68	8.44	15.00	19.50
f M10 X 0.75	9.38	9.23	12.50	14.75
M10 X 1.25	8.91	8.70	15.00	18.75
M12 X 1.75	10.44	10.17	18.00	23.25
f M12 X 1	11.15	10.96	15.00	18.00
f M12 X 1.25	10.91	10.70	15.00	18.75
M14 X 2	12.21	11.91	21.00	27.00
f M14 X 1.5	12.68	12.44	21.00	25.50
f M15 X 1	14.15	13.96	18.75	21.75
M16 X 2	14.21	13.91	28.00	34.00
f M16 X 1.5	14.68	14.44	24.00	28.50
f M17 X 1	16.15	15.96	17.00	20.00
f M18 X 1.5	16.68	16.44	22.50	27.00
M20 X 2.5	17.74	17.38	30.00	37.50
f M20 X 1	19.15	18.96	20.00	23.00
f M20 X 1.5	18.68	18.44	20.00	24.50
f M22 X 1.5	20.68	20.44	22.00	26.50
M24 X 3	21.25	20.85	36.00	45.00
f M24 X 2	22.21	21.91	30.00	36.00
f M25 X 1.5	23.68	23.44	25.00	29.50
f M27 X 2	25.21	24.91	27.00	33.00
M30 X 3.5	26.71	26.31	37.50	48.00

Ⓐ Values in italics and parenthesis apply to zinc and magnesium only
Ⓑ f = Fine Pitch Series

Note:
For both Unified and Metric Series, if hole size tolerances for D1 and D2 are required, in place of maximum and minimum values, the recommended tolerance for D1 is -0.0005 in. (-0.015 mm) and for D2 is +0.0005 in. (+0.015 mm). Accurate measurement of holes with these Precision Tolerances requires measurement capability greater than what pin gages can measure.

Values in italics and parentheses are achievable but should be discussed with the die caster prior to finalization of a casting design.

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PRECISION TOLERANCES

Cored holes for formed threads are specified in die castings as Precision Tolerances, because they require special control in production. The specific diameter, depth and draft required will determine the added cost.

Note:
Tolerances for cored holes for thread forming fasteners (self tapping screws) should be provided by the manufacturer of the specific type of thread forming fastener to be used.

Engineering & Design: Tolerancing

Cored Holes for Formed Threads: Precision Tolerances

The Precision Tolerance recommendations for cored holes for formed threads, on the opposite page, are based on allowing 75% of full thread depth at the bottom D_2 (small end) of the cored hole and 50% at the top D_1 (large end) of the cored hole. When required, cored holes in aluminum, zinc and magnesium may be tapped without removing draft.

Cold form taps displace material in an extrusion or swaging process. As a result, threads are stronger because the material is work hardened as a part of the process for forming threads. Because material is displaced, a countersink is recommended at the ends of through holes and at the entry of blind holes.

Tests indicate that thread height can be reduced to 60% without loss of strength, based on the fact cold formed threads in die castings are stronger than conventional threads. However, the use of 65% value is strongly recommended.

Since cored holes in castings must have draft (taper), the 65% thread height Y should be at a depth that is an additional one-half of the required engagement length of the thread in the hole.

Blind holes should be cored deep enough to allow a four (4) thread lead at the bottom of the hole. This will result in less burr around the hole and longer tool life. Hole sizes of #6 or less, or metric M3 or less, are recommended for through holes only.

Cold form tapping is not recommended for holes with a wall thickness less than two-thirds the nominal diameter of the thread.

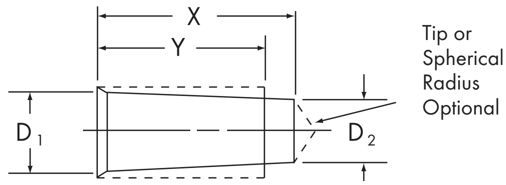
The Precision Tolerance recommendation should be considered as a starting point with respect to depth recommendations. There are many applications that do not require the percent of thread listed here. If a lesser percent of thread can be permitted, this would, in turn, allow more draft and a deeper hole. Amount and direction of required strength can be determined by testing.

PRECISION TOLERANCES

The Precision Tolerance values shown represent greater casting accuracy involving extra precision in construction and/or special control in production. They should be specified only when and where necessary, since additional cost may be involved.

Cored Holes for Formed Threads: Precision Tolerances

The tolerances below apply to AI, Mg, Zn and ZA die casting alloys, as footnoted. Note that, when required, cored holes in aluminum, zinc, and magnesium may be tapped without removing draft.



Guidelines are provided on the opposite page regarding thread height, depth, and limitations on wall thickness.

Table P-4-10: Cored Holes for Formed Threads (Precision Tolerances) – Unified Series and Metric Series

Unified Series Class Ⓐ	Hole Diameter D1, Max.	D2, Min.	Thread Depth Y, Max.	Hole Depth X, Max.
	inches	inches	inches	inches
0-80, UNF/2B, 3B	(0.0558)	(0.0536)	(0.090)	(0.120)
1-64, UNC/2B, 3B	(0.0677)	(0.0650)	(0.110)	(0.146)
1-72, UNF/2B, 3B	(0.0683)	(0.0659)	(0.110)	(0.146)
2-56, UNC/2B, 3B	(0.0799)	(0.0769)	(0.129)	(0.172)
2-64, UNF/2B, 3B	(0.0807)	(0.0780)	(0.129)	(0.172)
3-48, UNC/2B, 3B	(0.0919)	(0.0884)	(0.149)	(0.198)
3-56, UNF/2B, 3B	(0.0929)	(0.0899)	(0.149)	(0.198)
4A-40, UNC/2B, 3B	(0.1035)	(0.0993)	(0.168)	(0.224)
4A-48, UNF/2B, 3B	(0.1049)	(0.1014)	(0.168)	(0.224)
5-40, UNC/2B, 3B	(0.1165)	(0.1123)	(0.188)	(0.250)
5-44, UNF/2B, 3B	(0.1173)	(0.1134)	(0.188)	(0.250)
6-32, UNC/2B, 3B	(0.1274)	(0.1221)	(0.207)	(0.276)
6-40, UNF/2B	(0.1295)	(0.1253)	(0.207)	(0.276)
8-32, UNC/2B	0.153	0.148	0.328	0.492
8-36, UNF/2B	0.155	0.150	0.328	0.492
10-24, UNC/2B	0.176	0.169	0.380	0.570
10-32, UNF/2B	0.179	0.174	0.380	0.570
12-24, UNC/2B	0.202	0.195	0.432	0.648
12-28, UNF/2B	0.204	0.198	0.432	0.648
1/4A-20, UNC/1B, 2B	0.233	0.225	0.500	0.750
1/4A-28, UNF/1B, 2B	0.238	0.232	0.500	0.750
5/16-18, UNC/1B, 2B	0.294	0.284	0.703	0.938
5/16-24, UNF/1B, 2B	0.298	0.291	0.703	0.938
3/8-16, UNC/1B, 2B	0.354	0.343	0.844	1.125
3/8-24, UNF/1B, 2B	0.361	0.354	0.844	1.125
7/16-14, UNC/1B, 2B	0.413	0.401	0.984	1.313
7/16-20, UNF/1B, 2B	0.421	0.412	0.984	1.313
1/2-13, UNC/1B, 2B	0.474	0.461	1.125	1.500
1/2-20, UNF/1B, 2B	0.483	0.475	1.125	1.500
9/16-12, UNC/1B, 2B	0.534	0.520	1.266	1.688
9/16-18, UNF/1B, 2B	0.544	0.534	1.266	1.688
5/8-11, UNC/1B, 2B	0.594	0.579	1.406	1.875
5/8-18, UNF/1B, 2B	0.606	0.597	1.406	1.875
3/4A-10, UNC/1B, 2B	0.716	0.699	1.500	2.250
3/4A-16, UNF/1B, 2B	0.729	0.718	1.500	2.250
7/8- 9, UNC/1B, 2B	0.837	0.818	1.750	2.625
7/8-14, UNF/1B, 2B	0.851	0.839	1.750	2.625
1- 8, UNC/1B, 2B	0.958	0.936	2.000	3.000
1-12, UNF/1B, 2B	0.972	0.958	2.000	3.000

Metric Series Thread Size ⒶⒷ	Hole Diameter D1, Max.	D2, Min	Thread Depth Y, Max.	Hole Depth X, Max.
	mm	mm	mm	mm
M1.6 X 0.35	*(1.481)*	*(1.422)*	*(2.4)*	*(3.2)*
M2 X 0.4	*(1.864)*	*(1.796)*	*(3.0)*	*(4.0)*
M2.5 X 0.45	*(2.347)*	*(2.271)*	*(3.8)*	*(5.0)*
M3 X 0.5	*(2.830)*	*(2.745)*	*(4.5)*	*(6.0)*
M3.5 X 0.6	3.296	3.194	7.0	10.5
M4 X 0.7	3.762	3.643	8.0	12.0
M5 X 0.8	4.728	4.592	10.0	15.0
M6 X 1	5.660	5.490	12.0	18.0
M8 X 1.25	7.575	7.363	16.0	24.0
f M8 X 1	7.660	7.490	16.0	24.0
M10 X 1.5	9.490	9.235	20.0	30.0
f M10 X 0.75	9.745	9.618	12.5	30.0
fM10 X 1.25	9.575	9.363	20.0	30.0
M12 X 1.75	11.41	11.11	24.0	36.0
f M12 X 1	11.66	11.49	18.0	36.0
f M12 X 1.25	11.58	11.36	18.0	36.0
M14 X 2	13.32	12.98	28.0	42.0
f M14 X 1.5	13.49	13.24	21.0	42.0
f M15 X 1	14.66	14.49	18.8	45.0
M16 X 2	15.32	14.98	32.0	48.0
f M16 x 1.5	15.49	15.24	24.0	48.0
f M17 X 1	16.66	16.49	17.0	51.0
f M18 X 1.5	17.49	17.24	27.0	54.0
M20 X 2.5	19.15	18.73	40.0	60.0
f M20 X 1	19.66	19.49	20.0	60.0
f M20 X 1.5	19.49	19.24	30.0	60.0
f M22 X 1.5	21.49	21.24	27.5	66.0
M24 X 3	22.98	22.47	48.0	72.0
f M24 X 2	23.32	22.98	36.0	72.0
f M25 X 1.5	24.49	24.24	31.3	75.0
f M27 X 2	26.32	25.98	40.5	81.0
M30 X 3.5	28.81	28.22	60.0	90.0

Ⓐ Values in italics and parenthesis apply to zinc and magnesium only
Ⓑ f = Fine Pitch Series
Note:
For both Unified and Metric Series, if hole size tolerances for D1 and D2 are required, in place of maximum and minimum values, the recommended tolerance for D1 is -0.0005 in. (-0.015 mm) and for D2 is +0.0005 in. (+0.015 mm). Accurate measurement of holes with these Precision Tolerances requires measurement capability greater than what pin gages can measure.

Values in italics and parentheses are achievable but should be discussed with the die caster prior to finalization of a casting design.

NADCA

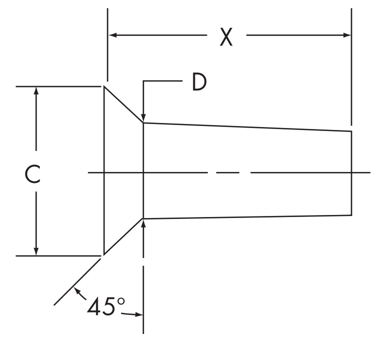
S-4-11-18

STANDARD TOLERANCES

The values shown for tapered pipe threads represent Standard Tolerances, or normal die casting production practice at the most economical level. N.P.T. threads should be specified, where possible, for most efficient production.

Engineering & Design: Tolerancing

Cored Holes for Pipe Threads: Standard Tolerances



Most pipes require taper to ensure that the connections seal as more of the thread is engaged. For example, when a garden hose is first threaded onto a threaded connection, it is very loose. As more of the thread is engaged by screwing the hose on, there is less play as the fitting gets tighter. A good fitting will become tight before the threads bottom out. Additional hole beyond the threads is provided so that fitting can be tightened against the taper to achieve the desired seal. Taper also allows for part wear.

There are two pipe thread taper standards. National Pipe Taper (N.P.T.) is the most common standard. A fitting should seal with at least one revolution of turn still available on the thread. The fitting should not bottom out in the hole. Standard taper is normally ¾ inches per foot. However, taper for special applications is determined by required strength formerly discussed in Cored Holes for Formed Threads.

Aeronautical National Pipe Taper (A.N.P.T.) is basically the same as N.P.T. pipe threads. However, diameter, taper and thread form are carefully controlled for military and aviation use. There is an associated cost increase using the A.N.P.T. standard since tighter controls are required.

The cored holes specified below are suitable for both N.P.T. and A.N.P.T. threads. The 1° 47' taper per side is more important for A.N.P.T. than N.P.T. threads. There is no comparable metric standard for pipe threads.

For the most economical die casting production, N.P.T. threads should be specified where possible. A.N.P.T. threads may require additional steps and cost.

The required taper for all N.P.T. and A.N.P.T. sizes is 1° 47'±10'per side.

The differences in measurement of these threads represent the differences in function. The N.P.T. thread quality in determined by use of the L1 thread plug gauge. This thread is intended as a tapered sealing thread using pipe dope or another sealing agent to provide a leak tight seal.

The A.N.P.T. thread, as well as the N.P.T.F. (American National Taper Dryseal Pressure-Tight Joints) thread, represents a tapered thread that is capable of sealing without the aid of sealing agents; thus their identification as dry seal threads. These threads are checked with the use of an L1 and L3 thread member as well as a six step plug gauge to verify thread performance on the crests. The difference of the A.N.P.T. and N.P.T.F. is in the tolerance of the gauging. The dry seal threads are more difficult to cast as the draft angle of the cores must be 1° 47' per side and without drags to avoid lobing at the tapping operation or an L3 failure.

Table S-4-11: Cored Holes for Tapered Pipe Threads Both N.P.T. and A.N.P.T.

Tap size	"D" Diameter	Minimum Depth "X" for Standard Tap	Minimum Depth "X" for Short Projection Tap	"C" Diameter ±.020
1/16 - 27	0.245 ±0.003	0.609	0.455	0.327
1/8 - 27	0.338 ±0.003	0.609	0.458	0.421
1/4 - 18	0.440 ±0.003	0.859	0.696	0.577
3/8 - 18	0.575 ±0.004	0.875	0.702	0.702
1/2 - 14	0.713 ±0.004	1.109	0.918	0.890
3/4 - 14	0.923 ±0.004	1.109	0.925	1.077
1 - 11 1/2	1.160 ±0.005	1.343	1.101	1.327
1 1/4 - 11 1/2	1.504 ±0.006	1.375	1.113	1.656
1 1/2 - 11 1/2	1.743 ±0.007	1.390	1.127	1.921
2 - 11 1/2	2.217 ±0.008	1.375	1.205	2.515
2 1/2 - 8	2.650 ±0.008	1.953	1.697	2.921
3 - 8	3.277 ±0.009	2.031	1.780	3.546

Engineering & Design: Tolerancing

Cast Threads

Threads can be cast in aluminum, magnesium, or zinc. Normally, cast threads are confined to external threads where precision class fits are not required. If a precision class fit is required, the die caster should be consulted. Secondary machining may be required.

External threads can be formed either across the parting line of a die (fig.1) or with slides (fig. 2). Tolerances shown in Table S-4-12 reflect the method by which the threads are formed.

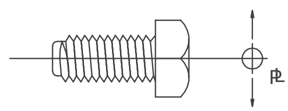
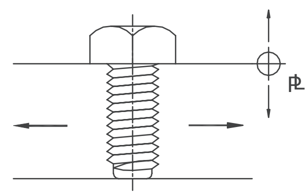
The Major diameter shall be in compliance with the specified thread form definition as agreed upon between the purchaser and the die caster.

Threaded parts are identified by a series of numbers known as a thread callout. A typical thread callout may be 1/16-28-0.960-0.580-0.12-7.02 where:

1/16 is the nominal thread size

28 is the number of Threads Per Inch (TPI)

Table S-4-12: Die Cast Threads Tolerances

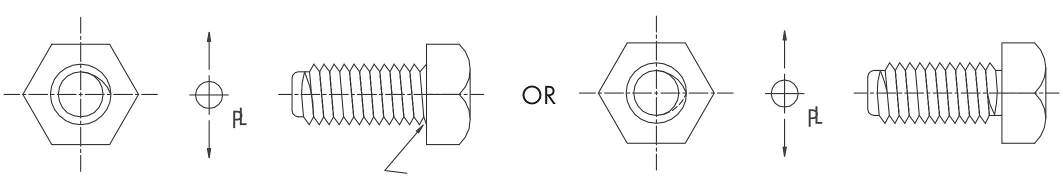
Method of Forming Threads	Figure 1 		Figure 2 	
Tolerances	**Zinc**	**Aluminum/ Magnesium**	**Zinc**	**Aluminum/ Magnesium**
Minimum pitch or maximum number of threads per inch	32	24	32	24
Minimum O.D.	0.187” (4.763 mm)	0.250” (6.350 mm)	0.187” (4.763 mm)	0.250” (6.350 mm)
Tolerance on thread lead per inch of length	±.005” (±.127 mm)	±.006” (±.152 mm)	±.005” (±.127 mm)	±.006” (±.152 mm)
Minimum Pitch Diameter Tolerance	±.004” (±.102 mm)	±.005” (±.127 mm)	±.005” (±.127 mm)	±.006” (±.152 mm)

Notes:

1. An additional trim or chasing operation may be necessary to remove flash formed between threads.
2. Direct tolerances shown should be applied wherever possible rather than specifying thread class or fit.
3. The values indicated include parting line, moving die component and linear dimension tolerances. If tighter tolerances are required, the caster should be consulted.

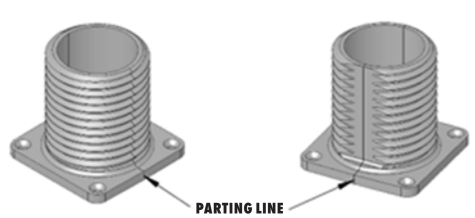
Figure 3. Design Considerations

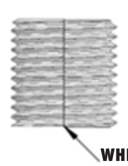
The recommended designs for terminating a die cast external thread are shown below:



Flats on the thread at the parting line will greatly simplify the trimming operation and result in the most economical means of producing die cast threads.

LESS DESIRABLE DESIGN **MORE DESIRABLE DESIGN**





WHEN DIES SHIFT (DUE TO STRESS OR OTHER FACTORS), THE THREADS WILL NOT BE ALIGNED AND CREATE MORE PROBLEMS.

Engineering & Design: Tolerancing

Machining Stock Allowance (Standard and Precision)

Machining stock allowances are a function of linear dimensions tolerances and parting line tolerances, and whether Standard or Precision Tolerances are required. Precision Tolerance values will usually represent greater casting accuracy involving extra precision in die construction and/or special control in production. For economical production, they should be specified only when and where necessary.

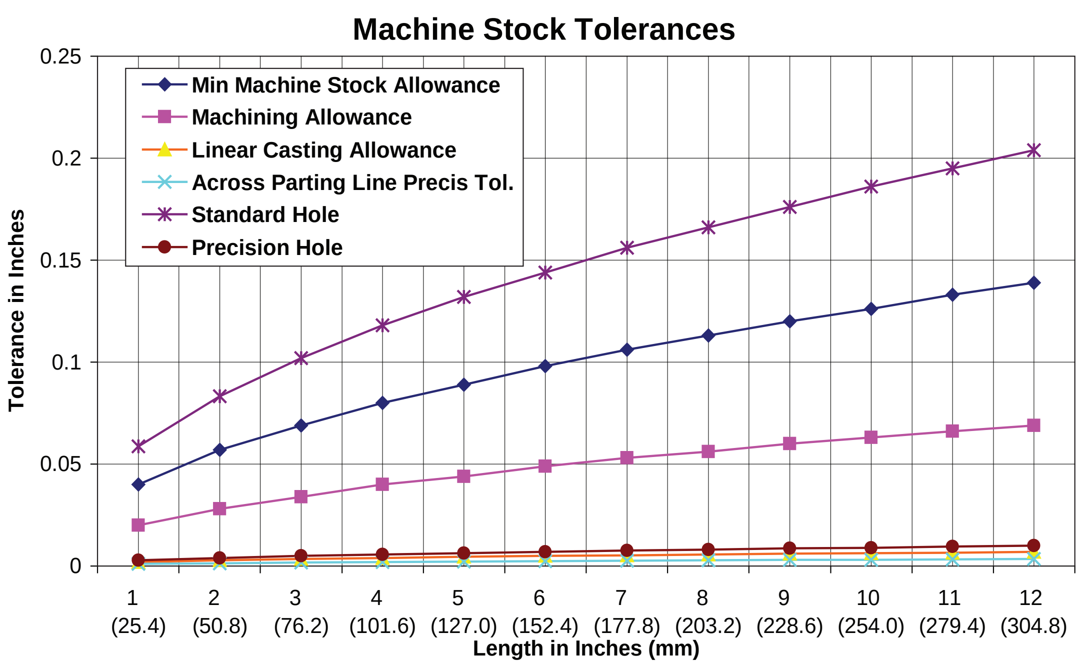
Note:
No consideration was given to flatness in the above examples. The part shape may dictate a flatness tolerance that exceeds the sum of the linear and across parting line tolerances. (See Flatness Tolerances S-4-8 and P-4-8.) Additional machining would then be required unless the part can be straightened prior to machining.

It is important to understand that the optimum mechanical properties and density of a casting are at or near the surface. If machining is to be performed on a casting, a minimum amount of material should be removed so as not to penetrate the less dense portion. However, to assure cleanup, an allowance must be provided for both the machining variables and the casting variables covered by NADCA Standards in this section.

Datum structure is very important to help minimize or eliminate the effect of these variables. (See Datum Reference Framework in Geometric Dimensioning, Section 5, for a preferred datum framework.) Best results are attained if the casting is located from datum points that are in the same die half as the feature to be machined.

Consulting with your caster early will help minimize the effect of tolerance accumulation and unnecessary machining.

Normal minimum machining allowance is 0.010 in. (0.25 mm) to avoid excessive tool wear and minimize exposure of porosity. The maximum allowance is the sum of this minimum, the machining allowance and the casting allowance. Machining stock is added on to existing tolerance.



Machining Stock Allowance (Standard and Precision)

Example:

Assume a 5.00 ± 0.001 in. (127 ± 0.025 mm) finish dimension on an aluminum die cast part that is 8.00 x 8.00 in. (203.2 x 203.2 mm).

In example "A" in the table on the facing page, surface to be machined is formed in the same die half as the datum points. In example "B", surface to be machined is formed in the opposite half of the die as the datum points. Both examples are shown using the Precision Tolerances for linear dimensions and parting line. The Standard Tolerances for linear dimensions and parting line would utilize the same format.

Machining Stock Allowance Comparative Example: Precision Tolerances

	Example A Datum Points In Same Die Half	Example B Datum Points In Opposite Die Half
Minimum Machine Stock Allowance inches (mm)	0.010 (0.25 mm)	0.010 (0.25 mm)
Machining Allowances (± 0.001 in. or ± 0.026 mm)	0.002 (0.05 mm)	0.002 (0.05 mm)
Linear Casting Allowance on 5.000 in. (127 mm) Dimension Precision Tolerance Ⓐ	0.012 (0.356 mm)	0.012 (0.356 mm)
Across Parting Line Precision Tolerances Ⓑ	—	0.008 (0.020 mm)
Maximum Stock	0.026 (0.56 mm)	0.034 (0.86 mm)
Casting Dimension Ⓒ	5.017 ± 0.006 (127.45 ± 0.18 mm)	5.026 +0.014/-0.006 (127.66 +0.38/-0.18 mm)

Ⓐ ±0.007 (±0.18 mm) P-4-1-03 Precision Tolerance
Ⓑ ±0.008 (±0.20 mm) P-4-2 Precision Tolerance
Ⓒ Casting dimension would not be needed if drawing was a combined drawing, only finish dimension of 5.00 ± 0.001 in. (127 ± 0.025 mm) would be needed.

Engineering & Design: Tolerancing

Additional Considerations for Large Castings

1 Wall Thickness:

1.1: Definition: Wall thickness is the distance between two parallel or nearly parallel surfaces. Wall thickness may vary depending on the application of draft. Wall thickness should be maintained as uniform as possible. A general guideline would be to keep the range of thickness within 2X of the thinnest wall. A second guideline is to keep the wall as thin as possible to meet the castings functional requirements.

1.2: General: 0.14" (3.5mm (+/- 0.5mm)

1.2.1 Deviations: from the nominal condition are based upon product function and manufacturing process requirements.

2 Radii:

2.1 Fillet Radii:

2.1.1 General: 0.14" (+0.08/-0.04") [3.5mm (+2.0mm/-1.0mm)]

2.1.1.1 Deviations: from the nominal condition are based upon product function and manufacturing process requirements.

2.1.2 Minimum: 0.060" (1.5mm)

2.2 Corner Radii:

2.2.1 General: 0.060" (+0.08/-0.04") [1.5mm (+2mm/-1mm)]

2.2.1.1 Deviations: from the nominal condition are based upon product function and manufacturing process requirements.

2.2.2 Minimum: 0.020" (0.5mm)

3 Cores:

3.1 Guidelines: Cores should be used to minimize machining stock, and should be pulled perpendicular to each other. Use stepped cores where possible to minimize finish stock, reduce heavy sections, and minimize porosity.

3.2 Minimum: Cored hole diameter to be 0.25" (6.0mm) in and parallel to the direction of die draw.

3.3 For holes Less Than: 0.50" (12.5mm) diameter the core hole length to diameter (L/D) ratio should not exceed 4:1.

3.4 For Holes Greater Than: 0.50" (12.5mm) diameter the core pin length to diameter (L/D) ratio should not exceed 10:1.

**Dimensions are for larger castings. Consult a die caster to discuss capabilities for dimensioning outside of the recommended hole length to diameter ratios.*

4 Bosses:

4.1: Minimize the boss height as much as possible.

4.2: When the height to diameter ratio of the boss exceeds 1, it is recommended that ribs be used to improve filling.

4.3: Design adjacent bosses with a minimum 0.25" (6.5mm) gap between bosses to minimize porosity.

Additional Considerations for Large Castings

5: Machining Stock:

5.1 General:

5.1.1: Machining stock should be minimized. Because die casting exhibit a "skin", the densest fine-grained casting structure is near the surface.

5.1.2: Deviations from nominal condition are based upon product function and manufacturing process requirements. Machine stock is added to existing tolerances.

5.2: 0.06" (1.5mm) maximum, on all faces, features found in the locator core, on remainder of part.

6 Ejector Pin Bosses:

6.1 Boss Diameter:

6.1.1: In functional areas the size and location is dependent upon product function and manufacturing requirements.

6.1.2: In non-functional areas and on machined surfaces the ejector pin diameter is to be 0.38" (10.0mm) minimum and the location is by mutual agreement of OEM and die caster.

6.2 Surface Geometry:

6.2.1: 0.06" (1.5mm) raised to 0.03" (0.8mm) depressed.

7 Trimming & Cleaning:

7.1 Parting Lines:

7.1.1 Trim Ribs-Gate and Parting Line: 0.12" maximum (1.5mm)

7.1.2 Gates & Overflows: 0-0.059" (0-1.5mm)

7.1.3 Flash: As specified in normal standard.

7.2 Cored Holes: 0-0.02" (0-0.5mm)

7.3 Openings:

7.3.1: 0-0.06" (0-1.5mm) at the finish machined face

7.3.2: 0-0.03" (0-0.8mm) on as-cast surfaces

7.3.3: 0-0.01" (0-2.5mm) of corner radii

7.4 Corners - Sharp: Not removed.

7.5 Ejector Pin Flash (Max. Projection):

7.5.1: 0-0.12" (0-3.0mm) on machined surfaces.

7.5.2: 0-0.04" (0-1.0mm) on as-cast surfaces.

7.6 Machined Surfaces: 0.12" (0-0.3mm) max.

7.7 Seam Lines: 0-0.02" (0-0.5mm)

7.8 Negative trim (shearing): condition is allowed when the nominal wall thickness is maintained.

Engineering & Design: Geometric Dimensioning

SECTION **5**

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5

Frequently Asked Questions (FAQ)

1) Is Geometric Dimensioning used on just Die Castings and why should it be used?
   See page 5-2 - Why should GD&T be used?
2) What is a Location Tolerance?
   See page 5-11, Location Tolerances
3) How do I convert a linear tolerance to true position?
   See pages 5-32 through 5-34, Conversion of Position.
4) Is a list of GD&T symbols availible?
   See page 5-8, GD&T Symbols and Meanings.
5) When can I use Profile of a surface instead of flatness?
   See page 5-14, Profile Tolerances.

1 Introduction

The concept of Geometric Dimensioning and Tolerancing (GD&T) was introduced by Stanley Parker from Scotland in the late 1930's. However, it was not used to any degree until World War II (WW II) because until then the vast majority of products were made in-house. The designer could discuss with the manufacturing personnel (die designer, foundry foreman, machinist, and inspectors) what features were to be contacted to establish the so called "centerlines" that were used on the drawing to locate features such as holes and keyways. Also when two (2) or more features were shown coaxial or symmetrical around these "centerlines", the questions that needed to be answered by the designer was, "how concentric or symmetrical do these features have to be to each other"?. During WW II companies had to "farm out" parts because of the quantities/schedules. This meant the new manufacturer had to interpret the drawing hence the "centerlines" were often established by contacting features that were not functional or important and features produced from these incorrect "centerlines" were not at the location required. The parts did not assemble and/or did not function properly and had to be fixed or scrapped. GD&T was the solution to this major problem. GD&T provides a designer the tools to have clear, concise, and consistent instructions as to what is required. It eliminates ambiguities so that everyone involved with the part will not have to interpret the dimensioning.

2 What is GD&T?

It is compilation of symbols and rules that efficiently describe and control dimensioning & tolerancing for all drawings (castings, machined components,etc.). It is documented in ASME Y14.5M which has the symbols, rules, and simple examples. Also ASME Y14.8 has guidance for casting and forging drawings.

3 Why should GD&T be used?

a. It is a simple and efficient method for describing the tolerancing mandated by the designer of the part.
b. It eliminates ambiguities as to what Datum features are to be contacted to establish the Datum planes and/or Datum axis that are to be used for locating other features. All inspection will result in the same result – the dimension is within or out of tolerance. Fig. 5-1 illustrates a simple example of ambiguities associated with the "old" type drawing. Fig. 5-2 illustrates the same example with GD&T.
c. It simplifies inspection because hard gages can often be utilized and inspection fixtures are often mandated which simplifies inspection for production quantities.
d. It forces the designer to totally consider function, manufacturing process, and inspection methods. The result is larger tolerances that guarantee function, but reduce manufacturing amd inspection costs. Also the "bonus" or extra tolerance for certain conditions can result in significant production cost savings. In addition the time to analyze whether a missed dimension is acceptable is dramatically reduced.

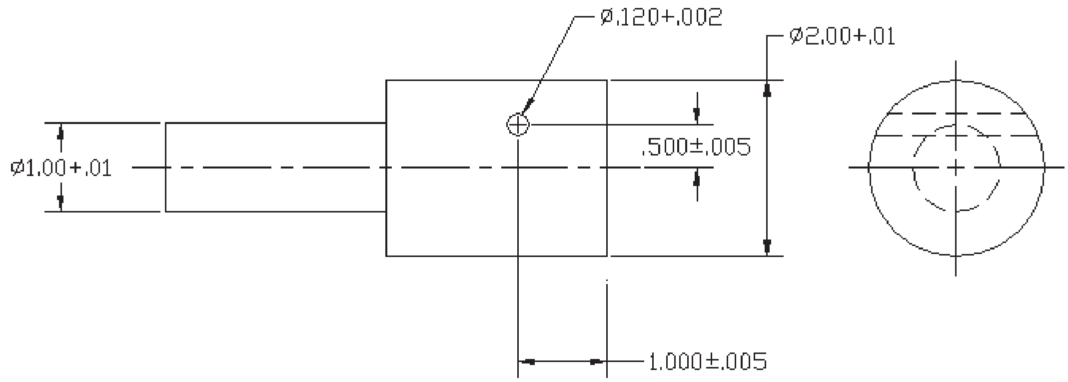


Figure 5-1 *"OLD" Drawing without GD&T.*

Questions:

1) What is the relationship (coaxiality tolerance) between the ∅1.00 and the ∅2.00?

2) Which feature (∅1.00 or ∅2.00) is to be used for measuring (locating) the .500±.005 dimension for locating the ∅.120 hole?

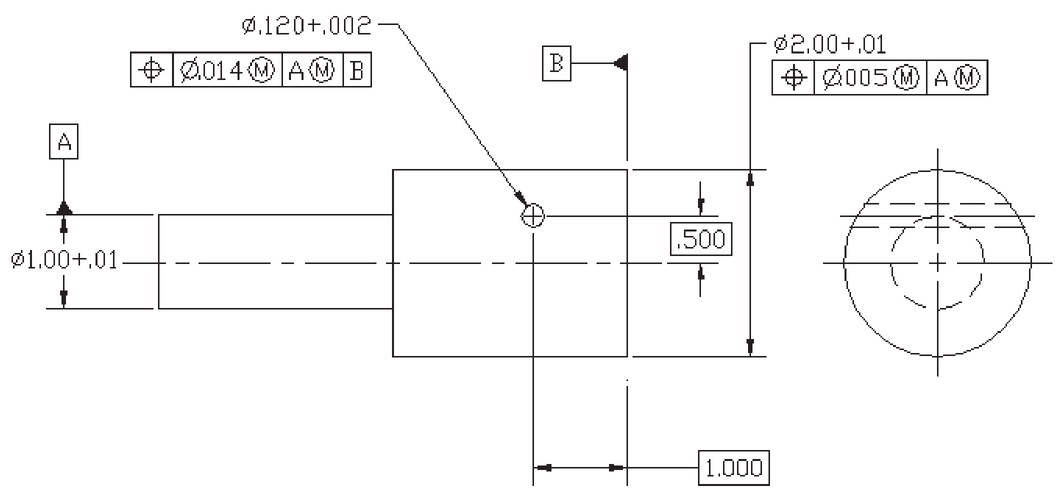


Figure 5-2 *"NEW" Drawing with GD&T.*

Questions asked in Fig. 5-1 answered:

1) The axis of the ∅2.00 has to be coaxial with the axis of the ∅1.00 within a tolerance zone that is a ∅.005 if the ∅ is 2.01 which is the Maximum Material Condition (MMC).

2) The ∅1.00 is the feature to be used for measuring the .500 dimension for locating the n.120 hole. The tolerance for locating the ∅.120 hole is a ∅ of .014 (the diagonal of the rectangular tolerance zone shown in Fig. 5-1) when the hole is a MMC (∅.120).

4 Datum Reference Frame (DRF)

The DRF is probably the most important concept of GD&T. In order to manufacture and/or inspect a part to a drawing , the three (3) plane concept is necessary. Three (3) mutually perpendicular (exactly 90° to each other) and perfect planes need to be created to measure from. In GD&T this is called Datum Reference Frame whereas in mathematics it is the Cartesian coordinate system invented by Rene Descartes in France (1596-1650). Often one would express this concept as the need to establish the X,Y, and Z coordinates. The DRF is created by so-called Datum Simulators which are the manufacturing, processing, and inspection equipment such as surface plate, a collet, a three jaw chuck, a gage pin, etc. The DRF simulators provide the origin of dimensional relationships. They contact the features (named Datum Features) which of course are not perfect hence measurements from simulators (which are nearly perfect) provides accurate values and they stabilize the part so that when the manufacturer inspects the part and the customer inspects the part they both get the same answer. Also if the part is contacted during the initial manufacturing setup in the same manner as when it is inspected, a “layout” for assuring machining stock is not required. The final result (assuming the processing equipment is suitable for the tolerancing specified) will be positive.

4.1 Primary, Secondary, and Tertiary Features & Datums

The primary is the first feature contacted (minimum contact at 3 points), the secondary feature is the second feature contacted (minimum contact at 2 points), and the tertiary is the third feature contacted (minimum contact at 1 point). Contacting the three (3) datum features simultaneously establishes the three (3) mutually perpendicular datum planes or the datum reference frame. If the part has a circular feature that is identified as the primary datum feature then as discussed later a datum axis is obtained which allows two (2) mutually perpendicular planes to intersect the axis which will be the primary and secondary datum planes. Another feature is needed (tertiary) to be contacted in order orientate (fix the two planes that intersect the datum axis) and to establish the datum reference frame. Datum features have to be specified in an order of precedence to properly position a part on the Datum Reference Frame. The desired order of precedence is obtained by entering the appropriate datum feature letter from left to right in the Feature Control Frame (FCF) (see Section 5 for explanation for FCF). The first letter is the primary datum, the second letter is the secondary datum, and the third letter is the tertiary datum. The letter identifies the datum feature that is to be contacted however the letter in the FCF is the datum plane or axis of the datum simulators. Note that there can be multiple datum sets used to reference different features on the casting. See Fig. 5-3 for Datum Features & Planes.

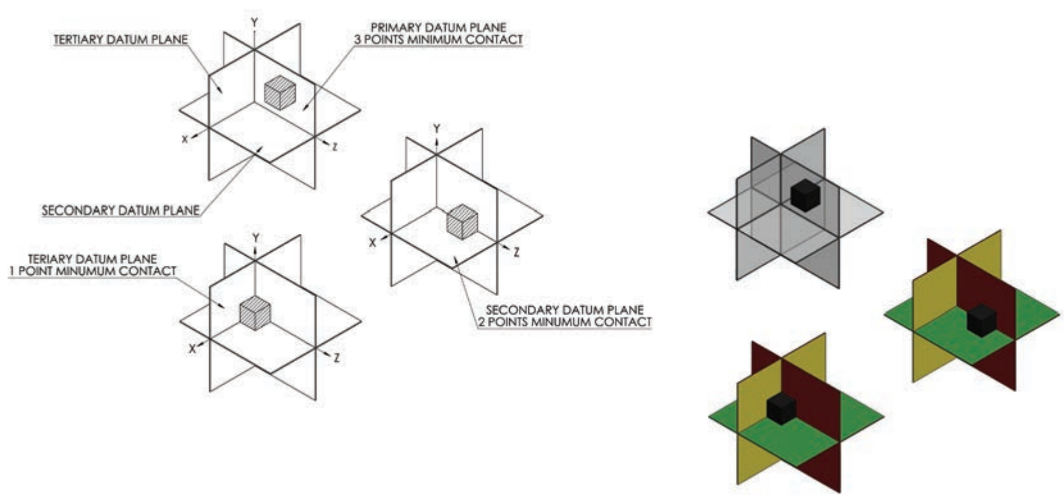


Figure 5-3 *Primary, secondary, tertiary features & datum planes.*

4.2 Datum Feature vs Datum Plane

The datum features are the features (surfaces) on the part that will be contacted by the datum simulators. The symbol is a capital letter (except I,O, and Q) in a box such as [A] used in the 1994 ASME Y14.5 or -[A]- used on drawings made to the Y14.5 before 1994. The features are selected for datums based on their relationship to toleranced features, i.e., function, however they must be accessible, discernible, and of sufficient size to be useful. A datum plane is a datum simulator such as a surface plate. See Fig. 5-4 for a Datum Feature vs a Datum Plane.

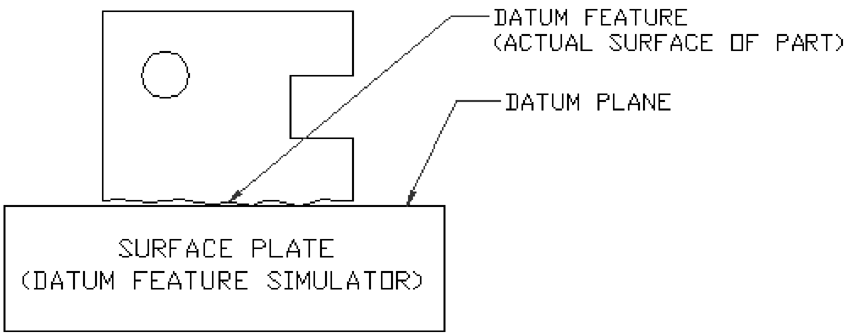


Figure 5-4 *Datum feature vs. datum plane.*

4.3 Datum Plane vs Datum Axis

A datum plane is the datum simulator such as a surface plate. A datum axis is also the axis of a datum simulator such as a three (3) jaw chuck or an expandable collet (adjustable gage). It is important to note that two (2) mutually perpendicular planes can intersect a datum axis however there are an infinite number of planes that can intersect this axis (straight line). Only one (1) set of mutually perpendicular planes have to be established in order to stabilize the part (everyone has to get the same answer – does the part meet the drawing requirements?) therefore a feature that will orientate or "clock" or "stabilize" has to be contacted. The datum planes and datum axis establish the datum reference frame and are where measurements are made from. See Fig. 5-5 for Datum Feature vs Datum Axis.

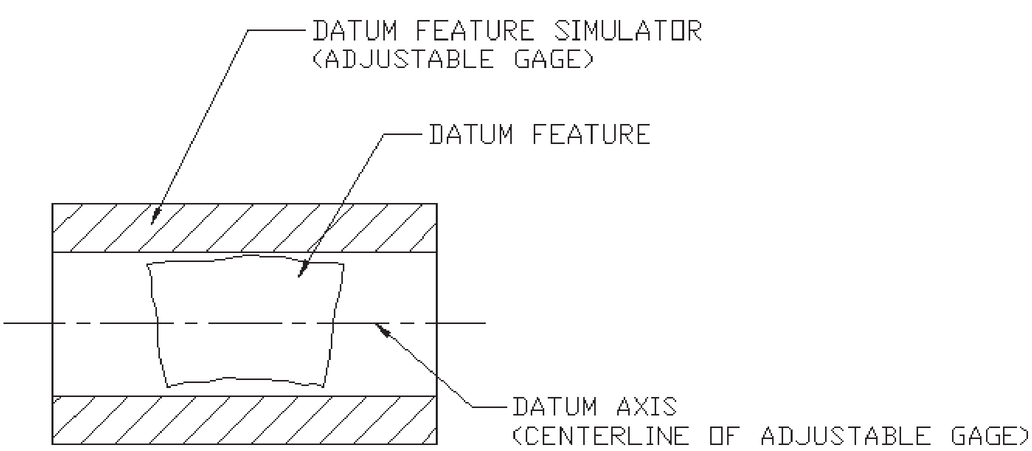
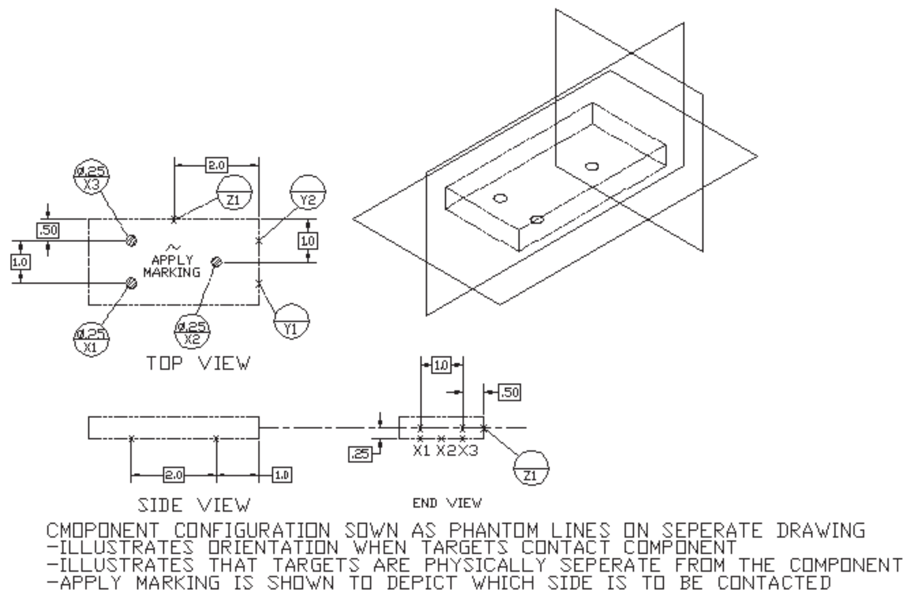


Figure 5-5 *Datum feature vs. datum axis.*

4.4 Datum Target Sizes & Locations

Datum targets are datum simulators such as spherical pins or round flat bottom pins or three (3) jaw chucks or centers that establish datum planes or a datum axis. They contact the datum features and are often specified to be used for inspecting parts that are inherently not round or straight or flat or they are large parts. If targets are not used then the entire datum feature has to contact a datum simulator. An example of what can result is the part could "rock" on a surface plate if the part was not relatively flat which would result in an unstable scenario and conflicting results. If the datum feature is large a datum simulator that contacts the entire feature may not exist or would be extremely expensive to produce. The datum targets are the datum planes and datum axis and often are assembled together to create an inspection fixture and or a manufacturing fixture. See Fig. 5-6 for Datum Target Sizes & Locations.



Component configuration shown as phantom lines on separate drawing
• Illustrates orientation when targets contact component
• Illustrates that targets are physically separate from the component
• Apply marking is shown to depict which side is to be contacted by the targets

Figure 5-6 *Target sizes & locations.*

5 Feature Control Frame

The geometric tolerance for an individual feature is specified in the Feature Control Frame which is divided into compartments – see Fig 5-7. The first compartment contains the type of geometric characteristic such as true position, profile, orientation, etc. The second compartment contains the tolerance (where applicable the tolerance is preceded by a diameter symbol and followed by a material condition symbol). The remaining compartments contain the datum planes or axis in the proper sequence (primary datum is the first letter).

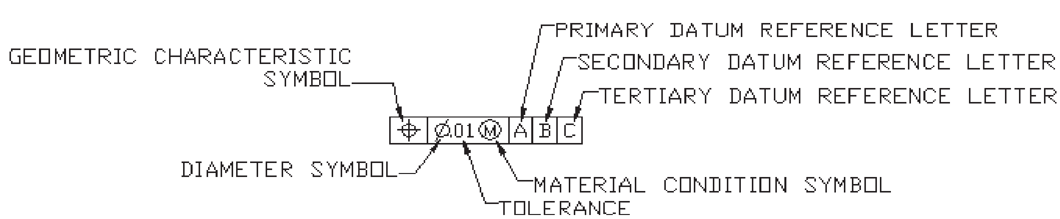


Figure 5-7 *Feature control frame.*

6 Rule # 1 – Taylor Principle (Envelope Principle)

When only a size tolerance is specified for an individual feature of size the form of this feature shall not extend beyond a boundary (envelope) of perfect form at maximum material condition (MMC). In other words, when the size is at MMC the feature has to be perfectly straight. If the actual size is less than the MMC the variation in form allowed is equal to the difference between the MMC and the actual size. The relationship between individual features is not controlled by size limits. Features shown perpendicular, coaxial or symmetrical to each other must be controlled for location or orientation otherwise the drawing is incomplete. In other words Fig. 5-1 is an incomplete drawing. Fig. 5-8 shows the meaning of Rule #1 for an external cylinder (pin or shaft) and an internal cylinder (hole). Note that a hard gage can be used to inspect this principle or requirement.

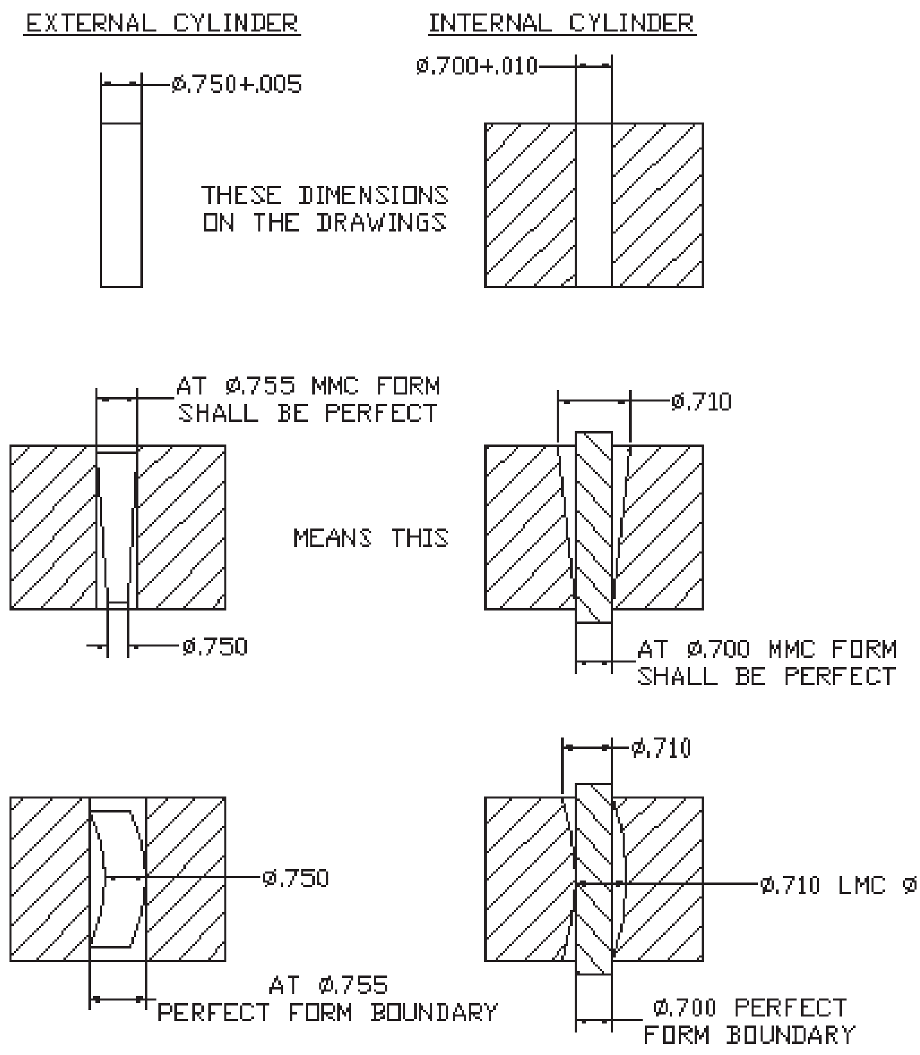


FIG. 8 – RULE #1

Figure 5-8 *Rule #1.*

7 GD&T Symbols / Meanings

Tolerance Type	Geometric Characteristics	Symbol	Applied To		Datum Reference Required	Use Ⓛ or Ⓜ Material Condition	Gages Used
			Feature Surface	Feature of Size Dim.			
Form	Straightness	⏤	YES	YES	NO	YES	YES***
	Flatness	⏥		NO		NO	NO
	Circularity	○					
	Cylindricity	⌭					
Location	Positional Tolerance	⌖	NO	YES	YES	YES	YES***
	Concentricity	◎				NO	NO
	Symmetry	⌯					
Orientation	Perpendicularity	⊥	YES	YES	YES	YES	YES***
	Parallelism	∥					
	Angularity	∠					
Profile	Profile of a Surface	⌓	YES	NO	YES*	YES**	NO
	Profile of a Line	⌒					
Runout	Circular Runout	↗	YES	YES	YES	NO	NO
	Total Runout	⌰					

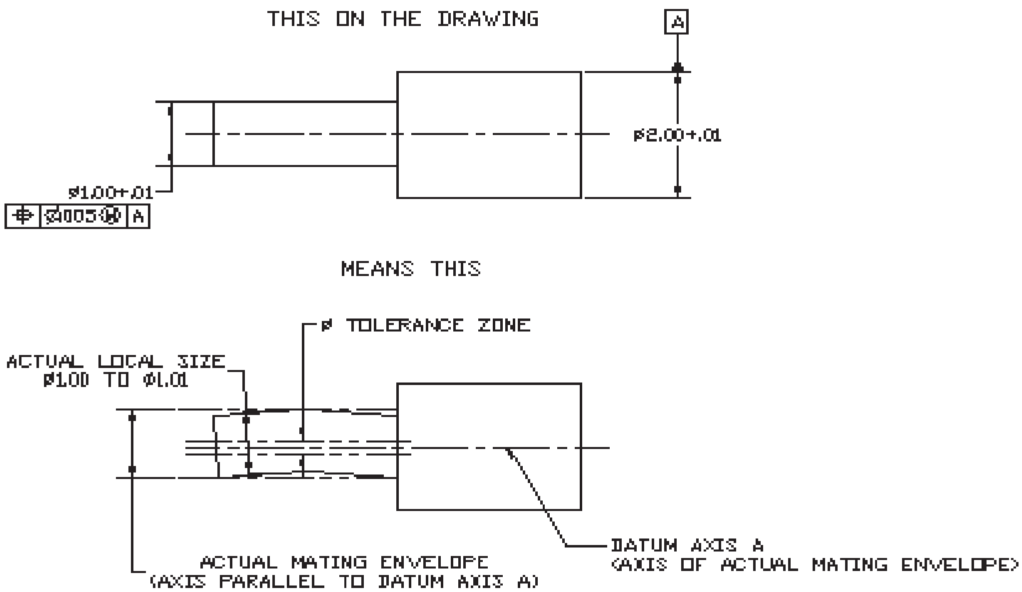
** Can be used to control form without a datum reference.*
*** Datum reference only.*
**** – Yes if Ⓜ is specified for the feature of size being controlled*
– No if Ⓢ or Ⓛ are specified for the feature of size being controlled.

8 Material Conditions

Features of size which includes datum features have size tolerances hence the size condition or material (amount of metal) condition can vary from the maximum metal condition (MMC) to the least metal condition (LMC). Consequently if the center planes or axes of a feature of size are controlled by geometric tolerances a modifying symbol can be specified in the feature control frame that applies the tolerance value at either the maximum or the least material condition. It also can be specified for a datum that is a feature of size. If a symbol is not specified the tolerance value applies regardless of material condition which is named regardless of feature size (RFS).

8.1 Maximum Material Condition (MMC)

This is the condition when the actual mating size or envelope size is at the maximum material condition which is maximum size for an external feature such as a cylinder and the minimum size for an internal feature such as a hole. Another way to look at MMC is that it always allows components to be assembled. The symbol is Ⓜ. The tolerance value specified for the feature being controlled in the FCF applies only if the actual mating envelope is the MMC size. If the actual mating envelope deviates from MMC an additional tolerance is allowed. The added tolerance is the difference between the actual mating envelope size and the MMC size hence the largest actual mating envelope named virtual condition is equal to the MMC size plus the tolerance specified in the FCF for an external feature and minus for an internal feature. The MMC symbol is used to assure that parts will assemble and it allows the use of so called hard gages (go gages) for quick inspections. An example of position with MMC is shown in Fig. 5-9. It should be noted that actual local size has to meet the size tolerance however the actual local size does not affect the geometric characteristic tolerance.



ACTUAL MATING ENVELOPE ø OF FEATURE BEING CONTROLLED	ø TOLERANCE ZONE
ø1.01	.005
ø1.00	.015

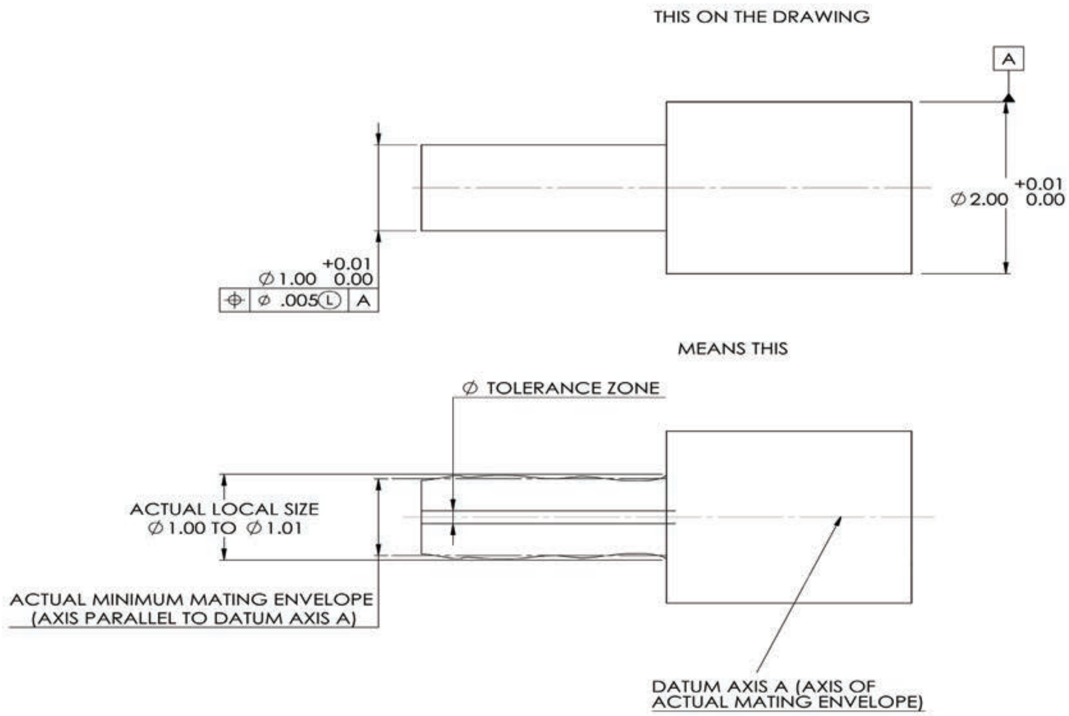
FIG 9–POSITION CONTROL WITH NMC

Figure 5-9 Position control with MMC.

5

8.2 Least Material Condition (LMC)

This is the opposite of MMC consequently this is the condition when the actual minimum mating size or envelope is at the minimum material condition which is minimum size for an external feature such as a cylinder and the maximum size for an internal feature such as a hole. Another way to look at LMC is that it always prevents components from being assembled. The symbol is Ⓛ. Additional tolerance is allowed if the actual minimum envelope deviates from LMC and is the difference between the actual mating size and the LMC size hence the smallest actual mating size is equal to the LMC size minus the tolerance specified in the FCF for an external feature and plus for an internal feature. The LMC symbol is used to assure a minimum amount of machining stock for features that are to be machined and for assuring a minimum amount of wall thickness between external and internal features. Hard gages cannot be used for inspection. An example of position with LMS is shown in Fig. 5-10. It should be noted that the actual local size has to meet the size tolerance however the local size does not affect the geometric characteristic tolerance.

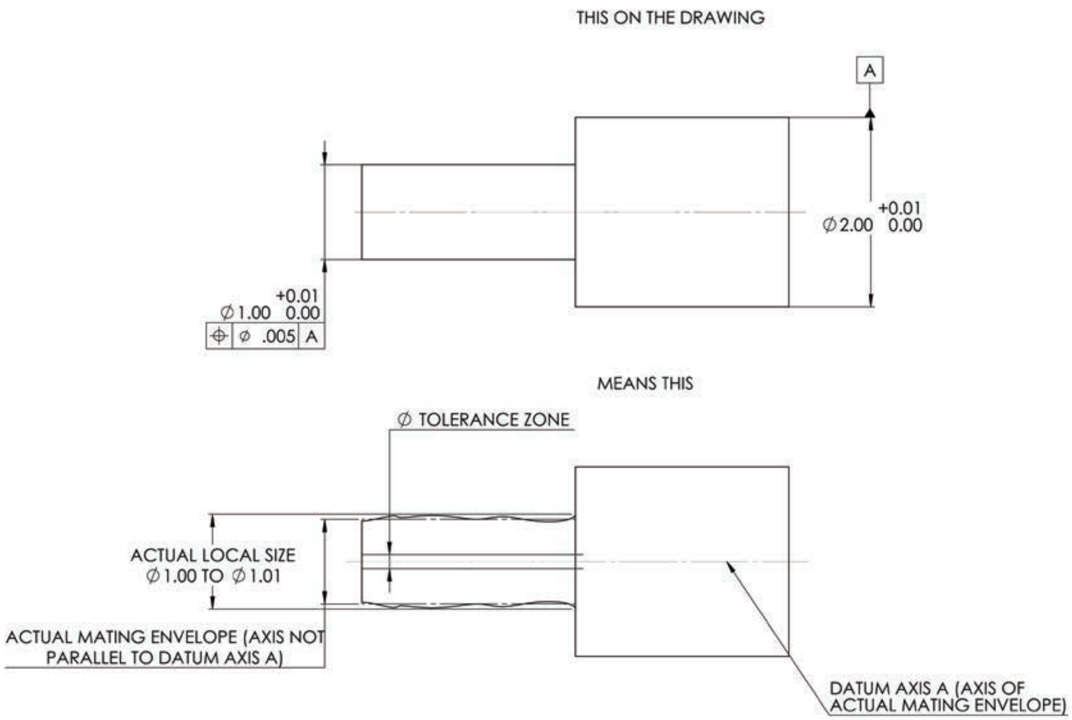


ACTUAL MINIMUM MATING ENVELOPE FEATURE BEING CONTROLLED	Ø TOLERANCE ZONE
Ø 1.00	.005
Ø 1.01	.015

Figure 5-10 *Position control with LHC.*

8.3 Regardless Of Feature Size (RFS)

There is no symbol in the 1994 Y14.5 whereas it was Ⓢ for the 1982 Y14.5. It is applicable if the MMC or the LMC are not specified for individual features of size tolerances or for datum features of size. The tolerance is limited to the specified value in the FCF and if applied to a datum feature of size the actual axis or center plane have to be established regardless of the feature size. It is always used for run out, concentricity, and symmetry controls as will be discussed in those sections. It is also used when targets are specified to establish datum axes and center planes because the targets have to contact the datum features to be useful. Also it is used to control wall thickness variation between external and internal features. Hard gages are not applicable since there is no additional or bonus tolerance as allowed for MMC and LMC. An example of position with RFS is shown in Fig. 5-11.



ACTUAL MINIMUM MATING ENVELOPE FEATURE BEING CONTROLLED	Ø TOLERANCE ZONE
Ø 1.00	.005
Ø 1.01	.005

Figure 5-11 Position control with RFS.

9 Location Tolerances

These include position, concentricity, and symmetry tolerances. Position is used to control coaxiality of features, the center distance between features, and the location of features as a group. Concentricity and symmetry are used to control the center distance of feature elements. These three (3) tolerances are associated with datum's because the obvious question is – located from what?

9.1 Position Tolerance

Positional tolerances are probably used more than any other geometric control. It is used to locate features of size from datum planes such as a hole or keyway and used to locate features coaxial to a datum axis. The tolerance defines a zone that the axis or center plane of a feature of size may vary from. The concept is there is an exact or true position that the feature would be if it was made perfect however since nothing is made perfect a tolerance zone allows deviation from perfection. The exact location of a feature of size is defined by basic dimensions which is shown in a box (☐) and are established from datum planes or axes. Coaxial controls are typically a cylindrical tolerance zone which has a diameter value and the true position is a datum axis. A positional control is indicated by the position symbol (∅), a tolerance value (diameter symbol precedes the tolerance value if desired), the applicable material condition modifier (Ⓜ or Ⓛ) if desired, and the appropriate datum references placed in a feature control frame. When a material condition modifier is specified a boundary named virtual condition is established. It is located at the true position and it may not be violated by the surface or surfaces of the considered feature. Its size is determined by adding or subtracting depending on whether the feature is an external or an internal feature and whether the material condition specified is Ⓜ or Ⓛ. An example for controlling the location of holes is shown in Fig. 5-12 and of a keyway in Fig. 5-13.

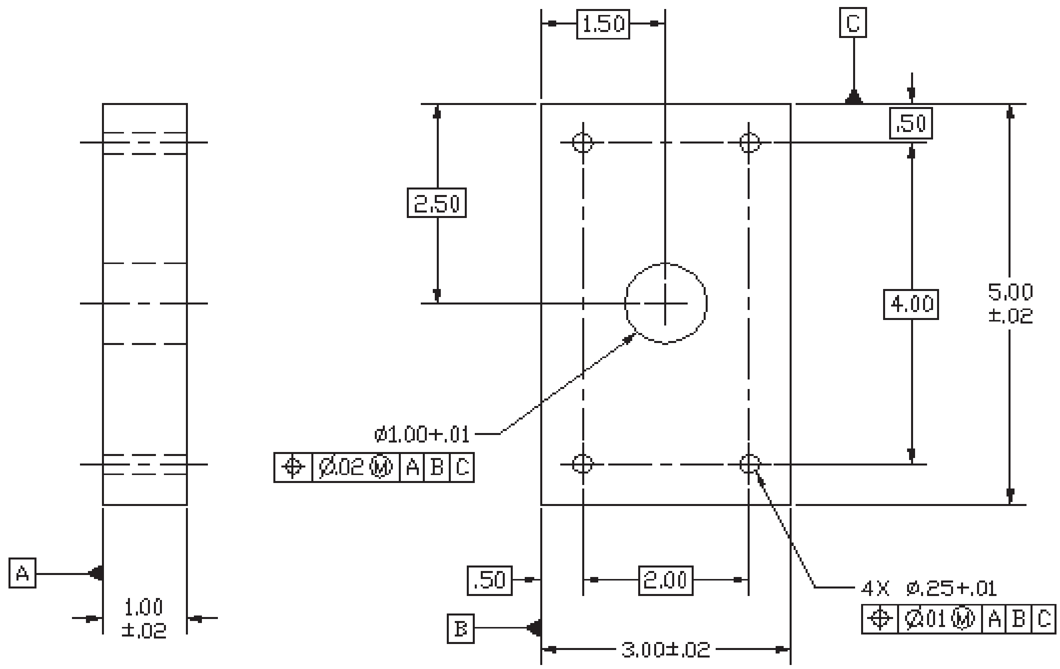


Figure 5-12 *Positional tolerancing of holes.*

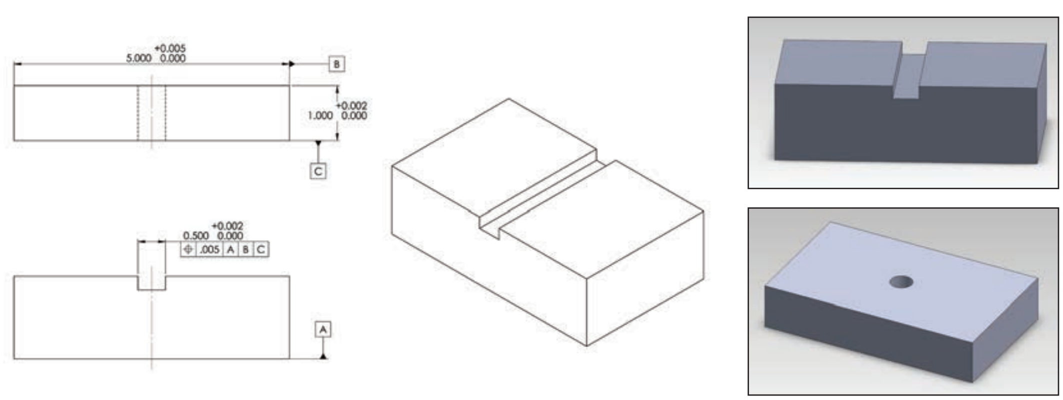


Figure 5-13 *Positional tolerance for keyway.*

Notes:

1) *Datum B is the feature of size (5.000+.005) hence the true position for the keyway is the midplane of datum B.*

2) *No material condition modifier specified for either the keyway location tolerance .005 or the datum B, hence the material condition is 'regardless of feature size' for both features.*

9.2 Concentricity & Symmetry Tolerances

These both control the median points of a feature of size: concentricity (◎) is applied to circular features (often where the part or nearby parts are rotating) whereas symmetry (⌯) is applied to non circular features. Both require that the median points of the controlled feature, regardless of its size, to be within the tolerance zone (cylindrical zone for concentricity and two parallel planes for symmetry). The tolerance zone is equally disposed about the datum axis for concentricity and datum plane for symmetry. These controls are not used very often because median points are difficult to establish due to irregularities of form and the only reason to use these controls is for controlling the out of balance that can exist if the mass center is not close to the axis of rotation or center plane. Examples of controlling concentricity and symmetry are shown in Fig. 5-14 & 5-15 respectively.

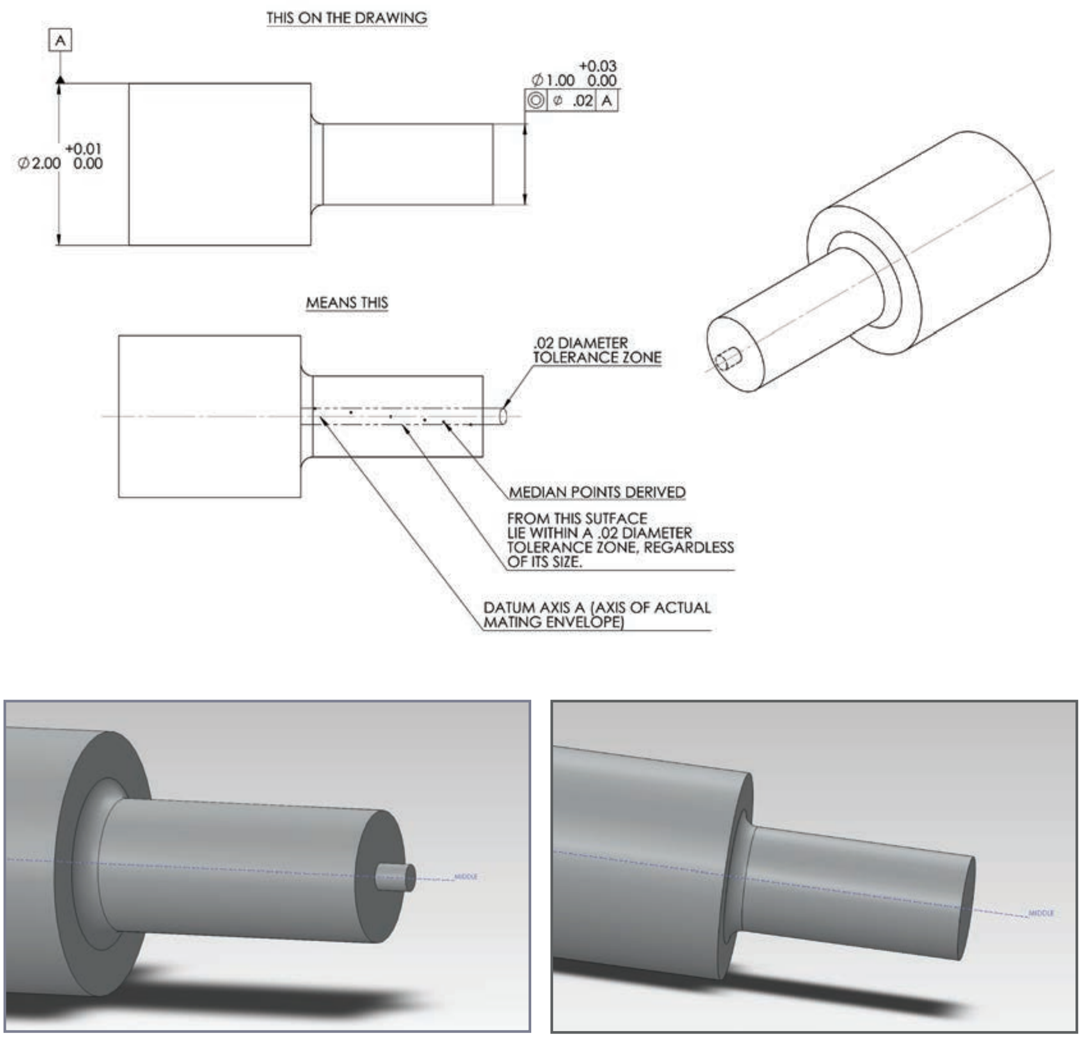


Figure 5-14 *Concentricity tolerancing.*

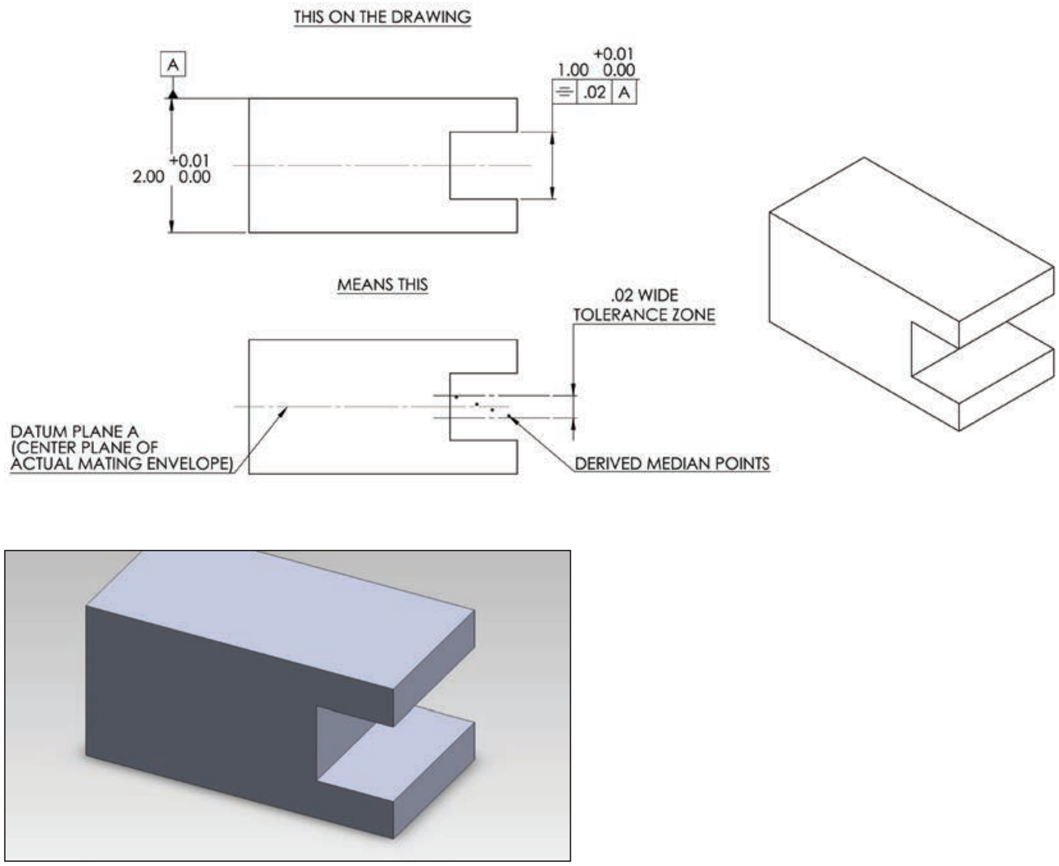


Figure 5-15 *Symmetry tolerancing.*

10 Profile Tolerances

Profile tolerances can control the location, orientation, and form of a feature that has no size (surface). There are two (2) types – profile of a surface (⌓) and profile of a line (⌒). The exact or true profile of a feature is established by basic dimensions of radii, angular dimensions, and coordinate dimensions established from datums however a profile tolerance can be specified to an individual surface without specifying a datum – see Fig. 16. The elements of a profile (outline of an object in a given plane) are straight lines or arcs. The tolerance is a boundary of two (2) parallel planes disposed (equally – see Fig. 17 or in one direction – see Fig. 16) and normal (perpendicular) along the perfect or true profile within which the entire surface must lie. The profile can be controlled between two (2) points – see Fig 16. Also if datum planes are established by targets – see Fig. 18 the tolerance zone is equally disposed about the datum planes whereas if the datum planes are established by complete contact with the datum features the tolerance zone is unidirectional and ½ the tolerance value in the FCF – see Fig. 17 vs Fig. 18.

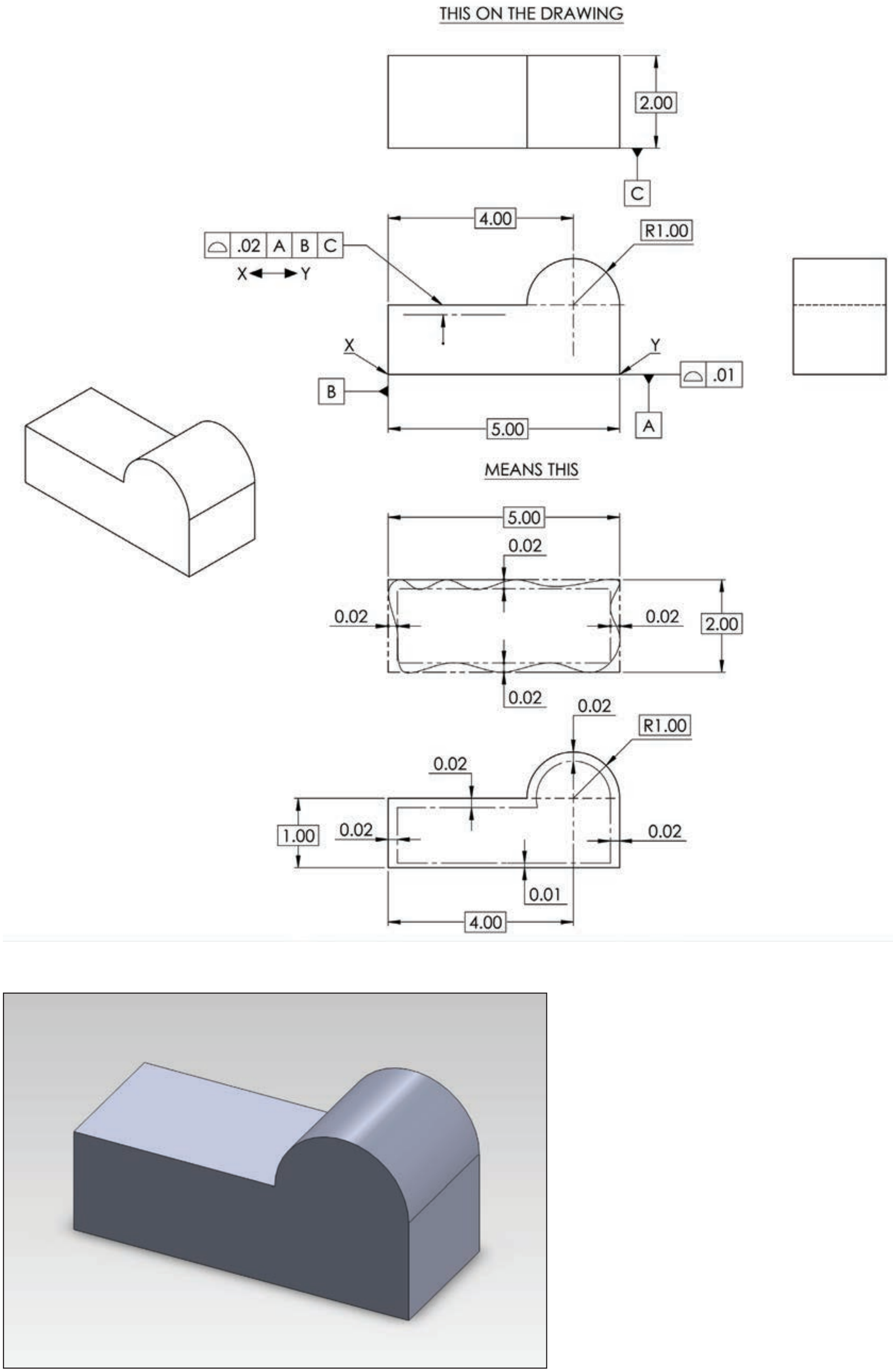
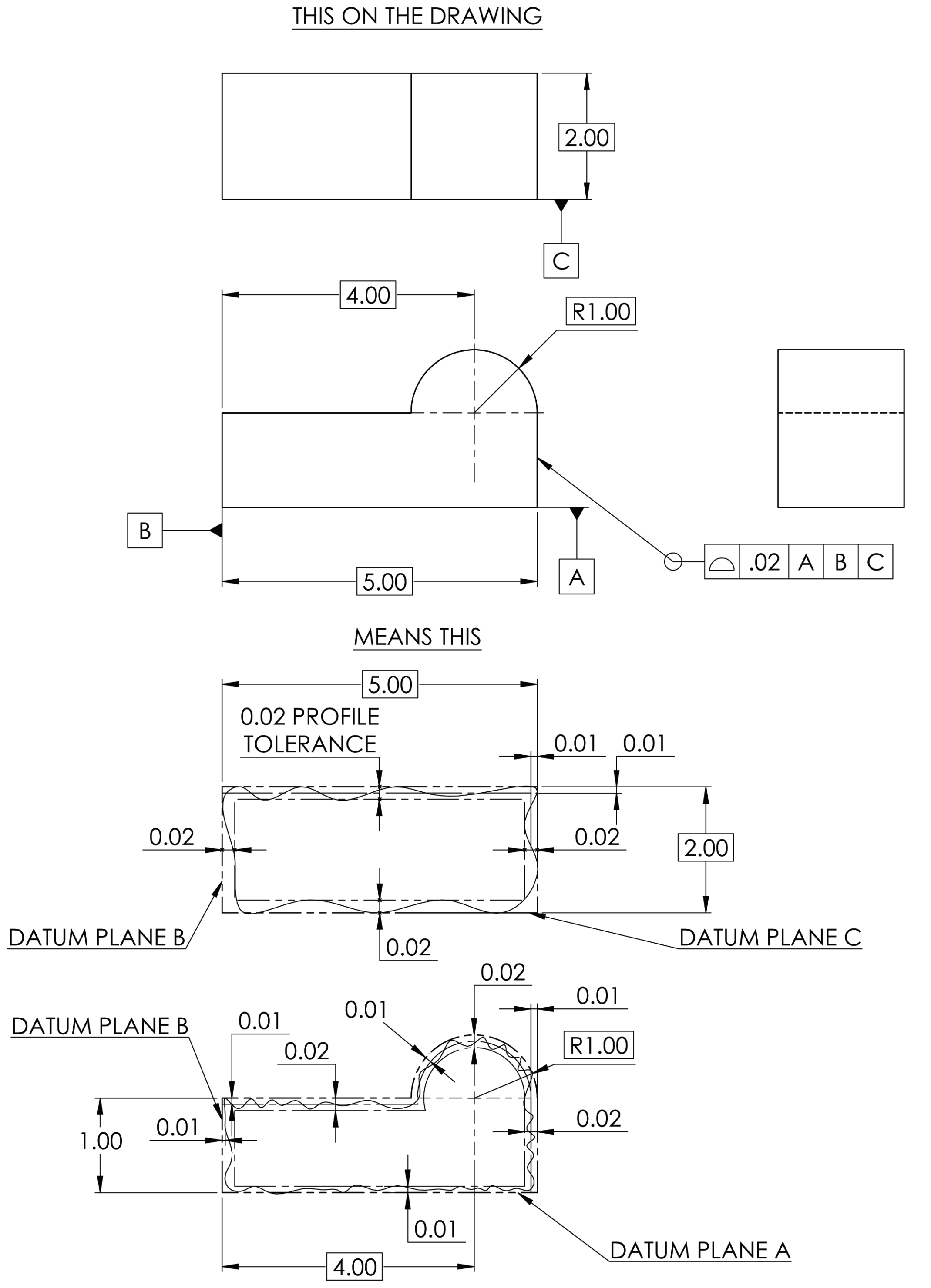


Figure 5-16 *Profile control – unidirectional and between points.*



Notes:

1) *All surfaces to be within .02±.01 tolerance zone of true or perfect profile.*

2) *Datum* A B and C to be within *.01 of datum planes A, B, and C.*

Figure 5-17 *Profile control – all around entire part without targets.*

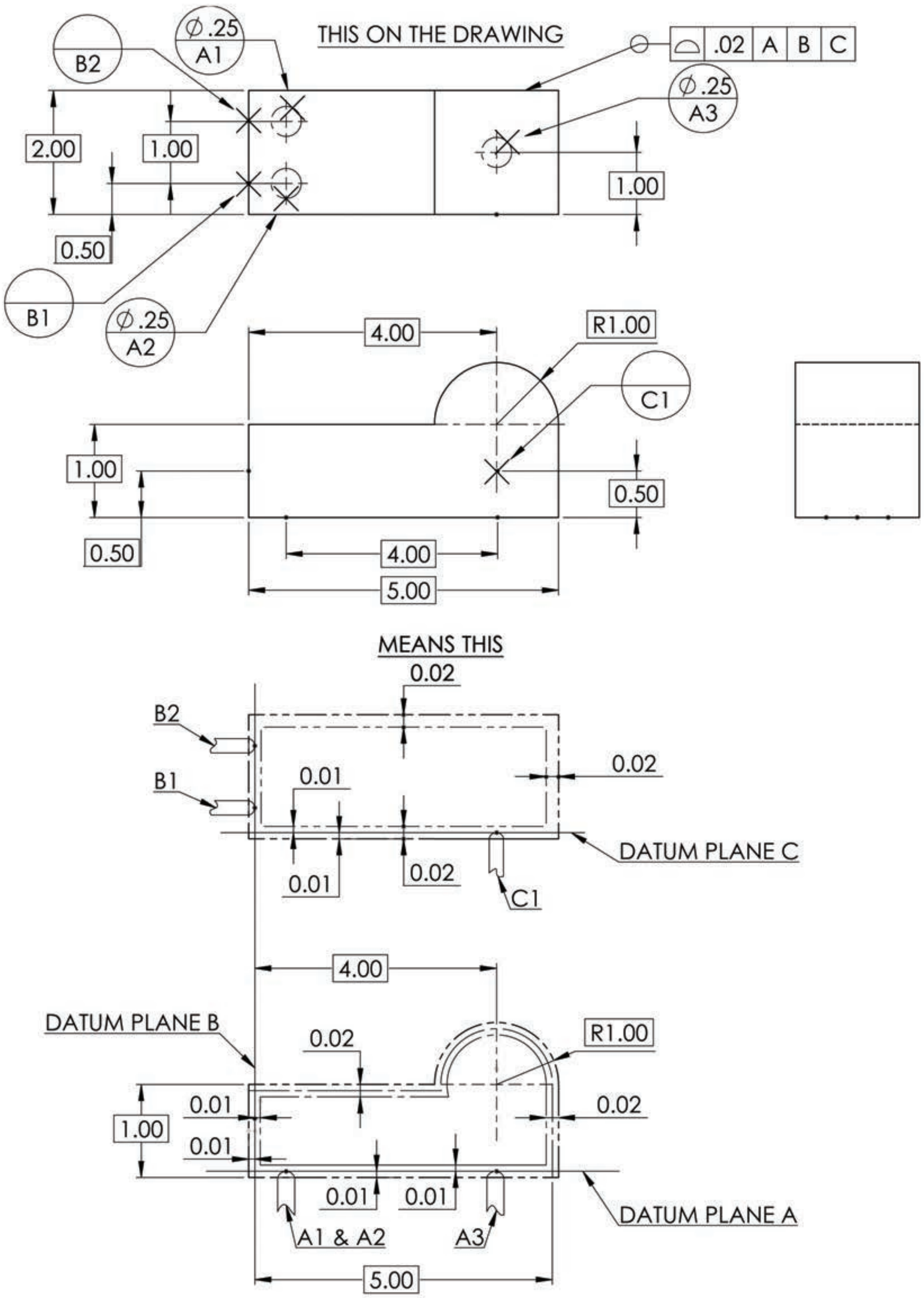


Figure 5-18 *Profile control – all around entire part with targets.*

11 Run Out Tolerances

Run out tolerances control the relationship of a feature relative to a datum axis established from one (1) diameter or two (2) diameters separated axially – see Fig. 5-19. The material condition applied to the feature being controlled and the datum feature or features is always RFS because 360˚ rotation is required to conduct the inspection. If targets are not specified to establish the datum axis the entire datum feature has to be contacted which may not be practical. There are two (2) types of run out controls – circular (↗) and total (⌰). Circular run out controls the cumulative variation of circularity (roundness) and coaxiallity for features constructed around a datum axis and circular elements of a surface constructed an angle not parallel to the datum axis (control wobble). The tolerance is the full indicator movement (FIM) for each circular element independently as the part is rotated 360˚. For each measurement the dial indicator is removed from the part after each 360˚ rotation and reset at a new location. Total run out controls the entire surface simultaneously hence it controls cumulative variations in circularity, coaxiality, straightness, taper, angularity, and profile of a surface. The dial indicator is not removed from the part after each 360˚ rotation. If applied to surfaces that are at an angle to the datum axis it controls variation in angularity (wobble) and flatness (concavity or convexity). See Fig. 5-19 for circular run out and Fig. 5-20 for total run out.

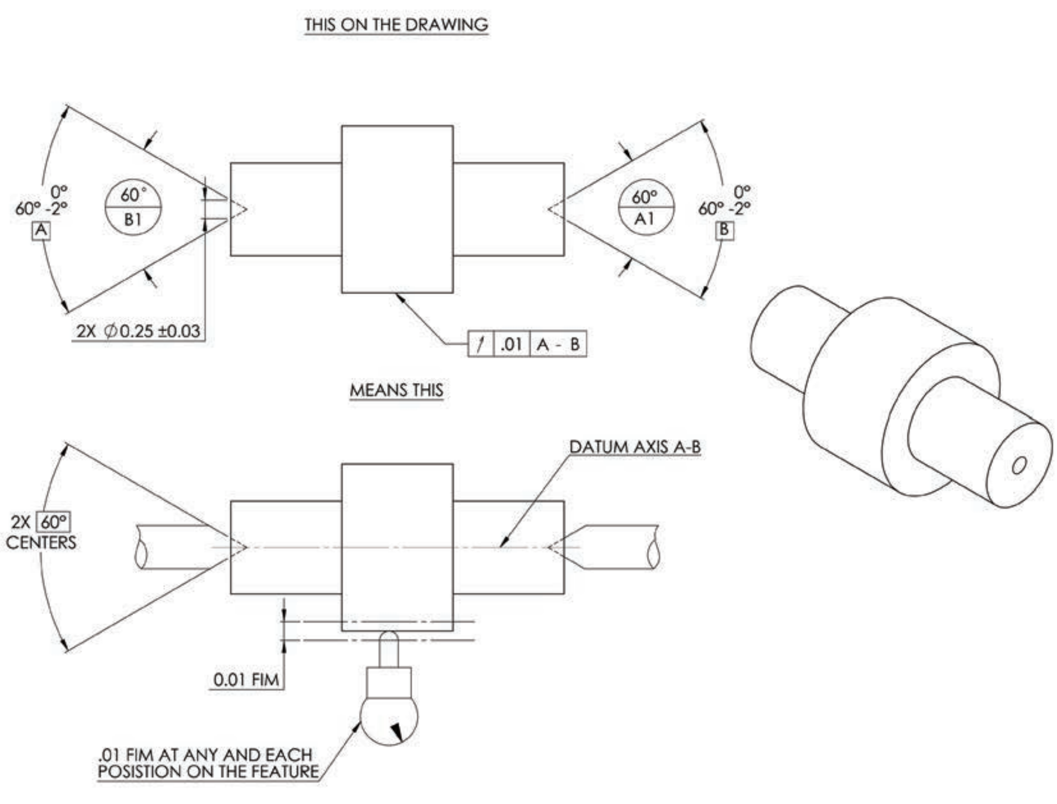
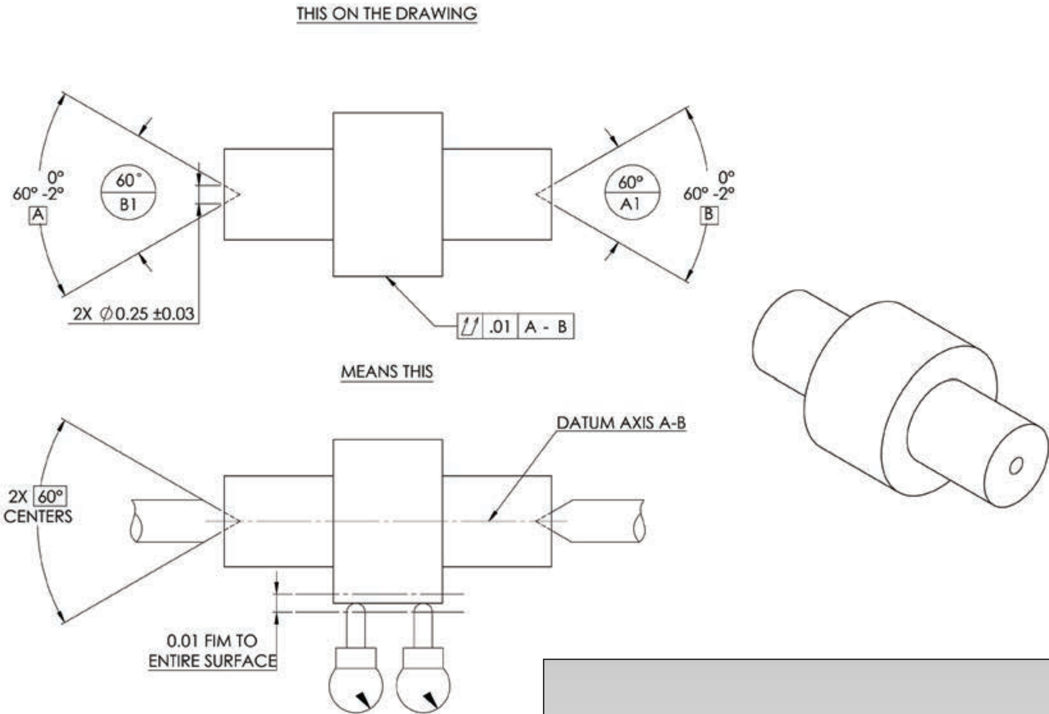


Figure 5-19 *Circular runout with targets.*



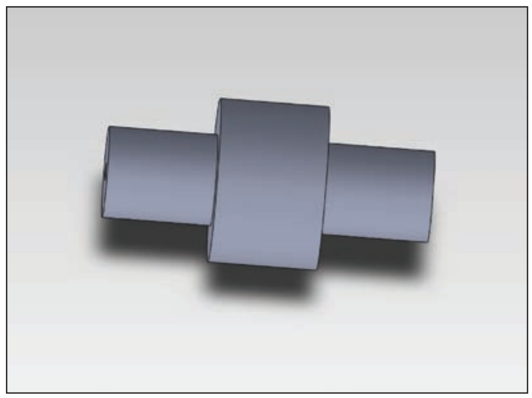
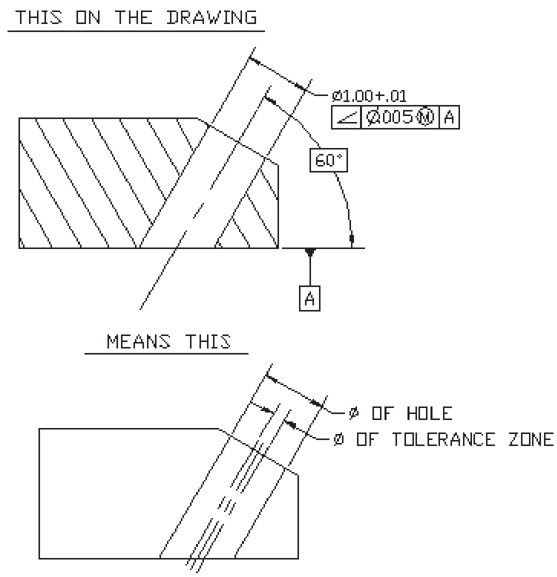


Figure 5-20 *total runout with targets.*

12 Orientation Tolerances

There are three (3) separate orientation tolerances however two (2) of the three are specific values of the general tolerance named angularity. The two (2) specific tolerances are named perpendicularity (90˚ to a datum) and parallelism (180˚ to a datum). These tolerances control the orientation of features to a datum plane or axis. Angularity controls a surface (non feature of size), a center plane or an axis of a feature of size to a specified angle and its symbol is ∠. Perpendicularity symbol is ⊥ and parallelism symbol is ⫽ and they do the same as angularity except the angles are specific as previously stated. The tolerance zone may be either two (2) parallel planes at the specified basic angle from a datum plane or axis within which the surface, center plane or axis must lie or it may be a cylindrical zone within which the axis of the considered feature must lie. Of course if angularity tolerance is specified for a feature of size the material condition modifiers Ⓜ or Ⓛ may be specified. If neither Ⓜ or Ⓛ is specified then as always the regardless of feature size (RFS) is applicable. See Fig's 5-21 thru 5-23 for examples of ∠, ⊥, and ⫽.

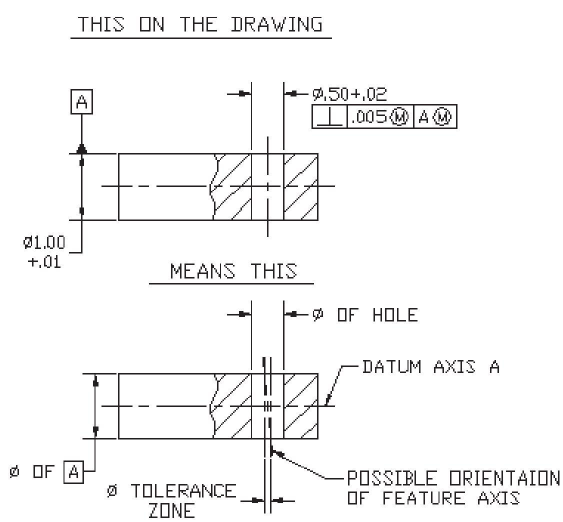
5



HOLE Ø	TOL. ZONE Ø
1.00	.005
1.01	.015

FIG 21-ANGULARITY OF A FEATURE OF SIZE AXIS AT MMC

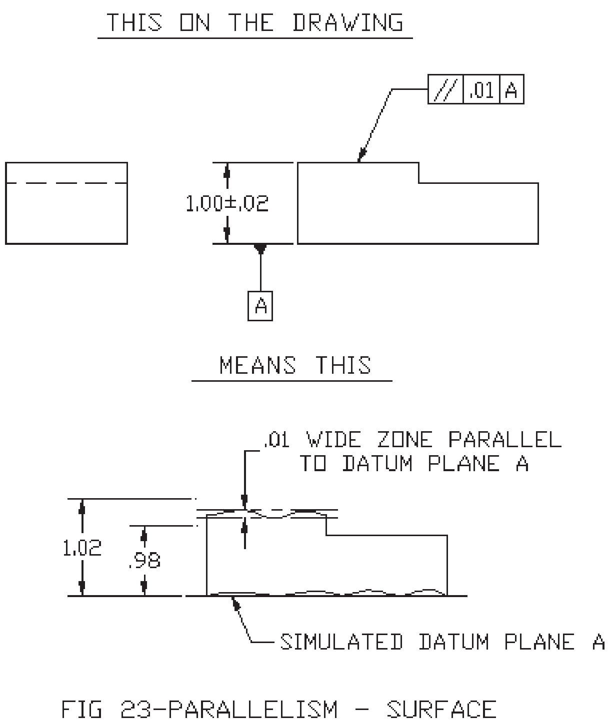
Figure 5-21 *Angularity of a feature of size axis at MMC.*



Ø OF A	HOLE Ø	TOL. ZONE Ø
1.01	.50	.005
1.01	.52	.025
1.00	.50	.015
1.00	.52	.035

FIG 22-PERPENDICULARITY OF A FEATURE OF SIZE AXIS
AT MMC WITH DATUM FEATURE OF SIZE AT MMC

Figure 5-22 *Perpendicularity of a feature of size axis at MMC with datum feature of size at MMC.*



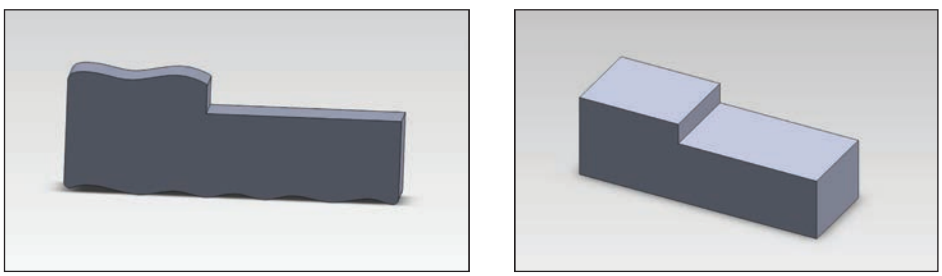


Figure 5-23 *Parallelism – surface.*

13 Form Tolerances

There are four (4) form tolerances : straightness, flatness, circularity, and cylindricity. They apply to individual features therefore the tolerances are not related to datums. Straightness can be used to control the straightness of median line of a feature of size hence material condition modifiers can be applied. The other form tolerances control surfaces hence material condition modifiers are not applicable.

13.1 Straightness

There is one symbol (—) for straightness but there are two (2) kinds of controls that are very different from each other. One control is for line elements of surfaces (FCF attached to the surface) and the other is control of an axis or median plane of feature of sizes (FCF attached to the size tolerance). The axis or median plane control relaxes the form control provided by Rule #1 because a perfect form boundary at MMC can be violated if the Ⓜ symbol is specified. Fig. 5-24 illustrates control of line straightness and Fig's 5-25 & 5-26 illustrate control of axis and median plane straightness respectively. The surface straightness tolerance is only for line elements in the view that the FCF is attached.

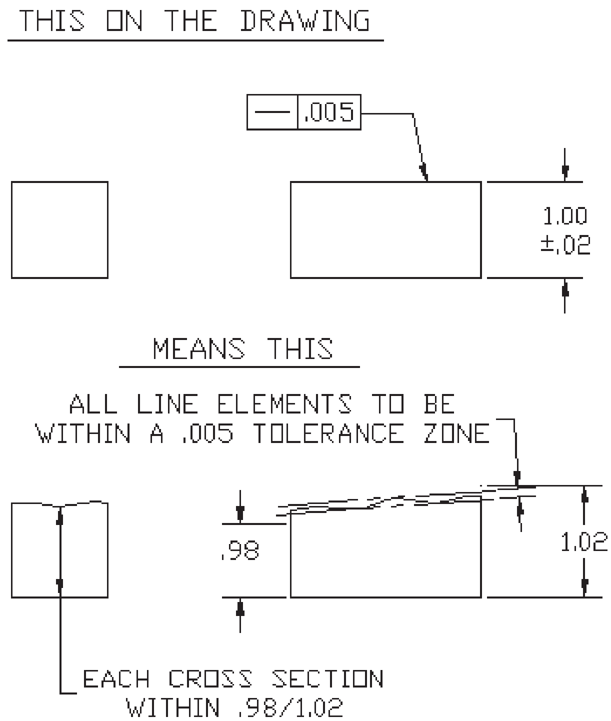


Figure 5-24 *Straightness of a surface.*

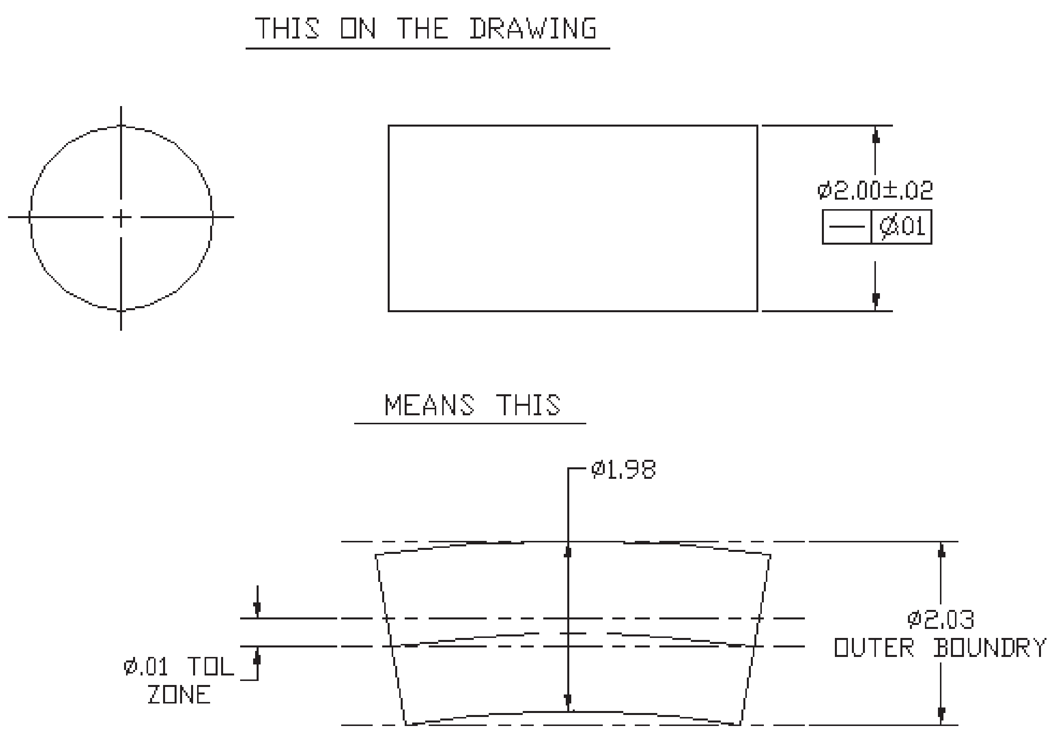
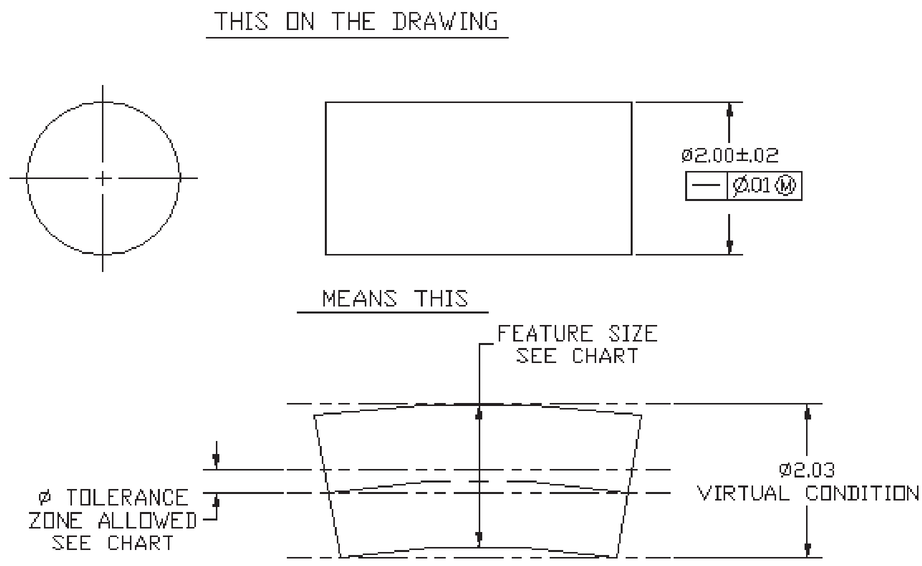


Figure 5-25 *Straightness of an axis RFS.*



FEATURE SIZE	Ø TOLERANCE ZONE ALLOWED
2.02	.01
2.00	.03
1.98	.05

Figure 5-26 *Straightness of an axis at MMC.*

13.2 Flatness

Flatness controls the distance between the high and low points of a surface. The tolerance zone is the distance between two parallel planes that have no particular orientation. All elements of the entire surface must lie between these two planes. See Fig. 5-27 for an illustration of flatness control. The symbol is ▱. Flatness is the same as straightness of a surface except straightness controls line elements only in the view that the control is applied whereas flatness controls the entire surface, i.e., all views.

13.3 Circularity (Roundness)

Circularity controls each circular element of a cylinder independent of each other. The circular elements of the surface in a plane perpendicular to an axis must lie between two concentric circles whose radii differ by the tolerance value in the FCF. The symbol is ○. See Fig. 5-28 for an illustration.

13.4 Cylindricity

Cylindricity controls the entire surface of a cylinder. The tolerance zone is two (2) concentric cylinders parallel to the axis of the actual mating envelope. The radii of the concentric cylinders differ by the tolerance value specified in the FCF. It is a composite tolerance that controls circularity, straightness, and taper. The symbol is ⌭. See Fig. 5-29 for an illustration.

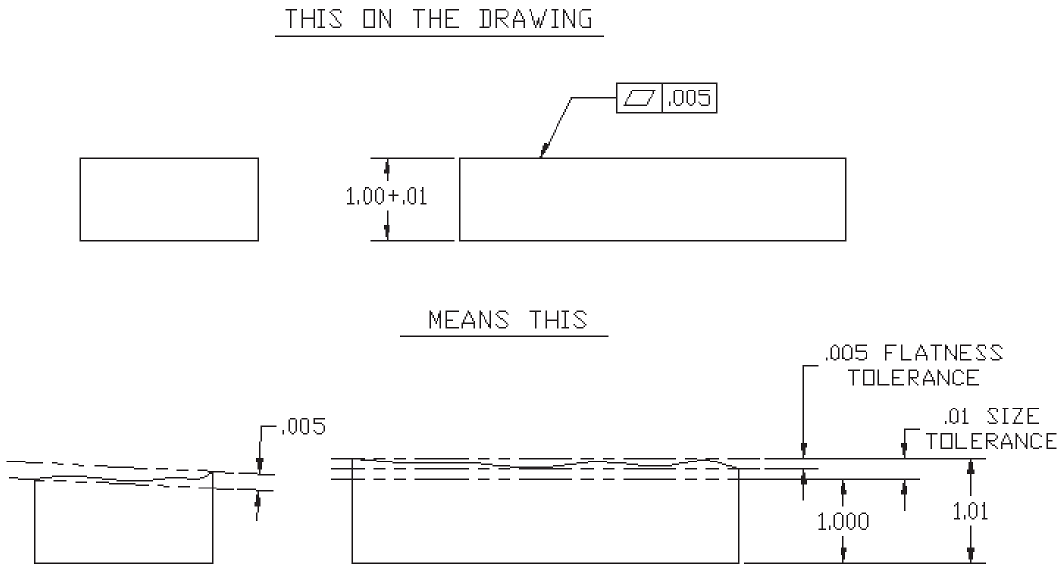
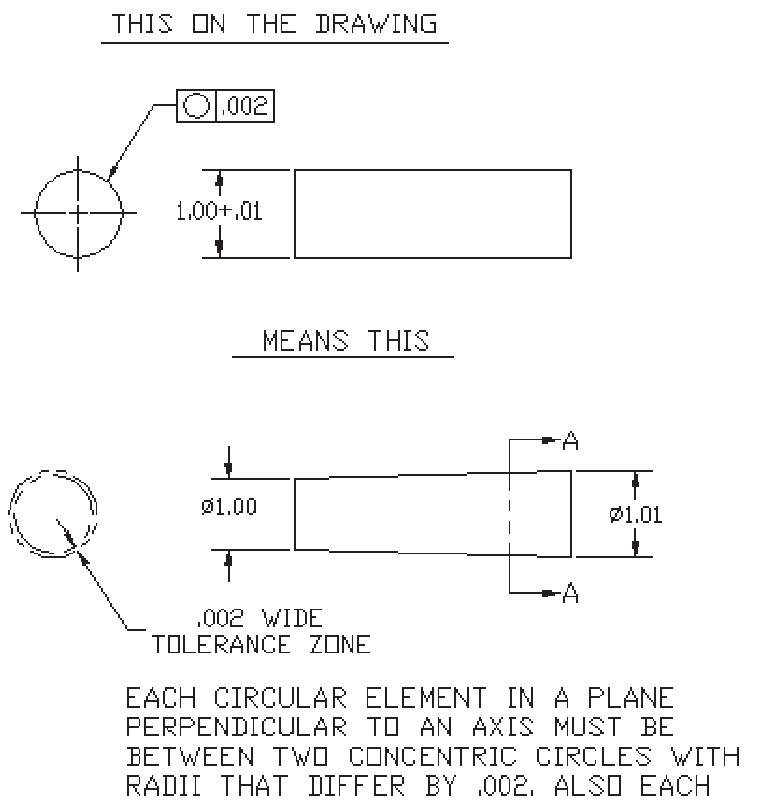


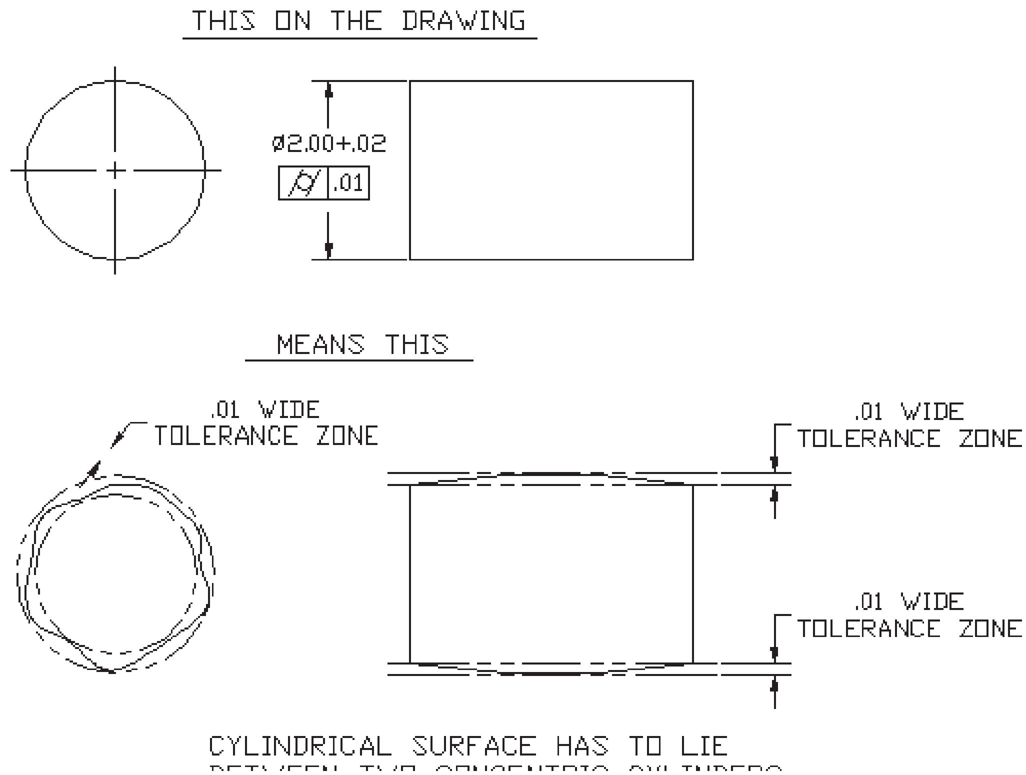
Figure 5-27 *Straightness of an axis at MMC.*



Notes:

Each circular element in a plane perpendicular to an axis must be between two concentric circles with radii that differ by .002. Also each element must be within the size limits.

Figure 5-28 *Circularity.*



Notes:

Cylindrical surface has to lie between two concentric cylinders with radii that differ by .01. Also the surface must be within the specified size tolerance.

Figure 5-29 *Cylindricity.*

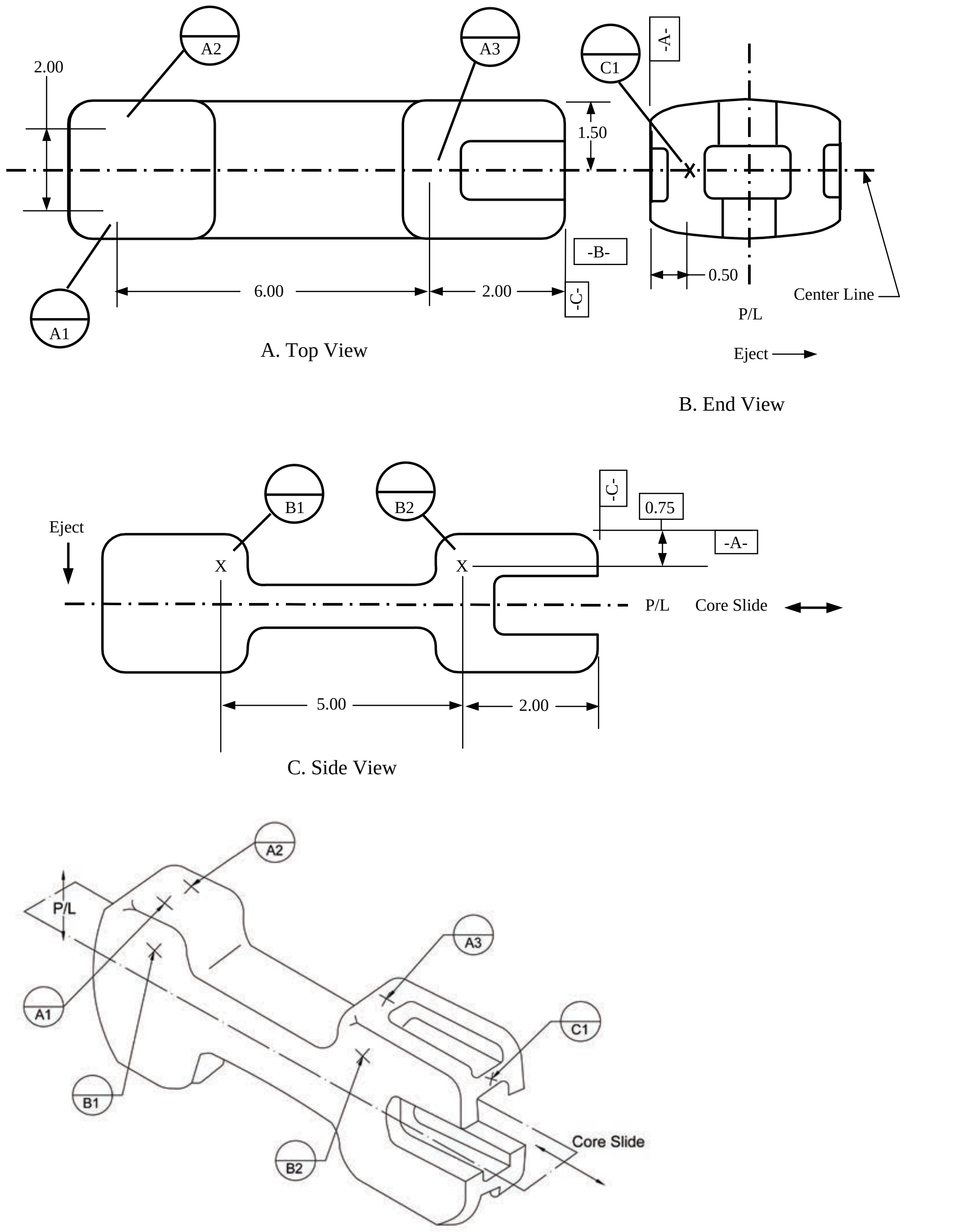


Figure 5-30 Example of an optimal datum reference framework for a die cast part design (all datums on same side of p/l).

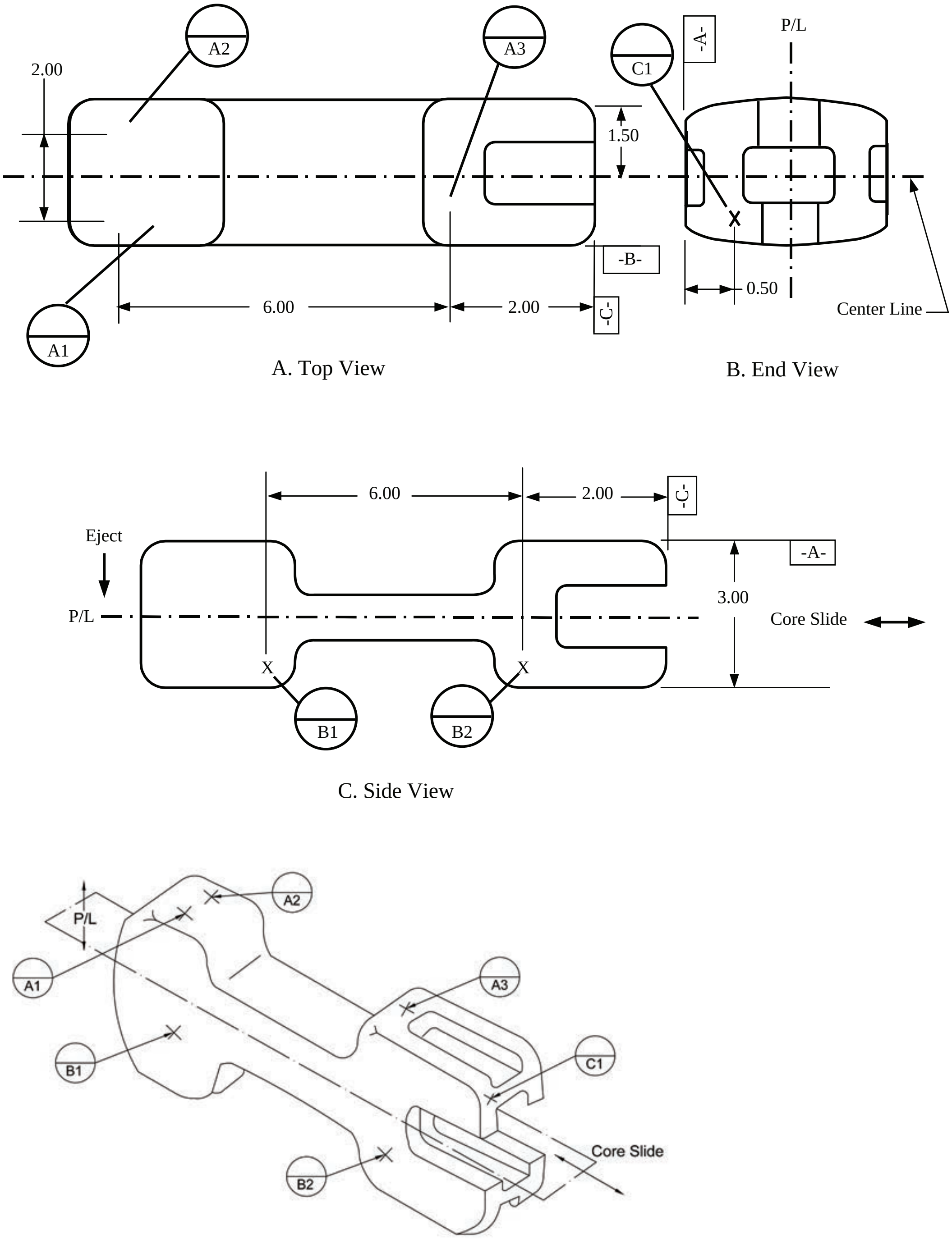


Figure 5-31 Example of a less desirable datum reference framework for a die cast part design (datums across p/l). May require additional qualification of some datums.

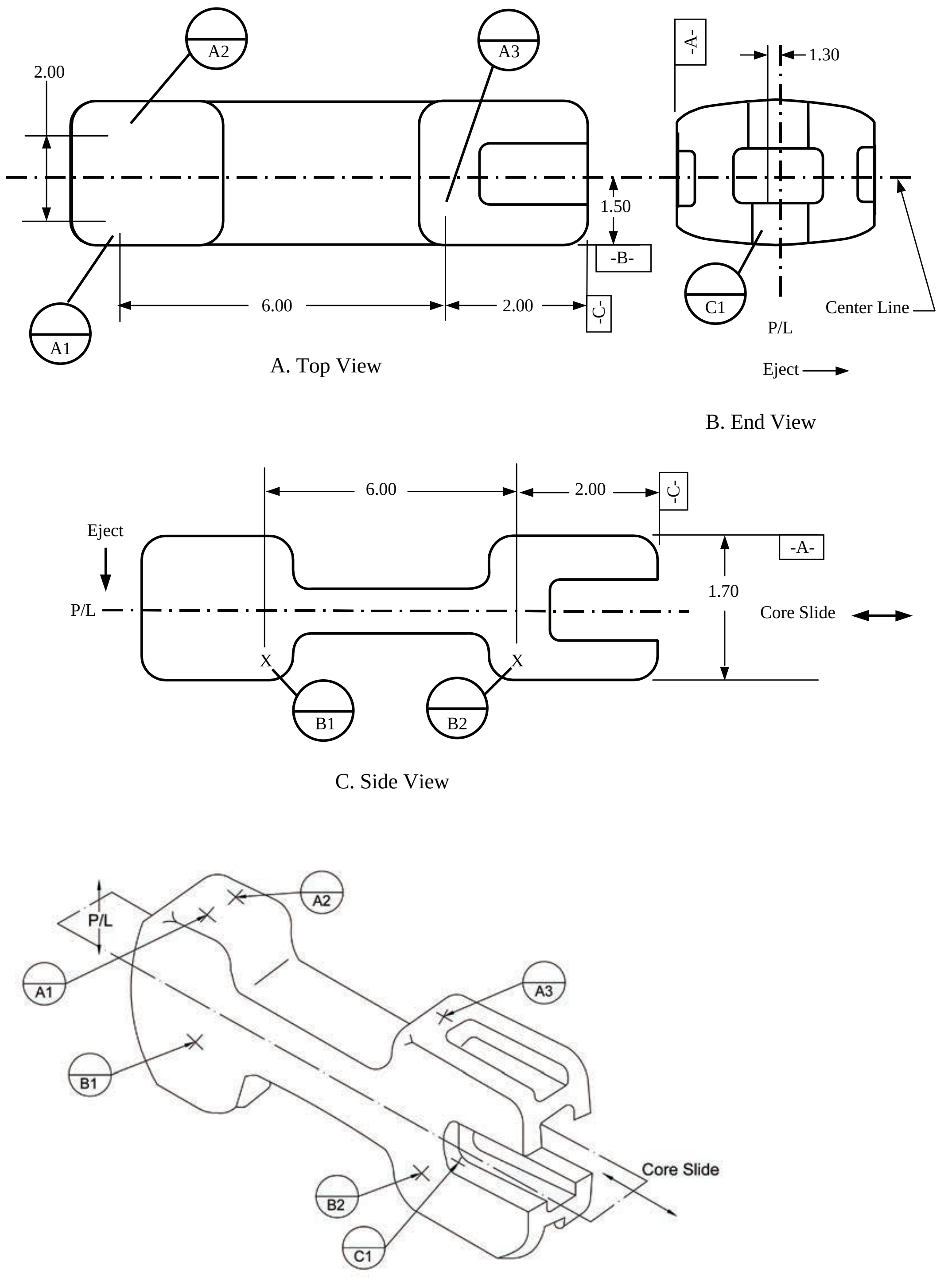


Figure 5-32 Example of a least preferred datum reference framework for a die cast part design (datums across p/l and datum on moving component). Will require qualification of all datums.

14 Conversion Charts

Coordinate dimensioning defines parts by their location on a three-dimensional grid, utilizing the X-Y-Z coordinate system as in Fig. 5-2. Since the Coordinate Dimensioning System may not consider part function when defining dimensions and tolerances, GD&T is a preferred method of defining and dimensioning parts based on functional relationships to other parts and part features. Sometimes it is necessary for dimensions and tolerances to be converted from one system to the other. Geometric dimensioning and tolerancing is steadily replacing coordinate dimensioning as more emphasis is placed on "designing for manufacturing" early in the product design stage. This section will demonstrate how to convert between coordinate dimensioning and geometric dimensioning.

14.1 Conversion of Position (Cylindrical) Tolerance Zones to/from Coordinate Tolerance Zones

When converting total position (cylindrical) tolerance zones to total coordinate tolerance zones, a general rule of thumb is that total coordinate zone is approximately 70% of total position tolerance zone. This is only useful for non-critical applications. For example, for a non-critical part to be converted from position (cylindrical) tolerance zone to coordinate tolerance zone, the position (cylindrical) tolerance is multiplied by 0.7 (70%). The total coordinate tolerance zone is then divided by 2 to obtain the bilateral tolerance zone.

Figure 5-33 visually demonstrates the conversion from coordinate tolerance zone to position (cylindrical) tolerance zone.

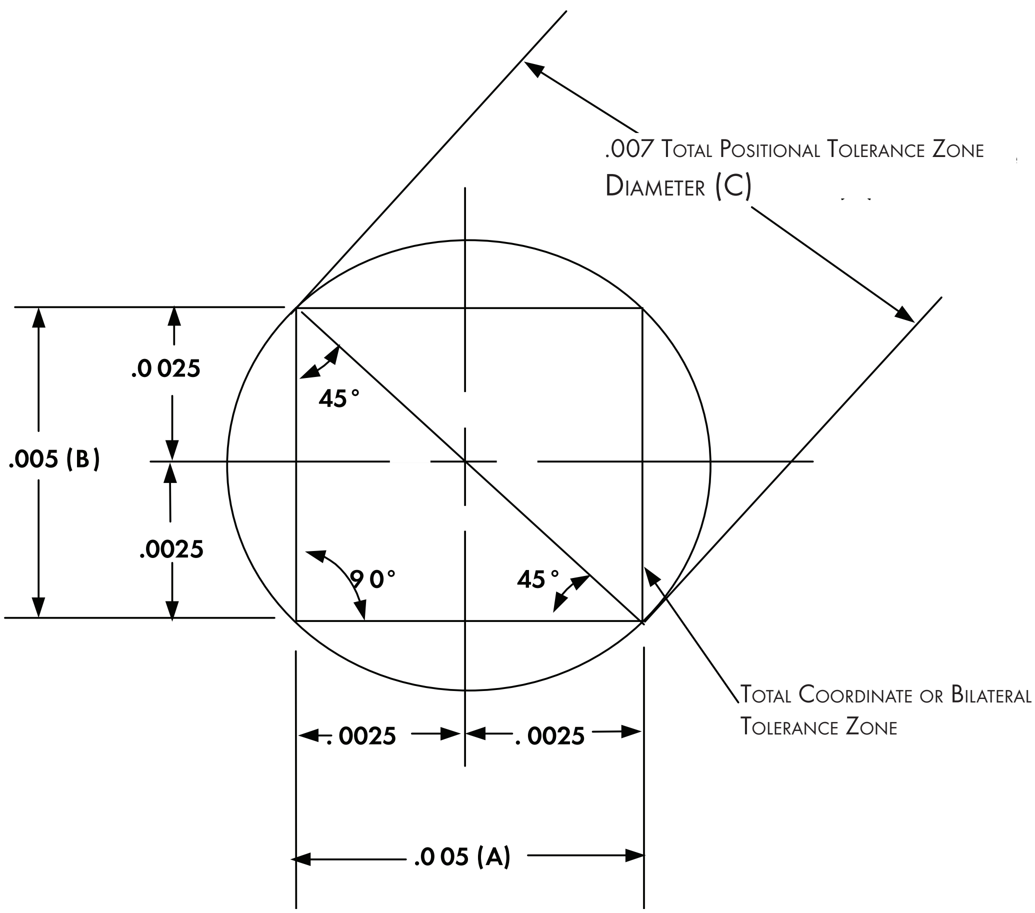


Figure 5-33 *Conversion of positional (cylindrical) tolerance zones to/from coordinate tolerance zones.*

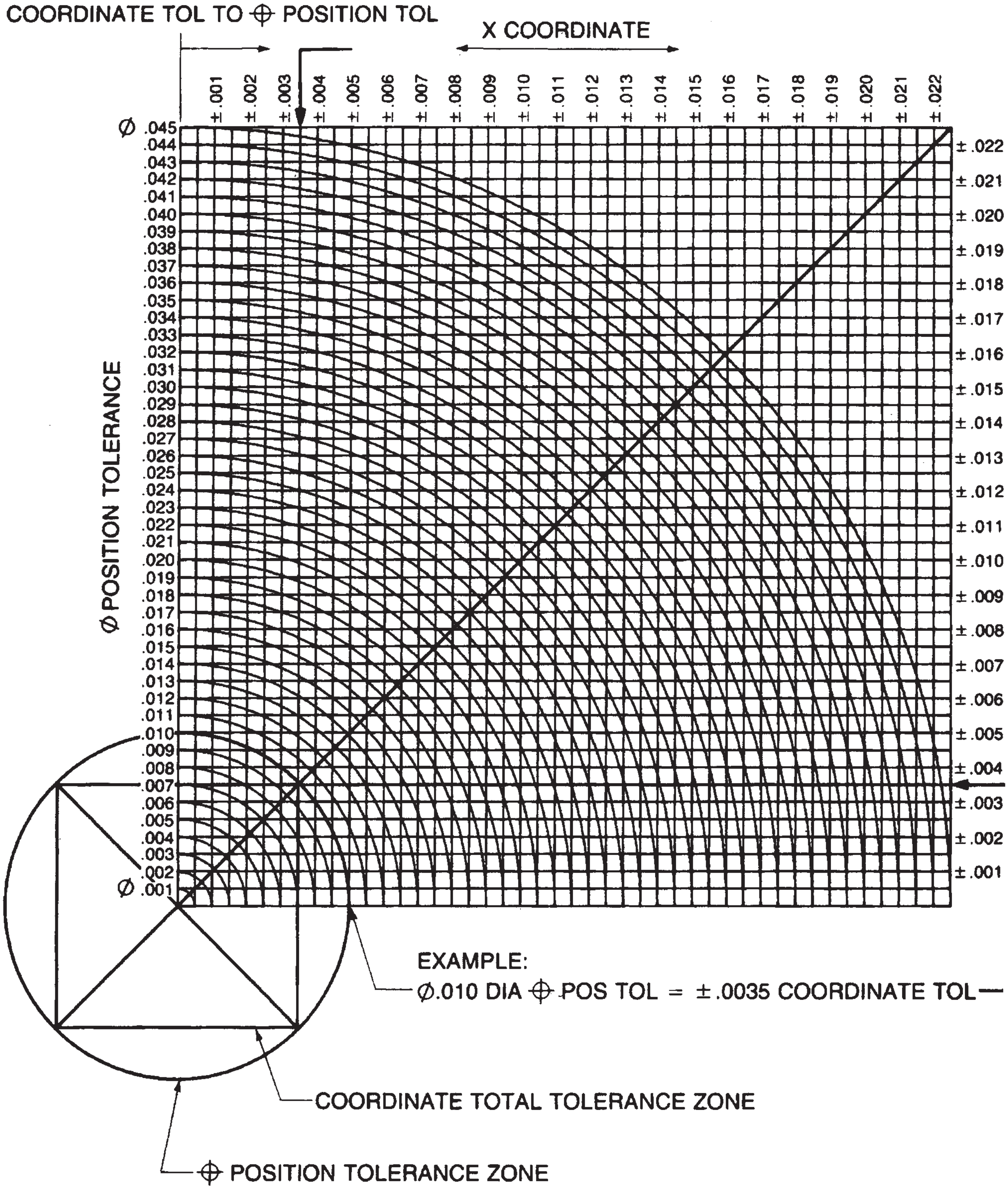


Figure 5-34 *Conversions chart for converting between position tolerance and coordinate tolerance.*

Total Coordinate Tolerance Zone =
[Total Position (Cylindrical) Tolerance Zone] X [0.7]

Example: Bilateral Tolerance Zone = [Total Coordinate Tolerance Zone] / 2

Sometimes parts require a more precise conversion. When a critical application is required, the conversion factor is 0.70711. The position tolerance will be multiplied by 0.70711 (70.711%) to obtain the total coordinate tolerance.

Total Coordinate Tol. Zone = [Total Position (Cylindrical) Tol. Zone] X [0.70711]

Bilateral Tolerance Zone = [Total Coordinate Tolerance Zone] / 2

For example, to convert 0.007 total position (cylindrical) tolerance to total coordinate tolerance:

Total Pos. Tol. Zone X Conversion Factor = Total Coordinate Tolerance Zone
0.007 Tol. X 0.70711 = 0.00495 ~ 0.005 Tot. Coordinate Tol.

Or

Total Coordinate Tol. Zone / 2 = Bilateral Tol. Zone 0.005 / 2 = 0.0025 Bilateral Tolerance

The following example demonstrates a simple conversion from total position tolerance zone to total coordinate tolerance zone and bilateral tolerance zone. Figure 5-36 visually demonstrates the conversion from position (cylindrical) tolerance zone to the coordinate tolerance zone.

When converting from total coordinate tolerance zone to total position (cylindrical) tolerance zone, the total coordinate tolerance zone is multiplied by 1.4142. A bilateral tolerance zone is multiplied by 2 then multiplied by 1.4142 to obtain the total position (cylindrical) tolerance zone.

For non-critical applications, it is acceptable to multiply the total coordinate tolerance zone by 1.4 to obtain the total position tolerance zone. A bilateral tolerance may be multiplied by 2 to obtain the total coordinate tolerance zone, then multiplied by 1.4 to get the total position tolerance zone.

Total Position Tol. Zone =[Total Coordinate Tol. Zone] X [1.4142]

Total Position Tol. Zone = [Bilateral Tol. Zone] X [2] X [1.4142]

For example, to convert .005 total coordinate tolerance to total position (cylindrical) tolerance:

[Total Coordinate Tolerance Zone] X [Conversion Factor] = Total Position Tol. Zone
[0.005 Total Coordinate Tol. Zone] X [1.4142] = 0.007 Total Tol. Zone

Or
[Bilateral Tolerance Zone] X [2] X [Conversion Factor] = Total Position Tol. Zone
[0.0025 Bilateral Tol.] X [2] X [1.4142] = 0.007 Total Tol. Zone

14.2 Conversion of Position Tolerance Zone to/from Coordinate Tolerance Zone

Figure 5-34 is a chart for converting position tolerance zones to coordinate tolerance zones, and for converting coordinate tolerance zones to position tolerance zones.

When looking at the conversion chart in Fig. 5-34, coordinate tolerance zones are listed across the top of the grid and increasing from left to right, and on the right side of the grid increasing from bottom to top. The position tolerances are listed on the left side of the grid and increase from bottom to top. The position tolerances, however, follow the arced line across the grid. The diameter of a position tolerance is given on the drawings, however, the diameter of a coordinate tolerance is given by the length of the diagonal line. A diagonal line is drawn from the lower left corner of the grid at a 45° angle to the upper right corner of the chart. The diameter is calculated by using $A^2 + B^2 = C^2$. In figure 5-33, A is the total length of the horizontal line at the bottom and connected to the circle, squared, plus B, the square of the vertical line at the left or right edge and connected to the circle. Take the square root of the sum of the two sides will equal the diameter C.

For example, suppose one wanted to convert a 0.010 diameter position tolerance to a coordinate tolerance. While looking at the chart in Fig. 5-34, begin at the 0.01 position tolerance on the left side of the chart. Follow the corresponding arced line until it crosses the diagonal line on the chart. Where the arced line and the diagonal line intersect, follow the horizontal line across to the right side of the chart. The number on the right side of the chart that corresponds with the horizontal line will give the appropriate bilateral coordinate tolerance. In this example, the corresponding bilateral tolerance is ± 0.0035. To quickly verify this conversion, use the multipliers identified in on page 5-31. Multiplying the coordinate tolerance by 0.7 will yield the total coordinate tolerance. This number is then divided by 2 to obtain the bilateral coordinate tolerance.

Position Tolerance = 0.010
Total Coordinate tolerance = Position Tol. X Conversion Factor = [0.010] X [0.7] = 0.007
Bilateral Tolerance Zone = Total Coordinate Tolerance / 2 = [0.007] / [2] = ±0.0035

Bilateral Position Tol. = ± 0.0035
Total Position Tol = Bilateral Position Tol. X 2 = [0.0035] X [2] = 0.007
Position Tol. X Conv. Factor = [0.007] X [1.4] ~ 0.01

The number obtained from the conversion chart and the number obtained by using the multiplier should be approximately the same.

Suppose it was desired to convert a coordinate tolerance such as 0.007 to a position tolerance. In order to use the conversion chart in Fig. 5-34, the coordinate tolerance must be in bilateral coordinates, so 0.007 is divided by 2. This yields a bilateral coordinate tolerance of ± 0.0035. Next, the number .0035 is located on the left side of the conversion chart. Follow the corresponding horizontal line across to the left until it intersects the diagonal line. At this intersection, follow the intersecting arced line all the way across and to the left. The number corresponding to that arced line on the left of the chart gives the associated position tolerance. If done correctly, the position tolerance identified on the chart should be 0.010. This can be double-checked by using the multipliers on page 5-31.

The number obtained from the conversion chart and the number obtained by using the multiplier should be approximately the same.

To convert between position tolerancing and coordinate tolerance, either the conversion table identified in Fig. 5-34, or the multiplication factor identified on page 5-31 may be used.

.020	.0400	.0402	.0404	.0408	.0412	.0418	.0424	.0431	.0439	.0447	.0456	.0466	.0477	.0488	.0500	.0512	.0525	.0538	.0552	.0566
.019	.0380	.0382	.0385	.0388	.0393	.0398	.0405	.0412	.0420	.0429	.0439	.0449	.0460	.0472	.0484	.0497	.0510	.0523	.0537	.0552
.018	.0360	.0362	.0365	.0369	.0374	.0379	.0386	.0394	.0403	.0412	.0422	.0433	.0444	.0456	.0469	.0482	.0495	.0509	.0523	.0538
.017	.0340	.0342	.0345	.0349	.0354	.0360	.0368	.0376	.0385	.0394	.0405	.0416	.0428	.0440	.0453	.0467	.0481	.0495	.0510	.0525
.016	.0321	.0322	.0325	.0330	.0335	.0342	.0349	.0358	.0367	.0377	.0388	.0400	.0412	.0425	.0439	.0452	.0467	.0482	.0497	.0512
.015	.0301	.0303	.0306	.0310	.0316	.0323	.0331	.0340	.0350	.0360	.0372	.0384	.0397	.0410	.0424	.0439	.0453	.0469	.0484	.0500
.014	.0281	.0283	.0286	.0291	.0297	.0305	.0313	.0322	.0333	.0344	.0356	.0369	.0382	.0396	.0410	.0425	.0440	.0456	.0472	.0488
.013	.0261	.0263	.0267	.0272	.0278	.0286	.0295	.0305	.0316	.0328	.0340	.0354	.0368	.0382	.0397	.0412	.0428	.0444	.0460	.0477
.012	.0241	.0243	.0247	.0253	.0260	.0268	.0278	.0288	.0300	.0312	.0325	.0339	.0354	.0369	.0384	.0400	.0416	.0433	.0449	.0466
.011	.0221	.0224	.0228	.0234	.0242	.0250	.0261	.0272	.0284	.0297	.0311	.0325	.0340	.0356	.0372	.0388	.0405	.0422	.0439	.0456
Y .010	.0201	.0204	.0209	.0215	.0224	.0233	.0244	.0256	.0269	.0283	.0297	.0312	.0328	.0344	.0360	.0377	.0394	.0412	.0429	.0447
.009	.0181	.0184	.0190	.0197	.0206	.0216	.0228	.0241	.0254	.0269	.0284	.0300	.0316	.0333	.0350	.0367	.0385	.0402	.0420	.0439
.008	.0161	.0165	.0171	.0179	.0189	.0200	.0213	.0226	.0241	.0256	.0272	.0288	.0305	.0322	.0340	.0358	.0376	.0394	.0412	.0431
.007	.0141	.0146	.0152	.0161	.0172	.0184	.0198	.0213	.0228	.0244	.0261	.0278	.0295	.0313	.0331	.0349	.0368	.0386	.0405	.0424
.006	.0122	.0126	.0134	.0144	.0156	.0170	.0184	.0200	.0216	.0233	.0250	.0268	.0286	.0305	.0323	.0342	.0360	.0379	.0398	.0418
.005	.0102	.0108	.0117	.0128	.0141	.0156	.0172	.0189	.0206	.0224	.0242	.0260	.0278	.0297	.0316	.0335	.0354	.0374	.0393	.0412
.004	.0082	.0089	.0100	.0113	.0128	.0144	.0161	.0179	.0197	.0215	.0234	.0253	.0272	.0291	.0310	.0330	.0349	.0369	.0388	.0408
.003	.0063	.0072	.0085	.0100	.0117	.0134	.0152	.0171	.0190	.0209	.0228	.0247	.0267	.0286	.0306	.0325	.0345	.0365	.0385	.0404
.002	.0045	.0056	.0072	.0089	.0108	.0126	.0146	.0165	.0184	.0204	.0224	.0243	.0263	.0283	.0303	.0322	.0342	.0362	.0382	.0402
.001	.0028	.0045	.0063	.0082	.0102	.0122	.0141	.0161	.0181	.0201	.0221	.0241	.0261	.0281	.0301	.0321	.0340	.0360	.0380	.0400
	.001	.002	.003	.004	.005	.006	.007	.008	.009	.010	.011	.012	.013	.014	.015	.016	.017	.018	.019	.020

X

Figure 5-35 Conversions chart for converting between coordinate measurement and position measurement.

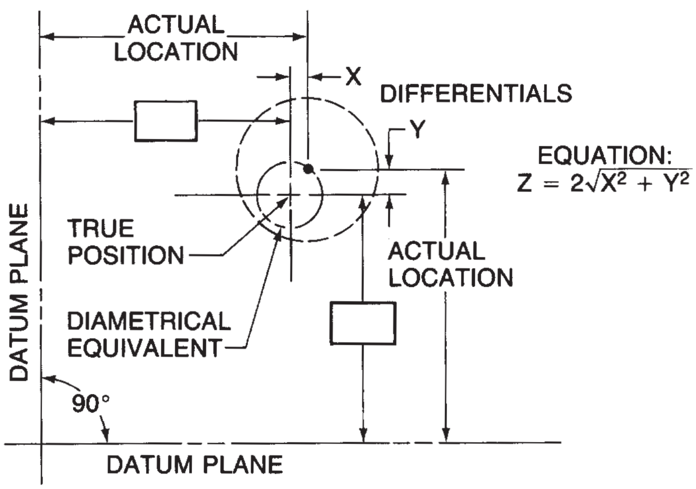


Figure 5-36 Schematic of conversion of coordinate measurements to position location.

14.3 Conversion of Coordinate Measurements to Position Location Measurements

In addition to sometimes having to convert between position tolerance zones and coordinate tolerance zones, it is also necessary to convert coordinate measurements to position location measurements. When converting from coordinate measurements to position measurements, the chart identified in Fig. 5-35 is used.

For example, if it was necessary to convert the position measurement 0.0311 to coordinate measurements the following steps need to be accomplished. First, locate the number 0.0311 on the chart in Fig. 5-35. Once the number is located, follow the vertical column down to the X-axis of the chart. The number identified at the very bottom of the column is the X-coordinate measurement. In this example, the X-coordinate is 0.011. Now, relocate the number 0.0311 on the chart and follow the horizontal row to the right until it crosses the Y-axis. The number on the very left end of that row is the Y-coordinate measurement. In this example, the Y-coordinate is 0.011. Since position measurements are three-dimensional, a Z-coordinate must also be identified. To find the corresponding Z-coordinate measurement, a simple equation must be performed. This equation is as follows:

$$Z = 2\sqrt{\quad X^2 + Y^2}$$

For this example, Z = 2 times the square root of X squared plus Y squared.

$$Z = 2\sqrt{\quad (0.011)^2 + (0.011)^2}$$

$$Z = 2\sqrt{\quad (0.000121) + (0.000121)}$$

$$Z = 2\sqrt{\quad 0.000242}$$

$$Z = 2\sqrt{\quad 2(0.015556)}$$

$$Z = \quad 0.031112$$

The coordinate measurements that are associated with the 0.0311 position are

X = 0.011, Y = 0.011, and Z + 0.031112.

Engineering & Design: Additional Specification Guidelines

SECTION 6

Section Contents

Engineering & Design: Additional Specification Guidelines

Pressure-tightness specifications for die castings, to assure containment of liquids or gases in use, require deviations from standard production and inspection practice. Extra steps, including special pressure-testing equipment and testing procedures, are usually needed.

Frequently Asked Questions (FAQ)

1) How much flash can be expected to remain on a die casting after degating and trimming?
   See page 6-7, Metal Extension (Flash) Removal.
2) If lettering is cast into the part, what are the options?
   See page 6-10, Die Cast Lettering.
3) Are ejector pin marks required on the casting and will they have flash?
   See page6-6, Ejector Pins, Pin Marks and Pin Flash.
4) What is a typical pressure tightness that die castings can withstand?
   See page 6-3, Pressure Testing.
5) What is the best surface condition I can expect on die cast surfaces?
   See page 6-8, Typical As-Cast Surface Roughness Guide.
6) Why add ribs to the casting in-place of thick sections?
   See page 6-5, Ribs and Corners.

Introduction

The die casting specifications discussed in this section relate to aspects of die casting design and production for which precise standards are difficult to set forth. As in previous Engineering sections, they replace the former ADCI/NADCA "E" Series.

They include characteristics which are highly dependent on the design and shape of the particular part to be die cast, such as:

- Pressure tightness of the finished part
- The proper design of fillets, ribs and corners in a part
- The consideration of ejector pin locations, pin marks and pin flash
- Casting flash and its removal
- As-cast surface finish specifications
- The casting of lettering, logos and ornamentation on the part surface

The purpose of this section is to offer established engineering and design guidelines which, if implemented, can produce the most economical results under normal die casting operations. These conditions should be made in close consultation with a die casting partner prior to any final design decisions.

1 Pressure Tightness in Cast Parts

Assurance of pressure tight castings is highly dependent on the design configuration of the part. Consultation with the caster in the early design stages is essential where a specification for pressure tightness exists, in order to take advantage of basic product design, casting die design, and production processing factors. All of these factors are involved in insuring pressure tightness of the final cast part.

While most cast part designs can be cast pressure tight, specific castings may require impregnation to achieve required pressure tightness.

Special Notification Required

Specifications for pressure tightness will require deviations from standard production and inspection practice. Special pressure testing equipment and testing procedures are usually needed.

The requirement for pressure tightness should be made only where it is essential to the performance of the finished part. Where so specified, test methods and inspection procedures should be agreed upon in advance between the customer and the caster. Duplicate test fixtures and test methods are recommended wherever possible.

The discussion of "Porosity" and "Pressure Tightness" under Quality Assurance, Section 7 of this manual, should be reviewed.

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GUIDELINES

Pressure-tightness specifications for die castings, to assure containment of liquids or gases in use, require deviations from standard production and inspection practice. Extra steps, including special pressure-testing equipment and testing procedures, are usually needed.

Guidelines for Pressure Tightness

Important considerations relating to the economical production of pressure-tight castings include the following guidelines:

1. Product Design and Die Design

Successful casting of pressure-tight castings requires close conformance to the following principles of good casting product design to ensure quality within the die casting component:

a. *Guidelines concerning fillets, ribs and corners (G-6-2 and G-6-3), in this section, should be followed very carefully.*

b. *Part wall sections should be of uniform thickness as much as possible.*

c. *Holes and passages requiring pressure tightness should be cored to reduce porosity, as opposed to machined after casting.*

d. *Ample draft should be provided in all cored holes and passages which are not to be machined. Cored holes which are to be machined should be given minimum draft (see Draft Tolerances pg. 4-21).*

e. *Heavy sections, as well as abrupt changes in sectional thickness, should be avoided.*

f. *Special vacuum casting techniques may be required in addition to special steps in temperature control, the use of squeeze pins and other procedures to achieve final part specifications where the part design does not conform to good casting design guidelines.*

2. Secondary Machining

The outer section, or skin, of a die casting consists of a dense, fine grain microstructure which gives the casting greater strength and durability. For pressure tight applications, strict limitations to secondary machining operations must be observed to ensure adequate performance. The following guidelines are provided:

a. *A minimum amount of machining stock should be removed, to avoid exposing porosity by cutting deeply into a casting (see Machining Stock Allowance Tolerances, pg. 4-40).*

b. *Large draft angles, which would require the removal of a large amount of stock from a surface to be machined, should be avoided, particularly where holes are cored.*

c. *Machining both sides of the same section of a pressure-tight casting should be avoided.*

d. *Where machining can expose porosity, impregnation may be required to insure pressure tightness.*

3. Die Casting Alloy Selection

Certain alloys are best for producing pressure-tight castings. Refer to the Alloy Data sections for alloy comparisons of pressure-tightness characteristics to aid in the selection of the most favorable alloys.

4. Casting Requirements & Pressure Testing

Pressure-tightness testing for castings is generally specified in the range of 5 to 40 psi. Higher pressures will require special consideration by the caster and will be almost entirely a function of the part design.

In the case of pressure-tight casting requirements, review inspection procedures in Commercial Practices (Section 8), and Porosity Control (Section 2).

These recommendations regarding the design of fillets, ribs and corners represent guidelines which will result in die casting at the most economic level under normal production practice. Sharp inside surface junctions, acute angle corner conditions and delicate, deep and closely spaced ribs should be specified only where and when necessary, since additional costs may be involved.

Engineering & Design: Additional Specification Guidelines

2 Fillets in Die Cast Parts

Fillets

Intersecting surfaces forming junctions are best joined with fillets to achieve improved quality in both the die casting component and die casting die. Fillets function to:

- Distribute stresses in areas of the die casting which improve the strength and performance of the die casting
- Dissipate heat buildup during the casting process which helps avoid potential shrinkage porosity due to "hot spots" that can occur at sharp corners in die castings
- Improve die life by distributing stress and eliminating hot spots in the die

In the sketches below, consideration has been given to the normal stresses on the die cast part in use and to the stresses induced in the die castings by the casting process itself, as well as to other manufacturing and die maintenance considerations.

Fillet Draft

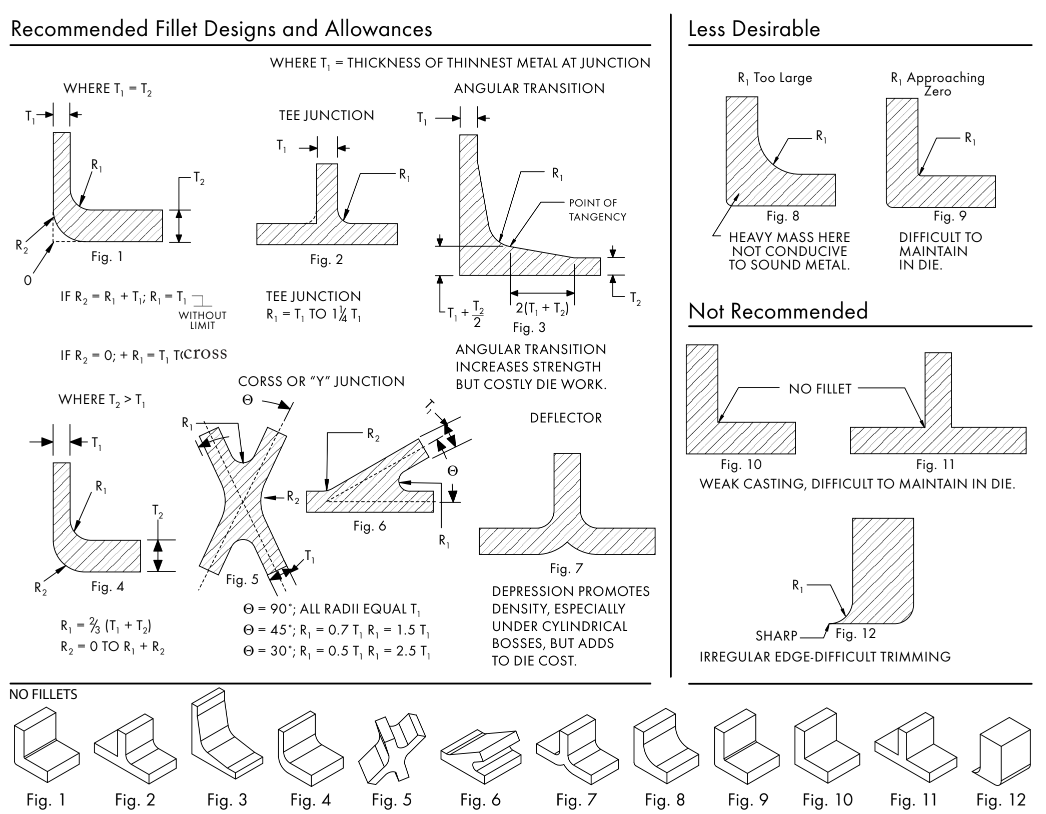
Fillets projected in a direction normal (perpendicular) to the parting line require draft. The amount of draft is always governed by the draft of the intersecting surface (see Section 4), if a constant fillet radius is maintained.

Shallow vs. Deep Die Casting Designs

These suggestions apply to fillets on corners which are projected normal to the parting plane in die castings of moderate depth. Shallow die castings may have much smaller fillets, while deep pockets and other inside corners should have larger fillets.

Avoid Long, Sharp Corners

Long, sharply squared corners projecting in a direction normal to the parting plane may cause spalled edges on the die casting and should be avoided.



Engineering & Design: Additional Specification Guidelines

3 Ribs and Corners in Die Cast Parts

These recommendations regarding the design of fillets, ribs and corners represent guidelines which will result in die casting at the most economic level under normal production practice. Sharp inside surface junctions, acute angle corner conditions and delicate, deep and closely spaced ribs should be specified only where and when necessary, since additional costs may be involved.

Ribs

Correctly designed ribs are used to efficiently increase the stiffness of, or add strength to, a die casting and to aid in making sound die cast parts, without the use of excess material. Often, ribs add more strength to die castings than solid material. If designed incorrectly, ribs can be a detriment if working stresses are concentrated by their use, or if high stresses are created at the edges of the ribs by their incorrect design. Considerations to rib design are given in the following topics and sketches.

External Corners

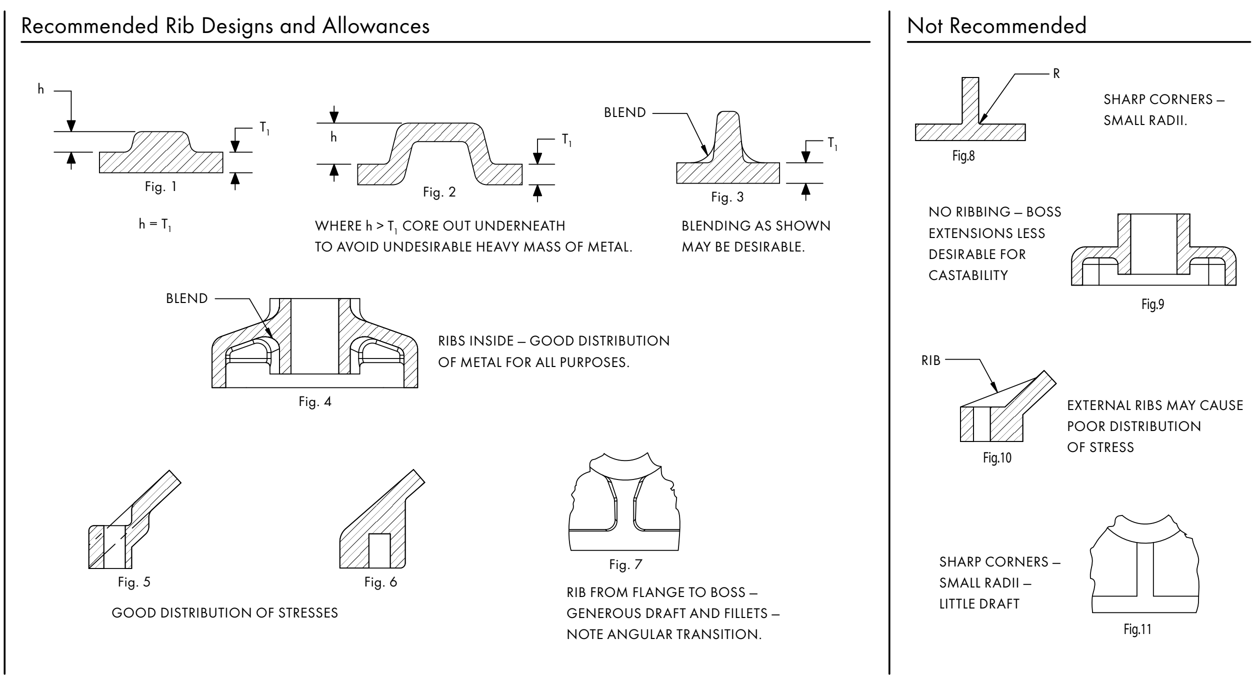
Sharply squared external corners may be used in some locations if die construction permits. This type of corner is mandatory at parting line locations and die block intersections. Elsewhere, corners of die castings should have radii to prevent early die failure, to reduce the probability of nicking the edge of the die casting in handling and assembly, and to minimize material handling hazards for personnel.

Small Metal Savers

Ribs are often an integral part of making a die casting stronger, but a die cast part designer needs to be cognizant of the steel as well. The empty space left in between ribs that serves no functional purpose on the part is called a metal saver. Often, adding ribs close together can result in thin or weak metal savers required in the die cast die to form the rib features in the part. The designer should review the part for:

- Relatively deep metal saver pockets
- Relatively sharp edges to metal saver pockets
- Relatively small draft on the sides of the metal saver pockets

All of the above should be avoided when designing the die cast part. The die caster or tool maker can be consulted for design suggestions as well.



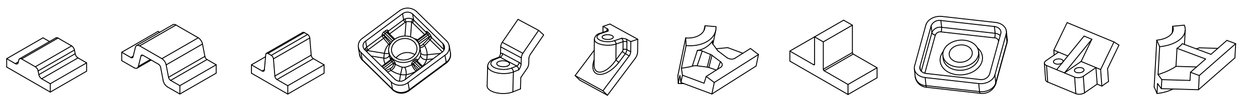


Fig. 1 Fig. 2 Fig. 3 Fig. 4 Fig. 5 Fig. 6 Fig. 7 Fig. 8 Fig. 9 Fig. 10 Fig. 11

Engineering & Design: Additional Specification Guidelines

4 Ejector Pins, Pin Marks and Pin Flash

The guidelines presented here for the location of ejector pins, pin mark tolerances and procedures regarding pin flash represent standard die casting production practice at the most economic level. Disregarding these guidelines should be done only when and where essential to the product design, since additional cost may be involved.

Ejector Pin Marks

Moveable ejector pins must be used to eject a die casting from the die casting die and will result in a residual ejector pin mark on the die cast part.

In addition to automatically pushing the casting from the die after part solidification, ejector pins also serve to keep the casting from bending.

The sequential illustrations at right demonstrate the action of the ejector pins in a die casting cycle.

Ejector Pin Operation

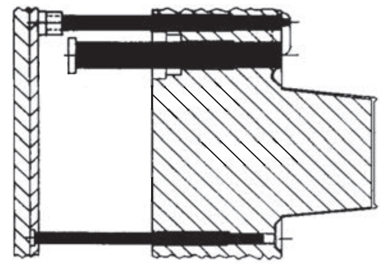


Figure A

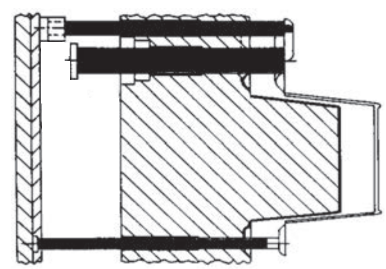


Figure B

Location Of Ejector Pins

Ejector pin locations should be at the option of the die caster, subject to the customer's agreement. Where considerations of cast surface cosmetics are important, ejector pin locations should always be discussed in advance of die design.

The number, size and location of ejector pins and bosses required will vary with the size and complexity of the die casting, as well as with other factors.

Acceptable Ejector Pin Marks

Ejector pin marks on most die castings may be raised or depressed .015" (.381 mm). Raised ejector pin marks are preferred for optimum production. Larger castings may require additional ejector pin tolerances for proper casting ejection.

Ejector Pin Operation

With each die casting cycle, the die opens and the ejector plate in the ejector half of the die (Fig. A) automatically moves all ejector pins forward (Fig. B), releasing the casting from the die. Then, the die casting is removed from the die manually or mechanically.

Ejector Pin Flash

Ejector pin marks are surrounded by a flash of metal. Normally, ejector pin flash will not be removed, unless it is objectionable to the end use of the part.

Alternatively, ejector pin flash may be specified as crushed or flattened.

In the case of either nonremoval or crushing/flattening, flash may flake off in use.

Complete removal of ejector pin marks and flash by machining or hand scraping operations should be specified only when requirements justify the added expense.

Bumping Ejector Pins

When ejector pins are placed on a flat surface, it can sometimes cause the side opposite the ejector pinto bulge out on the part (called bumping). Bumping can be minimized by:

- Increasing the wall thickness (increasing locally is an option as well).
- Placing ejector pins neat veticle walls (distributes some ejection force to ribs).
- Placing ejector pins on top of ribs.
- Increasing draft.

5 Metal Extension (Flash) Removal

The guidelines for removal of die casting metal extension (flash) presented here represent normal production practice at the most economic level. Precision flash trimming, closer than standard commercial trimming, or the complete removal of all extension involves additional operations and should be specified only when requirements justify the additional cost.

Metal Extension (Flash) Formation and Location

An extension of metal is formed on die castings at the parting line of the two die halves and where moving die components (also called moving die parts) operate (see Figure 6-1).

A seam of metal extension may also be formed where separate die parts cast a part feature. Residual metal extension is also formed by the normal operation of ejector pins and is discussed on the previous page.

Simplifying Extension (Flash) Removal

Necessary casting metal extension removal costs can be reduced by consideration, in the design stages, of the amount of metal extension to be removed and the removal method to be employed.

Early consultation with the die caster can often result in production economies in the treatment of metal extension removal.

Guidelines to Extent of Removal

The table below provides a guide to the types of die casting metal extension (flash) which occurs in typical die castings and the amount of metal extension material which remains after (1) degating (removal of any gates and runners from the casting), and (2) commercial trimming of die casting metal extension.

Note that in some instances, where special surface finish characteristics are not involved, the most economic method of degating and metal extension (flash) removal may include a tumbling or vibratory deburring operation.

Guide to Nominal Metal Remaining by Type of Extension

	Type of Metal Extension and Nominal Amount Remaining After Degating and Trimming				
Operation Description	Thick Gates & Overflows > 0.12" (3.0 mm)	Thin Gates & Overflows ≤ 0.12" (3.0 mm)	Parting Line and Seam Line Metal Extension	Metal Extension in Cored Holes	Sharp Corners
After Degating Nominal Flash Remaining	Rough within 0.12" (3.0 mm)	Rough within 0.12" (3.0 mm)	Excess Only Broken Off	Not Removed	Not Removed
After Commercial Trimming* Nominal Extension Remaining	Within 0.06" (1.59 mm)	Within 0.03" (0.8 mm)	Within 0.015" (0.38 mm)	Removed within 0.010" (0.25 mm)**	Not Removed

** "Commercially trimmed" does not include additional operations to remove loose material. For very heavy gates and overflows, consult your die caster.*

*** Shave trimming may be available to reduce amount of metal remaining in cored holes. Consult your die caster to determine what options are available.*

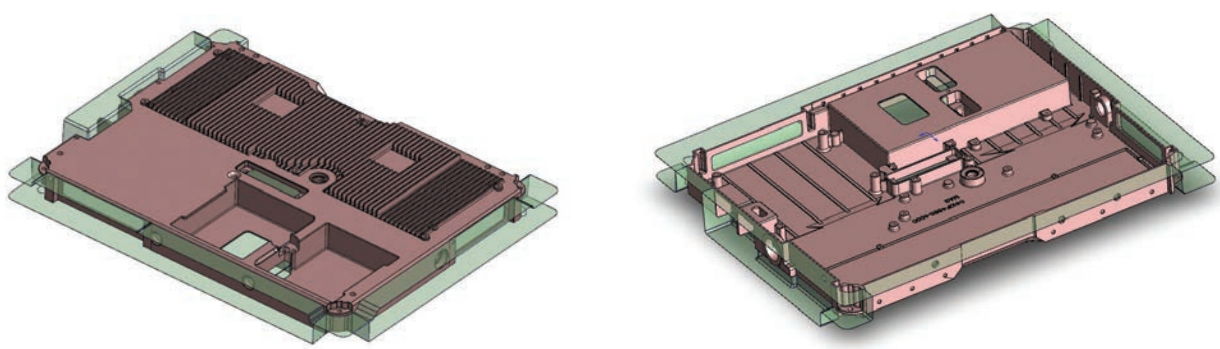


Figure 6-1: *Examples of complex parting lines that can make flash extension removal more difficult.*

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GUIDELINES

The as-cast external surface finish classifications shown here illustrate variations in production practice. Surface finish requirements should be specified for production at the most economic level. Generally, extra steps in die design, die construction and casting production are required for the more exacting finishes, and additional cost may be involved. Selection of the lowest classification number, commensurate with the die cast part application, will yield the lowest cost.

NOTE:

As-cast surface finish classification does not apply to machined surfaces. Finished machined surface requirements shall be as agreed upon between the die caster and customer and separately identified on the engineering part drawing.

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6 Surface Finish, As-Cast

General Guidelines for As Cast Surface Finish on Die Cast Parts

The specification of external surface finish requirements is desirable for selected die casting applications and, in the case of some decorative parts, essential.

The purpose of the guidelines presented here is to classify as-cast surface finish for die castings into a series of grades so that the type of as-cast finish required may be addressed and defined in advance of die design.

These guidelines should be used for general type classification only, with final surface finish quality requirements specifically agreed upon between the die caster and the customer.

The first four classes listed relate to cosmetic surfaces. Class five relates to selected surface areas where specified surface finish limitations are required.

As-Cast Surface Finish Classifications and Final Finish or End Use

Class		As-Cast Finish	Final Finish or End Use
1	Utility Grade	No cosmetic requirements. Surface imperfections (cold shut, rubs, surface porosity, lubricant build-up, etc.) are acceptable	Used as-cast or with protective coatings; Anodize (non-decorative) Chromate (yellow, clear)
2	Functional Grade	Surface imperfections (cold shut, rubs, surface porosity, etc.), that can be removed by spot polishing or can be covered by heavy paint, are acceptable.	Decorative Coatings: Lacquers Enamels Plating (Al) Chemical Finish Polished Finish
3	Commercial Grade	Slight surface imperfections that can be removed by agreed upon means are acceptable.	Structural Parts (high stress areas) Plating (Zn) Electrostatic Painting Transparent Paints
4	Consumer Grade	No objectionable surface imperfections. Where surface waviness (flatness), noted by light reflection, is a reason for rejection special agreement should be reached with the die caster.	Special Decorative Parts
5	Superior Grade	Surface finish, applicable to limited areas of the casting and dependent on alloy selected, to have a maximum value in micro inches as specified on print.	O-Ring Seats or Gasket Areas

Typical As-Cast Surface Roughness Guide

	Typical Surface Roughness (μ-inches)	
Alloy Family / Alloy	Expected in a New Die	Over the Life of a Die
Aluminum, ZA-12, ZA-27	63 or lower	100-125
Magnesium	63 or lower	63 should be maintainable
Zinc, ZA-8	32 or lower	63 should be maintainable

Notes:

1. *Part design, gate location, draft, flow lines, die surface treatments and other factors can impact surface roughness.*
2. *Roughness values for Over the Life of a Die do not include heat checking in the die.*
3. *Die lubricants utilized for special applications may impact surface roughness and the values in the table may not be achievable.*

Coatings for Castings

Operations	Coating	Applicable Material	Advantages	Price**
Pretreatments	Alodine 5200	Al, Mg	1, 2, 3	Low
Pretreatments	Chromate (Class 1A & 3)	Al, Zn	1, 2, 3, 4	Low
Pretreatments	Iron Phosphate	Al, Mg, Zn	1, 3	Low
Pretreatments	NH 35	Mg	1, 2, 3	Low
Primers	Urethane	Al, Mg, Zn	1, 3, 5	Medium
Primers	Epoxy	Al, Mg, Zn	1, 2, 3, 6	Medium
Primers	Zinc Rich	Al, Mg, Zn	1, 2, 3, 6	High
Primers	Zinc Chromate	Al, Mg, Zn	1, 2, 3, 5, 6	Medium
Primers	Vinyl Acid Wash	Al	1, 2, 3, 5	Low
Primers	E-Coat	Al, Mg, Zn	1, 2, 3, 6	Low
Liquid Topcoats	Urethane	Al, Mg, Zn	1, 3, 5, 6, 7	Medium
Liquid Topcoats	Epoxy	Al, Mg, Zn	1, 2, 3, 6	Medium
Liquid Topcoats	Acrylic	Al, Mg, Zn	1, 3, 5, 6, 7	Medium
Liquid Topcoats	Waterbase	Al, Mg, Zn	1, 2, 3, 5, 6, 7	Medium
Liquid Topcoats	Fluropons/ Architect	Al, Mg, Zn	1, 2, 3, 5, 6, 7	High
Powder Coats	Polyester	Al, Mg, Zn	3, 5	Low
Powder Coats	TGIC	Al, Mg, Zn	1, 2, 3, 5, 7	Medium
Powder Coats	Urethane	Al, Mg, Zn	3, 5, 7	Low
Powder Coats	Epoxy	Al, Mg, Zn	1, 2, 3	Medium
Powder Coats	Hybrid	Al, Mg, Zn	1, 2, 3	Medium
Anodic Films	Anodize	Al*, Mg	1, 2, 3, 5, 6, 7	Low
Anodic Films	Hardcoat - Hard Anodizing	Al, Mg	1, 2, 3, 6, 7	Medium
Electroplating	Copper	Al, Mg, Zn	1, 2, 4, 6, 8	High
Electroplating	Copper/Nickel	Al, Mg, Zn	1, 2, 4, 6, 8	High
Electroplating	Cu/Ni/Chrome	Al, Mg, Zn	1, 2, 4, 6, 8	High
Electroplating	Brass	Al, Zn	1, 2, 4, 6, 8	High
Electroplating	Bronze	Al, Zn	1, 2, 4, 6, 8	High
Electroplating	Zinc	Al, Zn	1, 2, 4, 6, 8	High
Electroplating	Silver	Al, Zn	1, 2, 4, 6, 8	Very High
Electroplating	Gold	Al, Zn	1, 2, 4, 6, 8	Very High
Electroless Plating	Electroless Nickel	Al, Mg, Zn	1, 2, 3, 4, 6, 8	High
Electroless Plating	Electroless Copper	Al, Mg, Zn	1, 2, 3, 4, 6, 8	High

For more details contact a viable coating source.

Note: *Not all die castings readily accept electro-coatings. Vacuum plating films such as PVD and CVD coatings, mechanical plating such as Zinc/Tin, and thermal spray coatings may also be applied. Consult with the the applicable coating suppliers.*

Legend for Advantages:

1 *Corrosion protection*
2 *Chemical resistance*
3 *Adhesion enhancement*
4 *Conductivity*
5 *Flexibility*
6 *Hardness/ wear resistance/ durability/ mar resistance*
7 *UV resistance*
8 *Decorative finish*

* Anodizing of aluminum is contingent upon the specific alloy and may not yield an aesthetically pleasing surface.

** Comparison of coating prices should be made with a constant cast material. Prices for coating aluminum will be higher than prices for coating zinc.

NADCA

G-6-7-18

GUIDELINES

The guidelines presented here for incorporating logotypes, lettering and ornamentation in a die cast part represent normal production practices at the most economic level. Fine detail in lettering and art styles can be achieved but may involve additional costs.

Engineering & Design: Additional Specification Guidelines

7 Die Cast Lettering and Ornamentation

Lettering, medallions, logotypes, trademarks and a range of identification symbols may be reproduced on the surfaces of die cast parts.

Such as-cast ornamentation may be raised or depressed, but note that raised lettering will result in lower die construction costs and reduced die maintenance over the life of the die.

Raised lettering on a depressed panel can be an economical substitute for depressed letters, as shown in the illustration below.

Cast-in Lettering/Ornamentation Guidelines

In addition to the avoidance of depressed lettering or symbols in the casting surface, the following guidelines will achieve the most satisfactory results. The terms used refer to the illustrations below.

1. *The Line Thickness (or "face") of any letter to be clearly cast should be 0.010 in. (0.254 mm) or greater.*
2. *The Height (or raised dimension) of a cast letter or symbol should be equal to or less than the line thickness.*
3. *The Draft Angle should be greater than 10°.*
4. *Letters or symbols containing fine serifs or delicate lines cannot be expected to die cast cleanly.*

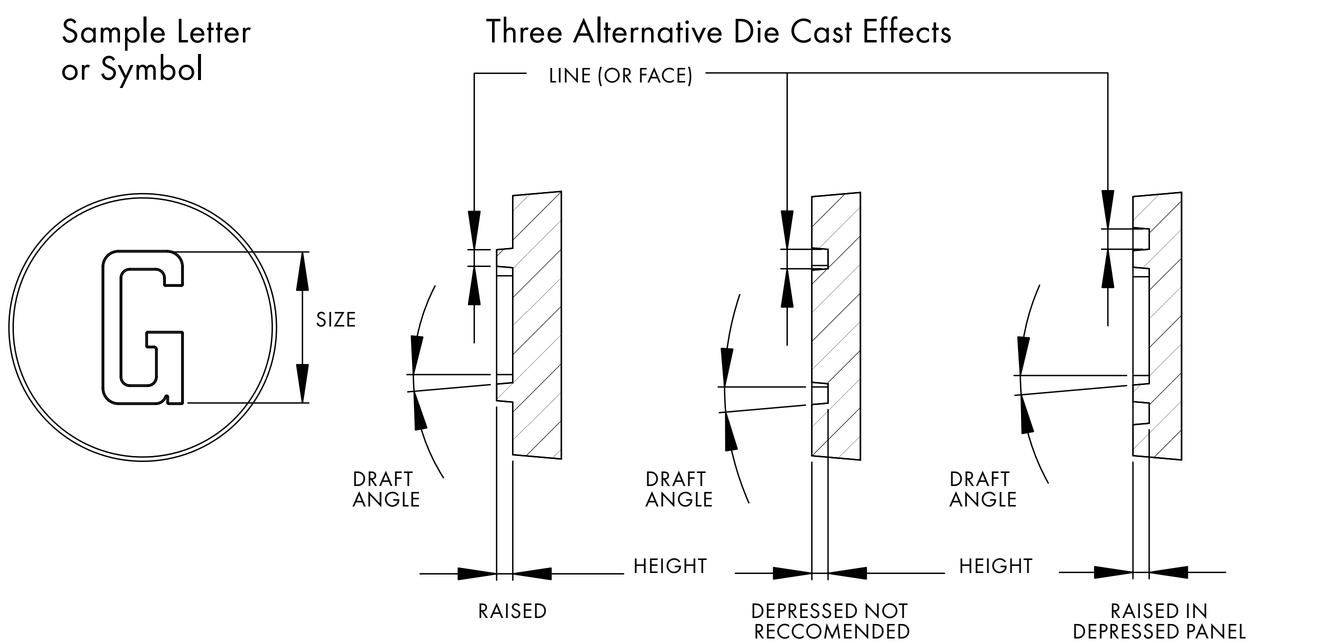

Fig. 1a Fig. 2a Fig. 2a

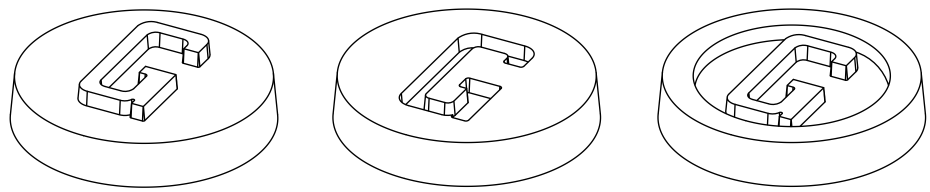

Fig. 1b Fig. 2b Fig. 2b

Quality Assurance

SECTION 7

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Quality Assurance

Frequently Asked Questions (FAQ)

1) Is there information available about porosity in a die casting?
   See pages 7-12 through 7-17 starting at Porosity.
2) What process variables affect the quality of die castings?
   See page 7-11, Process Variables.
3) Where can information on die casting defects be found?
   See page 7-7, Internal Defects.
4) When should CP or CPK be used?
   See page 7-12, Capability.
5) Is a simulation really necessary?
   See page 7-3, Simulation.
6) What are some typical images of porosity and/or breakout at parting lines?
   See pages 7-12 through 7-17, Porosity.
7) Can x-ray be used to view porosity?
   See page 7-16.

Introduction

Continuing advances in die cast processing and control technologies allow the specifier of die castings today to achieve very high levels of precision.

However, custom production requirements that are beyond readily manageable process capabilities can increase costs. It is therefore essential that the user of die castings discuss process capabilities with the die caster early to keep costs in line with expectations.

This section deals with the control of the variables in die casting production to achieve the specifications presented in the earlier Engineering and Design Sections. It is the aim of this section to clarify terminology and establish the criteria necessary to maintain acceptable product quality under normal die casting practice.

Communications by means of purchase orders, part drawings, CAD/CAM databases, corporate standards, manufacturing specifications, die casting industry standards and guidelines should all be used to clarify the job content. Working together to clearly define areas in doubt will obviously result in optimum service at lowest costs.

1 Balancing Process Capabilities With Product Requirements

The best opportunity to reduce costs and enhance quality lies in carefully specifying those characteristics that are clearly needed in the product, i.e., distinguishing between critical and less critical features. When the functional requirements have been clearly defined, the die caster can determine, in advance, the precise processing steps necessary to achieve them.

1.1 The Engineering/Quality Team

Developing the optimum set of product requirements consistent with process capabilities is best accomplished by forming a cross-functional engineering and quality team involving all parties who are concerned with the success of the product.

Often called a "concurrent engineering" or "simultaneous engineering" team, it should include representatives of design engineering, manufacturing engineering (from both the die caster and customer), quality assurance and marketing.[1]

If a formal cross-functional engineering team is not set up, an informal team of key personnel from both the customer and the die caster should be formed to meet several times during the product development process to address important questions.

1.2 Standard vs. Precision Tolerances

The die casting process can offer very high casting precision, as discussed under "Standard" and "Precision" Tolerances in "Engineering and Design," Section 4. Precision Tolerance levels should be specified only when product requirements justify the additional production steps that may be required. Otherwise industry Standard Tolerances should be used.

It is always advantageous, in terms of faster delivery and lower production costs, to avoid unnecessarily stringent tolerances and specifications.

1.3 Simulation

The term "Lean" is used to describe a manufacturing process. Lean is continually striving for perfection, continually declining costs, zero defects, zero inventories, and an increase in business. There are five major principles used in "Lean Thinking!"

- **Value**: Only the ultimate customer can determine value!
- **Value Stream**: All the actions and services required to bring a specific casting to market.
- **Flow**: Flow is a continuum from the order desk to the shipping dock. No stopping or storing!
- **Pull**: The customer can pull the product from the caster because of the quick turnaround time. Pulling is like turning on a switch for the desired product.
- **Perfection**: There is no end to the process of reducing effort, time, space, cost, and mistakes.

Lean employs five principles, but we will use two of those principles to highlight our improvement for Product Integrity. Value Stream is one of those concepts: "All the actions and services required to bring a specific casting or family of castings to market in a logical, timely sequence that promotes perfection. Perfection is an overriding principle for our premise of improvement: "Make sure we know exactly what the customer wants."

Software tools such as CAD/CAM, shot monitors, and simulation programs all assist the industry in optimizing the process. These tools are used in the industry in order to increase quality and efficiency. When NADCA metal flow principles are properly employed, it increases the probability for sample castings to be approved. When a shot monitor is employed, the engineering and process departments can easily determine whether the machine is achieving the simulated conditions. Finally, the use of simulation software can ensure proper placement of runners, gates, overflows, and venting/vacuum. Casting process simulation can also assist in cooling line design, process design, and stress and distortion analysis. It may take several simulation iterations to ensure and ideal design is created.

There are many automated features on the die cast machine, trim dies, and subsequent machining operations. If the mold is not producing an acceptable casting the speed created is not in the Perfection Mode of Lean Thinking.

For example, the following steps are used for a typical metal flow simulation:

- Engineering will create a 3-D model of the casting with runners and gates connected and export the file in an STL format for the simulation. A PQ^2 analysis will yield the desired fill time and optimum gate area. The gate depth and location can be determined for the simulation.
- A fast simulation, in the initial design stage can be made to ensure the position of inlets will yield the desired perfection. This is a critical stage to ensure the holder and mold will be oriented for machining. The neglect of this sequence in the value stream may result in welding and refashioning runners & gates, resulting in a time and material loss. If the gates have to be moved the result may result in a shortage of tool steel for the new gates. Emphasis must be placed on the proper sequence to avoid mistakes, rework and ultimate delays in the delivery of the mold. Perfection is a must at this step in the value stream.

Quality Assurance

Critical questions to ask at this critical stage are:

- Does the inlet gate satisfy the feeding of each cavity?
- Is the last place to fill well defined? (Figure 7-1)
- Are the overflows and/or vacuum lines in the last place to fill?
- Are there areas that may be porous or not filling properly? (Figure 7-2)
- Does it seem the gates are placed correctly? (Figure 7-3)
- Has a PQ^2 analysis determined gate size and filling speed? (Figure 7-4)
- Has the casting been checked for square corners or areas of difficult fill? (Figures 7-5)
- Will major changes have to be made to ensure perfection?
- If the simulation determines a change, the recommendations are put into a new model and STL for another iteration. If it seems the gate is adequate or a slight change is needed the mold can be aggressively machined.
- What are the casting quality requirements?
- What and where are the functional areas?

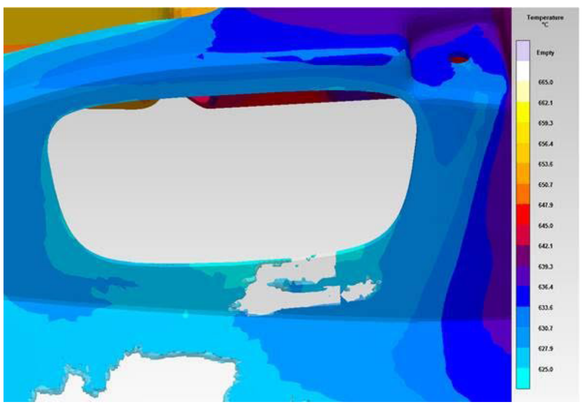


Figure 7-1: Temperature result showing splashing with the potential for cold shut and lamination

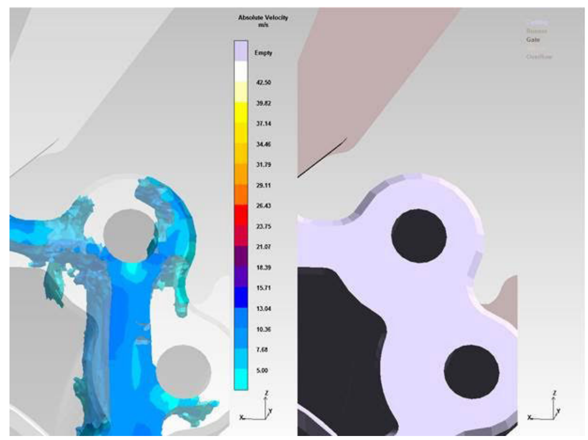


Figure 7-2: Velocity result showing challenges of filling bosses

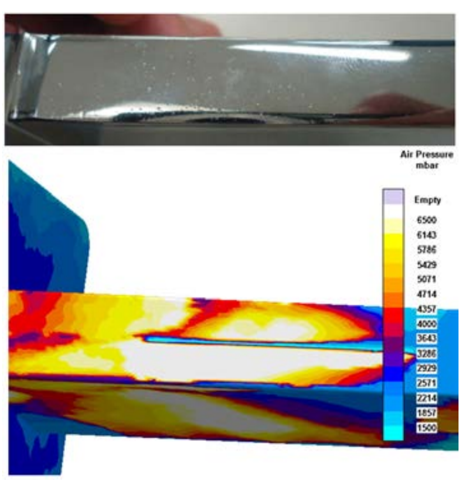


Figure 7-3: Air pressure in a casting correlating to outgassing on a cosmetic, plated casting

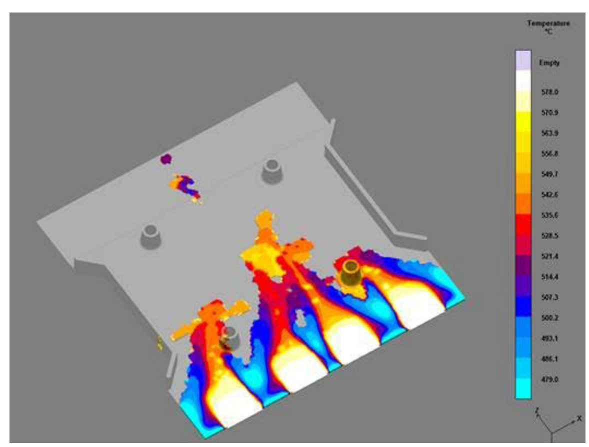


Figure 7-4: Filling pattern showing cold, solidifying metal potentially causing a flow defect

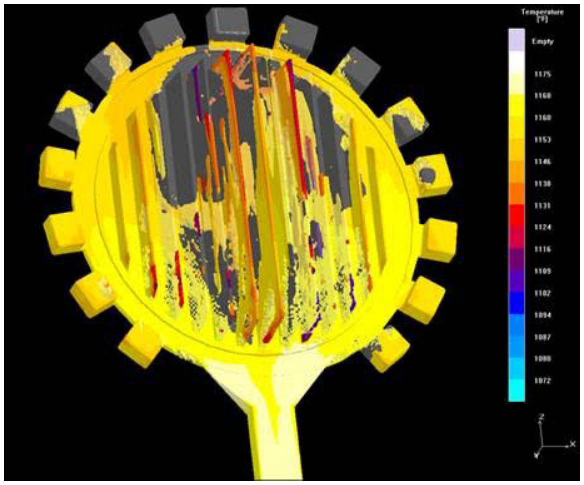


Figure 7-5: Filling pattern showing air pockets in the casting after all overflow and vents are blocked

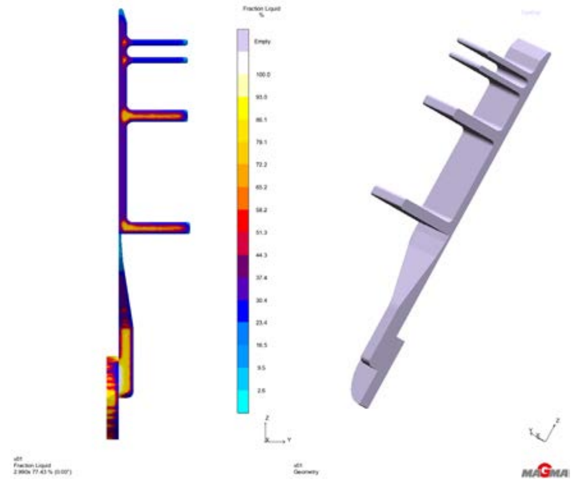


Figure 7-6: Fraction liquid of a casting showing the disconnection of the gate and intensification

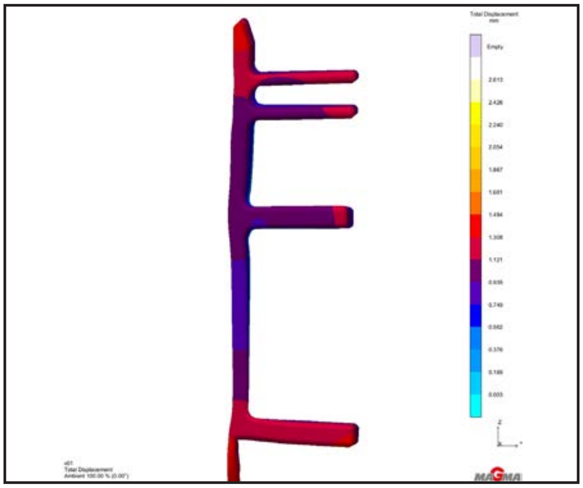


Figure 7-7: Total displacement showing casting shrinkage and distortion with a 25 times scale factor

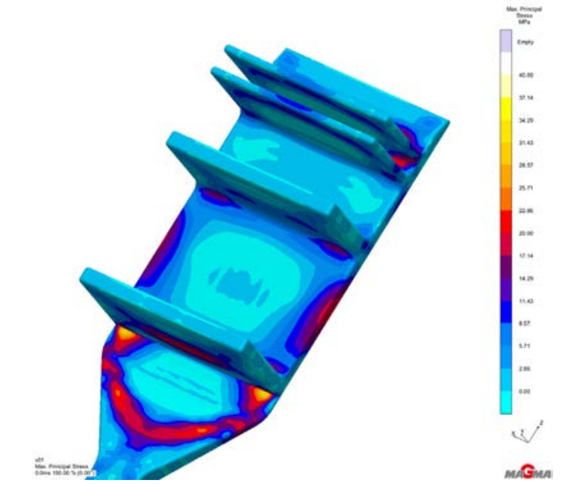


Figure 7-8: Example of the residual stresses on the casting after ejection and cooling to room temperature

Simulations can be used to optimize heat flow, determine the location of cooling lines and cooling requirements. Simulations can also be used to predict die distortion, casting ejection temperatures and dimensional capability, last place to fill, and areas of poor fill or non-fill, and pockets of porosity. They also indicate where the overflows should be placed as indicated by the last area of the casting to fill.

A time and cost saving for the entire supply chain is to have accurate information for the mold-maker to complete the mold building. Time and price increase when the project is delayed because of minute changes or uncertainty of design. The customer, caster, and mold maker must all be informed of the part design and specific areas of special concern. All questions must be answered so every party can be aggressive in executing their expertise. Then the project can mature in an orderly and speedy fashion.

FAQ Concerning Simulation:

What is the value or benefit of a simulation?

The simulation will give an accurate, graphic depiction of the filling process and will verify the suggested gating profile. Many times a runner and gate are cut only to find the results are not in the perfection mode of desirability. The simulation must be done prior to cutting steel.

Are the simulation results easy to understand or read?

It requires a skilled engineer or experienced person to explain the results. Any computer literate individual can create the simulation, but experience is required to understand the results.

Is the simulation cost effective?

If a caster or mold maker owns the software it can and should be used on every project. There are also consultants who will be cost effective in conducting a simulation. The process saves countless hours of die changes, welding and machining of gates to enhance flow. The relative small cost of the simulation saves time, money and increases the availability for increased business. The true reward for a proper value stream sequence is realized when the project goes into production as a result of careful planning and timely execution. All the members of the value stream make a profit and have capacity for increased business.

Finite Element and Finite Difference Methods

Both finite element and finite difference methods are used to numerically solve the partial differential equations that describe physical phenomena including heat transfer, fluid flow, stress, displacement, distortion and others. Both techniques require discretizing the object or spatial domain of analysis into a grid of nodes and applying numerical techniques to solve the problem of interest at these nodes. The main differences in the methods arise from differences in the solution techniques used.

Finite difference uses a grid of points, almost always uniform, and the derivatives present in the differential equations are approximated by differences constructed using neighboring points, hence the name. The problem is thereby reduced to a set of simultaneous equations that are solved iteratively. Because the grid is uniform, finite difference grids may not perfectly follow the surface of the object and may have a stair step like appearance. Newer grid generation procedures minimize these effects but not all finite difference-based programs support them.

Finite element also discretizes the space into a grid, but it is not necessarily uniform. Instead the spatial domain of the analysis is decomposed into discrete elements. The elements generally are polyhedra either with 6 rectangular sides and 8 corner nodes (brick elements) or four triangular sides and 4 corner nodes (tetrahedral elements). Accurate tetrahedral meshes are easily created by automatic meshing programs. Because of the meshing procedure FE meshes provide excellent surface fidelity.

Finite element methods solve the differential equations by using an approximate solution defined within the element in terms of the solution value at the nodes. Neighboring elements share nodes and the solution much match at these nodes leading to a set of simultaneous equations that must be solved consistent with specified boundary condition. Each element has so called fitting functions that are used to interpolate the solution within the elements and, because the element contains the approximate solution, different element types are required for each type of problem to be solved. That is, even with the same geometry and mesh, different elements are used for heat transfer and stress analysis for example. Finite elements will always have nodes at the corners and may have nodes at the center of each edge and at the center of the element depending on the element type and the solution approximation technique that is used. Even with the extra nodes, finite element meshes generally contain a smaller number of nodes than a finite difference grid for the same problem.

In principle either technique can be used to solve the differential equations of any of the common engineering problems although finite difference tends to the method of choice for fluid dynamics problems (such as metal flow analysis) and finite element for stress and deflection. Both methods handle heat flow equally well. For either type of system, there can be wide differences in the implementation of a particular type of solution across vendors. Also, for both special and general purpose packages, not all will have the ability to address nonlinearities such as contact and movement between components of the system (e.g., contact between the die and the machine platen or contact between the casting and cavity wall). The quality of the solution depends more on the quality of the implementation than on the method.

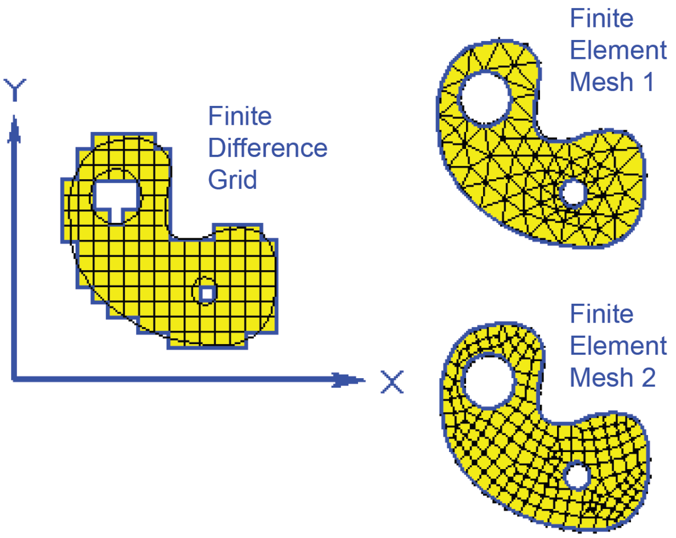


Figure 7-9: 2D illustration of the difference between finite difference and finite element meshes.

2 Defining Product Quality

The definition of product quality is fitness for end use. The definition will vary from design to design and usually varies for different areas of the same part.

The designer should expect to commit sufficient time and resources with the custom die caster, in the preliminary design stages before final drawings are completed, to determine what constitutes casting defects, and to precisely define acceptable product quality. This critical step will reduce rejections and rework, promote smooth operations between the die caster and the customer's design and procurement staff and increase successful results.

The checklists C-8-1 and C-8-2, which appear at the end of Commercial Practices, Section 8, should be used in specifying quality requirements.

It is rarely, if ever, practical to eliminate all casting discontinuities. Any attempt at total elimination will usually increase the cost of the casting unnecessarily.

There are two general types of discontinuities: internal and external. Internal defects can affect the structure of the casting, and may or may not be visible on the surface.

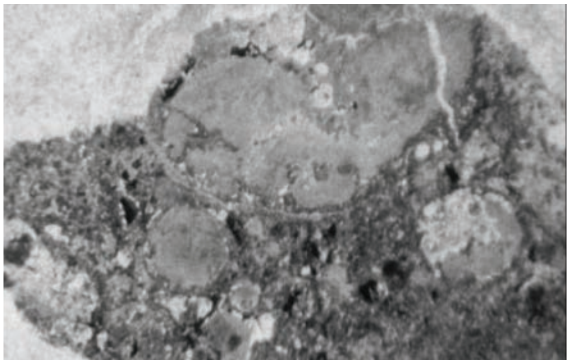


Figure 7-10: Magnified view of a non-metallic inclusion as an example of an internal defect other than porosity.

2.1 Internal Defects

Porosity is the most common type of internal defect (see page 7-14 Internal Porosity). In many cases internal porosity will have little or no effect on the overall strength and integrity of a casting.

Where pressure tightness for a gas or liquid application is not a requirement, a mechanical strength test (by a standard weight drop or torque wrench application) per an agreed upon sampling plan can be a cost-effective approach to quality assurance for casting strength.

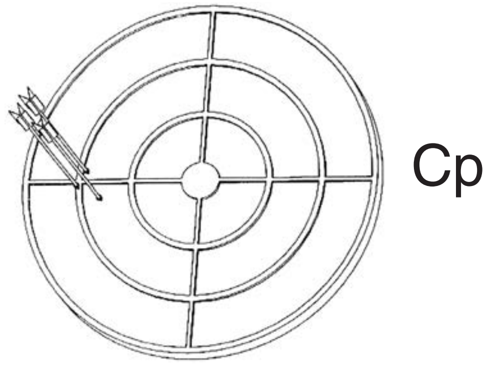


Figure 7-11: Cp is the raw capability index or in simpler terms = repeatability.

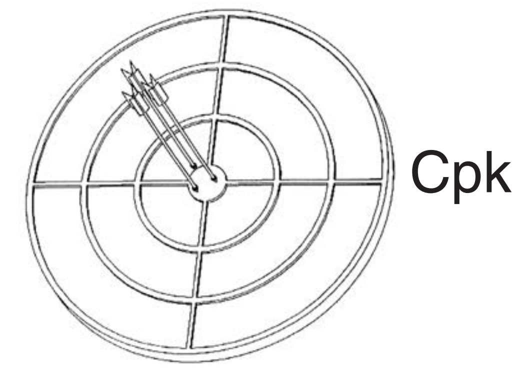


Figure 7-12: Cpk is the Total Process Capability or = accuracy and repeatability.

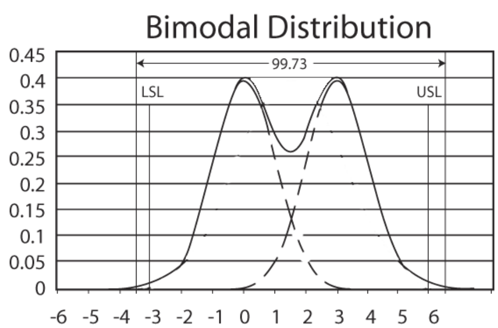


Figure 7-13: Cp can be applied to a bimodal distribution that allows for migration from one side of the tolerance range to the other. The higher the Cp number the more repeatable the process is.

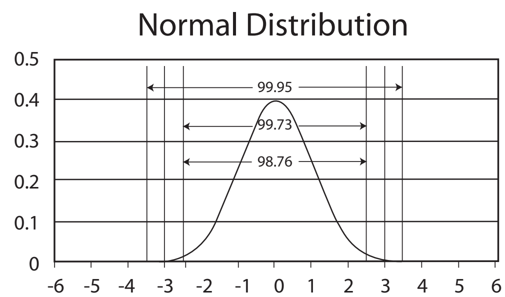


Figure 7-14: CPK indicates a normal distribution that allows within the distribution the maximum allowance of plus/minus tolerance that yields the greatest number of good parts in production. The higher the CPK number the more repeatable and accurate the process is.

2.2 External Defects

External, or surface defects, do not generally affect the structure of the casting. Surface defects are especially sensitive to the particular design of gates and runners in the die casting die. Calculated design parameters using proven metal flow design and process simulation techniques have been shown to be very effective.

The type and severity of external defect that can be accepted depends greatly on the type of final surface treatment to be applied. For example, a powder coating application deposits a relatively thick coat compared with painting systems, and will tolerate greater levels of surface roughness. Bright plating, such as chrome or brass, requires a very smooth surface finish.

Surface finish standards for die castings are normally developed on a part-by-part basis between the producer and the user.

It is important that the final finish acceptance standards developed be understood and agreed upon by all parties, with reference to a specific viewing standard such as “no objectionable imperfections, as specified, when viewed under normal lighting conditions at XX feet viewing distance.” This can be addressed on checklist C-8-2, in Section 8, checklist item Q.

Reference sample standards should be retained by all parties after agreement on the acceptable standard.

Some common types of surface defects that may occur in production over time are cold shuts (knit lines), swirls (surface roughness), build-up (die lube or soldering accumulation) and heat checking (very small raised fins on parts). See Guideline G-6-6 Surface Finish, As-Cast on page 6-8 for more details.

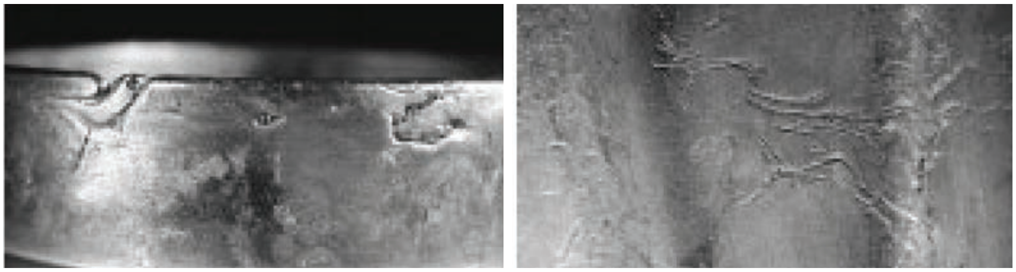


Figure 7-15: Examples of external defects.

Heat checking occurs during the life of a die when small cracks appear in the die due to thermal cycling. They sometimes cause concern on structural features because they appear, to the untrained eye, as cracks on a part. However, they do not affect the structural integrity of the casting, and are not generally objectionable on structural features that do not have cosmetic requirements.

Raised fins are routinely removed by surface blasting with shot or grit, or by vibratory finishing (which is normally the procedure used to prepare the surface for painting). How external defects are to be removed or eliminated depends on the type of surface finish required, whether painted, plated, or functional. The method to be used should always be discussed with the die caster. For more information on die casting defects see NADCA publication #E-515 Die Casting Defects – Causes and Solutions.

3 Drawings and Specifications

To insure uninterrupted production to specifications at the most economical level, it is important to supply all drawings and specifications to the die caster with the "Request for Quotation" (RFQ).

For correlation purposes, it is necessary that the drawings and specifications contain the following information:

1. *Dimensions or areas that are of critical, major or minor importance, and the Acceptance Quality Level (AQL) or Parts-Per-Million (PPM) level to which they will be checked, including the dimensions for which the customer will be requesting control charts.*
2. *Datum locations to be used for machining or gaging and the areas to be used for special checking*
3. *The gaging procedures the customer intends to follow and the special gages that will be furnished.*
4. *Special requirements and the areas to which they pertain.*
5. *Coded surfaces on parts to be plated, painted, etc., designating classification of surfaces.*
6. *Indication as to where die trimmed edges are not acceptable and specification of degree of metal extension removal required (See "Metal Extension," G-6-5, in Section 6).*
7. *Indication of any engineering change level requirements by purchase orders and accompanying drawings.*
8. *Specification of those surfaces which may not be used for location of the ejector pins.*
9. *A list of generic print tolerances which will adequately describe all the non-critical areas on the print.*
10. *Clear description of all standards for approval or rejection.*

Providing detailed and complete specifications at the time of the RFQ will benefit both the customer and the supplier. It will enable the die caster to submit more accurate, competitive quotes and help assure that the customer will receive quality die castings at the most economical level.

4 Gage, Measurement and Testing Equipment

Proper gaging equipment must be provided for effective measurement of product conformance. The customer is expected to furnish special-purpose gages which are required for inspection of specific die castings.

Special gaging requirements should be stated and the responsibility for maintenance of special gages should be established on the RFQ and on subsequent contracts between the die caster and customer. Gaging labor, when applicable, is included in the price quoted for the die casting.

When special gaging fixtures are necessary, they should be made in duplicate by the customer and one set furnished to the die caster. The customer should also furnish complete inspection methods and gage design information to the die caster at the time of the request for quotation. A gage and measurement instrument calibration system, with records maintained by the die caster, will assure consistent measurement control.

It is also suggested that gage Reproducibility and Repeatability (R & R) studies be done on all customer-supplied special gages. Further, it is recommended that all gaging sets be qualified by both the customer and die caster.

The responsibility for any preventative maintenance to be performed on customer-owned gaging should be made clear.

5 First Article Inspection Requirements (FAIR)

Whether the die caster or the customer is to perform the inspection of initial samples produced from a die casting die should be decided at the time the purchase order is issued.

When the inspection of initial samples is completed by the die caster, a report of the findings will be submitted to the customer. This is frequently referred to as a First Article Inspection Report (FAIR). Unless otherwise specified, first piece samples are supplied for dimensional check only. (Inspection of initial samples by the die caster may result in added cost.)

At the customer's request, the die caster will be responsible, after the inspection of initial samples, for correction of tooling for out-of-specification part dimensions before the start of production.

The customer should change the print for those dimensions for which tooling correction is not required in order to agree with the initial samples report. The general print tolerance will apply to the changed dimensions as noted, unless there is agreement to a new tolerance. Any automotive or other industry requirements such as preproduction approval pieces (PPAP) should also be known at the time of quoting. See figure 7-20 on an example PPAP flow chart.

In the event a print change will not be made, the customer should furnish an inspection report specifying those dimensions or tooling corrections which are not required. Any dimension not requested to be corrected or changed on the print is considered a valid dimension with normal tolerances, after the start of production, for the life of the tool.

The customer must acknowledge part acceptance by a formal letter before production is run. Such acknowledgment indicates either conformance to print or acceptance of a permanent deviation from specifications. The general print tolerances will apply to any deviations. Any die castings received by the customer which conform to the approved sample dimensions will be considered acceptable product.

If capability studies are to be done at the time of first-piece inspection, or in place of first piece inspection, this requirement should be specified at the time of the RFQ. Any automotive or other industry requirement such as Pre-Production Approval Process (PPAP) should be known at the time of quoting.

6 Statistical Quality Control

To assure uniform quality control standards acceptable sampling procedures and tables for inspection by attributes, such as ANSI/ASQC Z1.4, should be used.

Characteristics to be inspected for product conformity should be agreed upon by the customer and supplier prior to the first production run.

The classification of particular characteristics and AQL or PPM levels should be determined at the time the contract is negotiated. Classification of defects (critical, major, minor) should be in accordance with the latest revision of the acceptable sampling procedures to be utilized.

Normal inspection, as per ANSI/ASQC Z1.4 for instance, should be used.

Sampling plans to be used by the die caster will be left to the discretion of the individual die caster, recognizing, however, the responsibility to meet the agreed upon AQL or PPM levels.

6.1 SPC Procedures

Where the current revision of ANSI/ASQC Z1.4 is not desired or appropriate, a negotiated standard of sampling and acceptance should be established prior to die design, with early determination of SPC recording. Any requirement for process potential data or process capability studies should also be outlined at that time.

Dimensions and/or parameters requiring SPC data and Cp and Cpk values should be agreed upon by the customer and die caster prior to the first production run. This should include types of SPC charts, subgroup size, and sampling frequencies.

Determination must be made prior to production as to all specific SPC reporting requirements, data maintenance and its transmission. The die caster should be expected to point out to the customer the impact on Cpk values when cast die features are built on the "steel safe" or "wear safe" side of nominal, to allow the tooling maximum tool life and wear towards nominal dimensions.

6.2 Process Variables

There are five process variables that affect the quality of the die casting:

1. *Metal analysis*
2. *Metal temperature*
3. *Die temperature*
4. *Die lubricant characteristics*
5. *Die filling conditions*

In general, die casting is a setup-dominant process that exhibits variation of a serial, rather than random, nature. Of the five variables only No. 5, "die filling conditions," exhibits the "continuous drift" variation that the traditional X bar-R control charts were conceived to monitor.

Variables 2 and 3, metal and die temperature fluctuations, exhibit more of "cyclic drift" and are thus not well suited for periodic inspection associated with traditional SPC. A continuous monitoring system is better suited to measure the variability of temperature-related process variables. Monitoring within part variation will document significant temperature differences that can occur.

Variable 5, die filling conditions, consists of the elements of the shot profile that shot monitoring equipment can monitor and measure. Capability studies can be used to establish the range in the shot profile that the process will produce in casting production. More often than not, changes in the shot profile due to random, constant-cause conditions are minimal compared with the non-random conditions that are traceable to machine maintenance requirements.

Any special production requirements should be reviewed early with the die caster. Not all die casters may be able to apply SPC to machine parameters and may have to monitor the process, or the results of the process, through a less sophisticated method.

6.3 Capability

Capability studies have become increasingly more popular in the last several years. In the past, SPC and capability studies were tools used mainly by machine houses, but more and more die casters are being required to do them to qualify the die cast tooling. Capability studies can be very important in determining process ranges as well as helping to determine PPM levels. However, misuse of Cp vs. Cpk can take away much needed process variation and tool life in the die casting operation.

Due to the pressures used in the die cast process, several variables can come into play. These include parting line separation, mismatch at the parting line, core slide blow back and core slide shift or a combination of the above. Normally, dimensions that are affected by these conditions are built into the die cast die on the low side of the tolerance range. These dimensions should be considered as a plus side tolerance dimensions only.

In addition, the die cast process can be very abrasive on the die surface causing rapid tooling wear. Part features that are affected by this wear are normally built on the high side of the tolerance range. These dimensions should be considered as a minus side tolerance dimension only.

$$Cp = \frac{(USL-LSL)}{(6 \times \sigma)}$$

$$Cpk = \frac{(X-LSL)}{(3 \times \sigma)} \qquad Cpk = \frac{(USL-X)}{(3 \times \sigma)}$$

On as-cast features Cp should be used as the primary measurement if the dimension targeted is in tolerance and on the right side of the tolerance range. For example a cast hole dimensioned at 2.000 +/- 0.010 (50.8mm +/- 0.25mm) checks 2.008 with a Cp index of 6.0 and a Cpk of +0.85, should be considered a good dimension to yield maximum tool life and process repeatability.

On cored hole locations and machined features Cpk should be used as the primary measurement. For example a machined hole dimensioned at 2.000 +/- 0.010 (50.8mm +/- 0.25mm) checks 2.008 with a Cp index of 6.0 and a Cpk of +0.85, should be considered as bad and the size adjusted to get closer to 2.000.

6.4 PPM Levels

PPM goals and requirements are becoming increasingly popular in the procurement of die castings and die cast assemblies. Since the part complexity, customer requirements and level of processing contribute to the reject level, a threshold PPM level is not specified by NADCA.

Process capability studies may be used to assist in predicting PPM levels for specific castings, secondary processes, and/or assemblies. Ultimately, the PPM goal or requirement should be as agreed upon between the die caster and customer.

7 Porosity

It is usually necessary to address porosity when specifying die castings. While porosity specifications are very difficult to define generically, there are existing guidelines that provide a good starting point.

Solidification begins at the surface of die castings and progresses to the center generating two distinct zones in each wall section, as shown in Figure 7-16. The skin, which has finer grain structure, begins at each surface and extends inward to a typical thickness of .015 to .020 in. (.38 to .50 mm). This area is usually free of porosity compared to the center of the section. The porosity is located between the skins in the core. The finer grain structure and absence of porosity give the skin superior mechanical properties. Skin thickness of a die casting is relatively constant and is not a function of total wall thickness; therefore, thin-wall sections can actually be stronger and more consistent than thick sections. The removal of the skin to a depth greater than .020 in. (.50mm) by secondary processes, such as machining, increases the chance of exposing porosity in the core as can be seen in Figure 7-17. These important points are not widely recognized by designers.

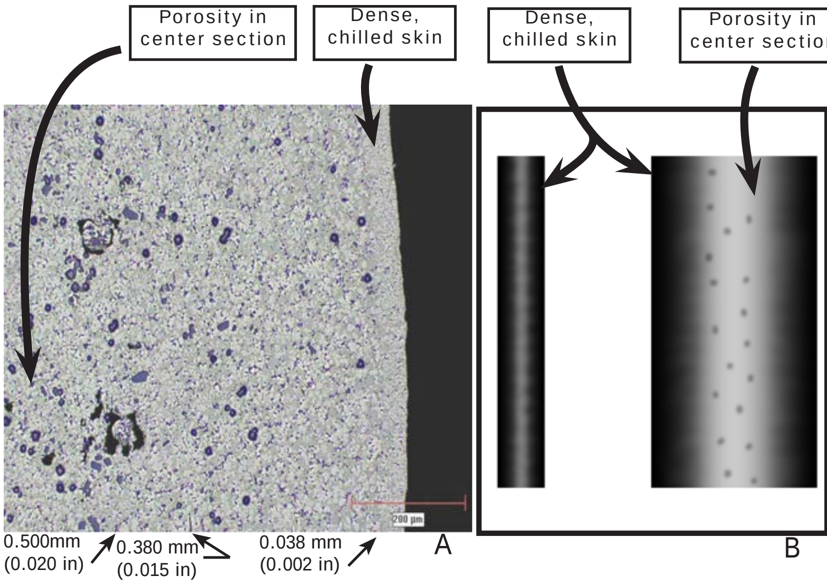


Figure 7-16: Skin Effect Due to rapid solidification in the die, a die castings outer skin has a dense, fine grained structure with a higher strength than underlying metal. According to Borland and Tsumagari (2007), the skin extends inward to a typical depth of 0.38 to 0.50mm (0.015 to 0.020"). The rapid solidification of the skin tends to drive porosity to the center of the section as portrayed here.

Exterior or surface porosity can be identified with the naked eye, magnification or with penetrant inspection methods.

The as-cast surface is more dense than the core, and hence, stock removal by machining should be minimized. The die caster should be aware of critical areas as porosity can be managed to large extent via gating, overflows, chills and various process parameters.

Castings can be inspected utilizing non-destructive inspection techniques NDT. When specified, reasonable detection levels should be employed. Non-destructive testing methods for internal porosity detection include ultrasound (UT), radiography/X-ray (film, real-time, ADR automatic defect recognition), eddy current (EC) and various weight techniques. Methods for external porosity detection include visible and fluorescent die penetrant (DPI).

If porosity is a major concern due to leakage/pressure tightness issues, the employment of a pressure test should be considered.

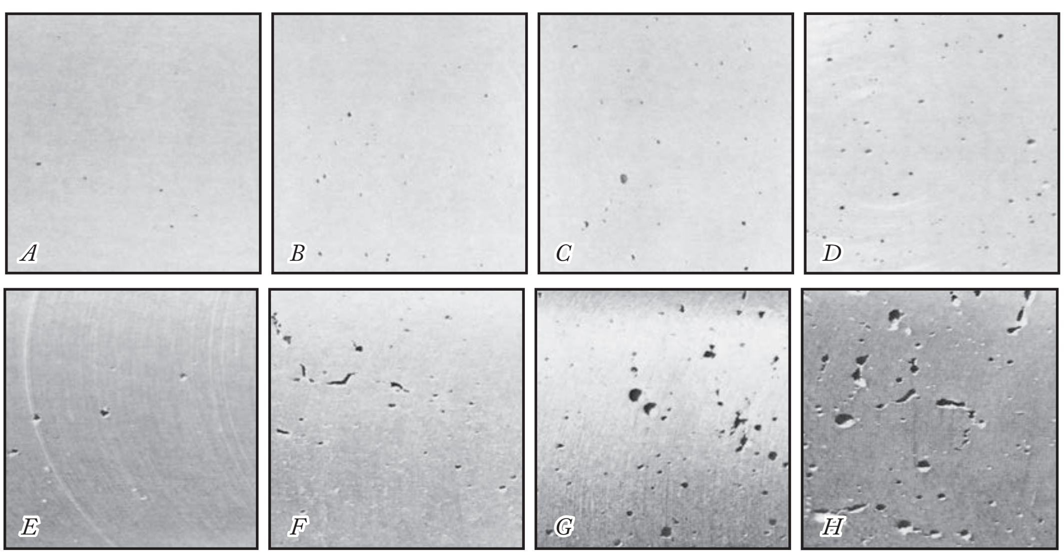


Figure 7-17: Various degrees of porosity exposed after machining.

Quality Assurance

7.1 Internal Porosity

Interior porosity can be detected by a range of techniques, including detection by fluoroscope, X-ray and ultrasonic procedures. Internal porosity can also be detected in the die casting plant through sectioning or simulated machining techniques, when the die caster is advised of the areas to be machined.

Part prints should call out the areas where only the lowest levels of pinpoint porosity can be tolerated, areas where additional porosity can be tolerated and areas where larger porosity will have no effect on the casting application.

Whether porosity levels are defined by "X-ray" or "sectioning" procedures, each party should retain a sample radiograph or part section that defines the minimum acceptance standard (see fig. 7-17).

It is important that the user not specify porosity limits that are more stringent than required for the application. It is also usually necessary to establish specific porosity standards independently for each component design. The specification of special porosity detection operations will increase the cost of the castings.

The type of porosity may be important in defining porosity standards. A small dispersion of smooth, round holes (salt and pepper generally less than 1mm in diameter), which are caused by release of disolved hydrogen or entrapped gas bubbles, may have a minimal effect on part strength and will not tend to cause leaks. Individual, non-grouped pores are generally less than 2mm in diameter. These types of gas porosity are those most commonly found in die casting. See figure 7-17A through 7-17E.

In critical areas of a casting. where porosity is a concern, the acceptable porosity is often specified in the following format:

1. *The maximum allowable size of individual porosity pores.*
2. *The minimum allowable spacing between pores.*
3. *The maximum allowable density of pores in a defined area (pores/distance2)*

For example a note based on this format may look like:
Porosity specification in crosshatched marked areas on print: 1mm maximum porosity pore size, 2mm minimum spacing between pores, maximum of 10 pores per 12mm^2.

More jagged-shaped shrinkage porosity, caused by solidification, can cause more problems. This is typically a part design-related issue, and is caused by heavy sections in the casting. Shrink porosity can be interconnected and may result in leakers. The shrink porosity does not have to be visible to cause leakers and is often microscopic in nature. Shrinkage porosity, when exposed, can be larger than gas porosity. For instance, a typical specification for a large drilled and tapped boss is < 2 mm on the first three threads, < 5 mm on other threads. See figures 7-17F through 7-17H and 7-17C, as well, as subsection 7.

Minimizing porosity begins with up-front planning in the design of the part and die casting die and the management of heat in both the die and the castings. Sophisticated process control and monitoring equipment as well as simulation software is best utilized for castings with stringent porosity requirements.

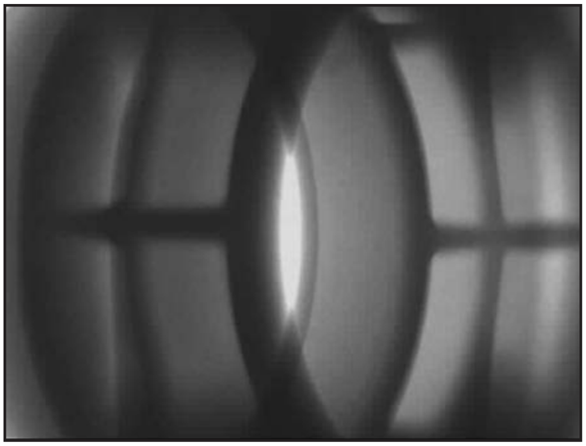


Figure 7-18A: Example radiograph of a casting with no visible porosity revealed by radiography. This level of soundness is achievable through consultation with your die caster and good part design, process design and process monitoring.

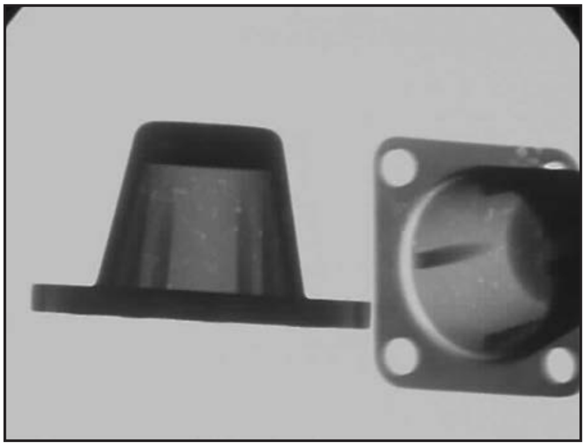


Figure 7-18B: Example radiograph of porosity that does not impact part form, fit or function. The user should be agreeable to accepting a specified amount of porosity in areas of the casting where it does not impact form, fit, or function.

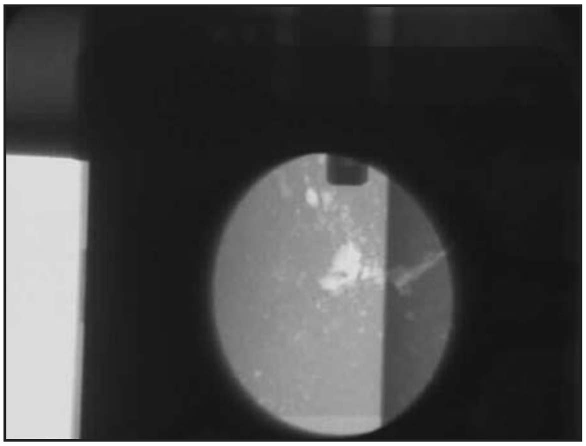


Figure 7-18C: Example radiograph of shrinkage in a thick cross-section.

If specific porosity will be detrimental to the use of the product being cast, the die caster must be informed of the areas that will require special control to reduce the incidence of such porosity. This information must be supplied in detail at the time of the RFQ, so that measures such as part design change requests, accountability for higher scrap or utilization of special processes, can be taken in advance of die design and construction.

Since zero porosity is virtually impossible to achieve in a die casting, the size, nature and location of permissible porosity should be identified by the customer, with the agreement of the die caster. The user should be agreeable to accepting a specified amount of porosity in areas of the casting where it does not impact form, fit or function. See figure 7-17.

Note: ASTM Nondestructive Testing Standard E505 provides reference radiographs for inspection of aluminum and magnesium die castings.

7.2 Parting-Line Porosity

It should be noted that some parting-line porosity may exist in some die castings. Whenever possible, castings should be designed to avoid parting lines on complex functional or cosmetic surfaces. Special measures will need to be taken when this cannot be done, such as adding changes in the parting line, adding a CAM-type movement or a hand-removal operation to blend surfaces. Parting line porosity should not be confused with parting line break-out (see figures 7-15A & B).

8 Pressure-Tight Castings

Pressure tightness (leakage) requirements for components add to die design and casting costs and should not be specified unless required for the application.

When a pressure-tight die casting is desired, the customer should specify at the time of quotation the pressure the die casting is expected to withstand and the relevant testing method to be employed.

Common leak testing methods for die castings include pressurized air bubble testing (to discover the location of the leak), gas pressure decay and mass flow testing (to determine the magnitude of the casting leakage in pressure loss or flow rate per unit time), and helium detection probe (when very low leak rates are required).

When the die casting is expected to withstand specified pressures, the die caster can offer pressure testing of a statistical sample of parts, 100% sampling or impregnating of parts to meet the pressure specification.

If machining of the pressure-tight die casting is required, it must be recognized that impregnation may be required after machining. The die caster should be advised of the specific areas to be machined in advance of the die design.

The die caster will not be responsible for machining, impregnating or testing costs if the machining is done by the customer. By mutual agreement, the die caster may accept for replacement or credit the die castings that have failed the pressure test after the machining and impregnation process.

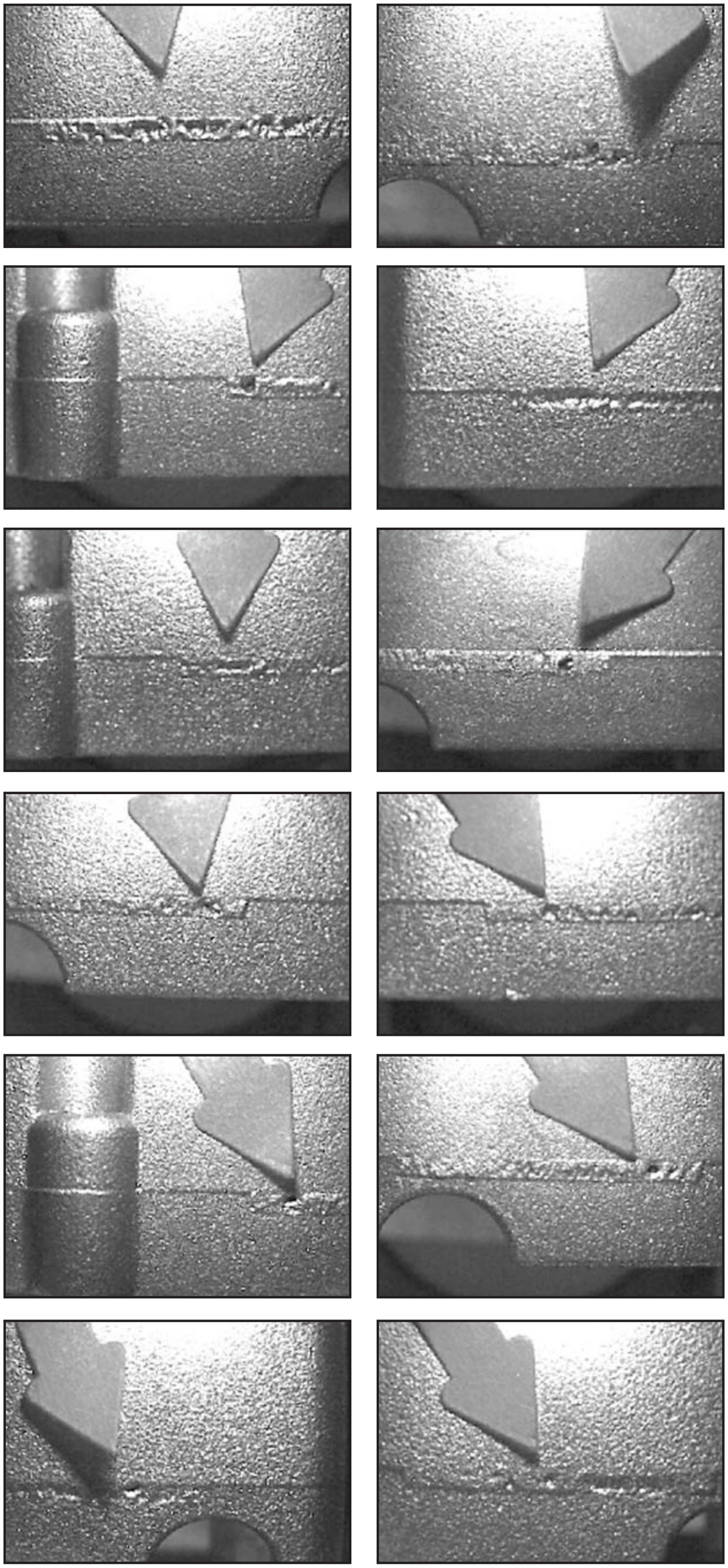
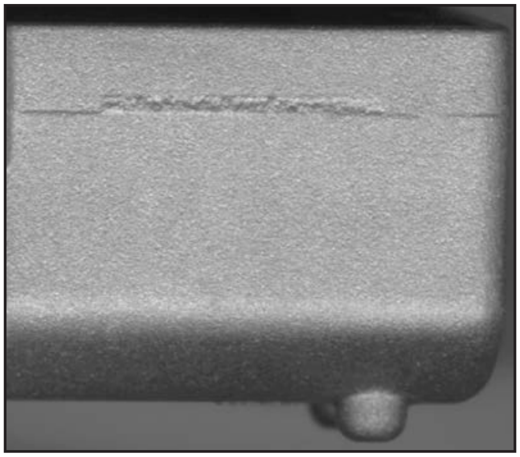
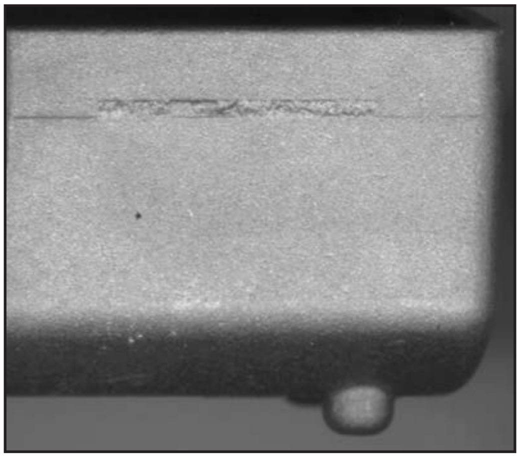


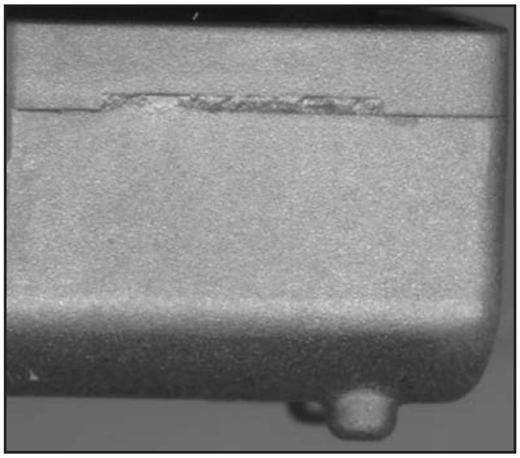
Figure 7-19A: Parting line porosity at various severity levels.



Minor



Moderate



Major

Figure 7-19B: Parting Line Break-Out placed into 3 groups.

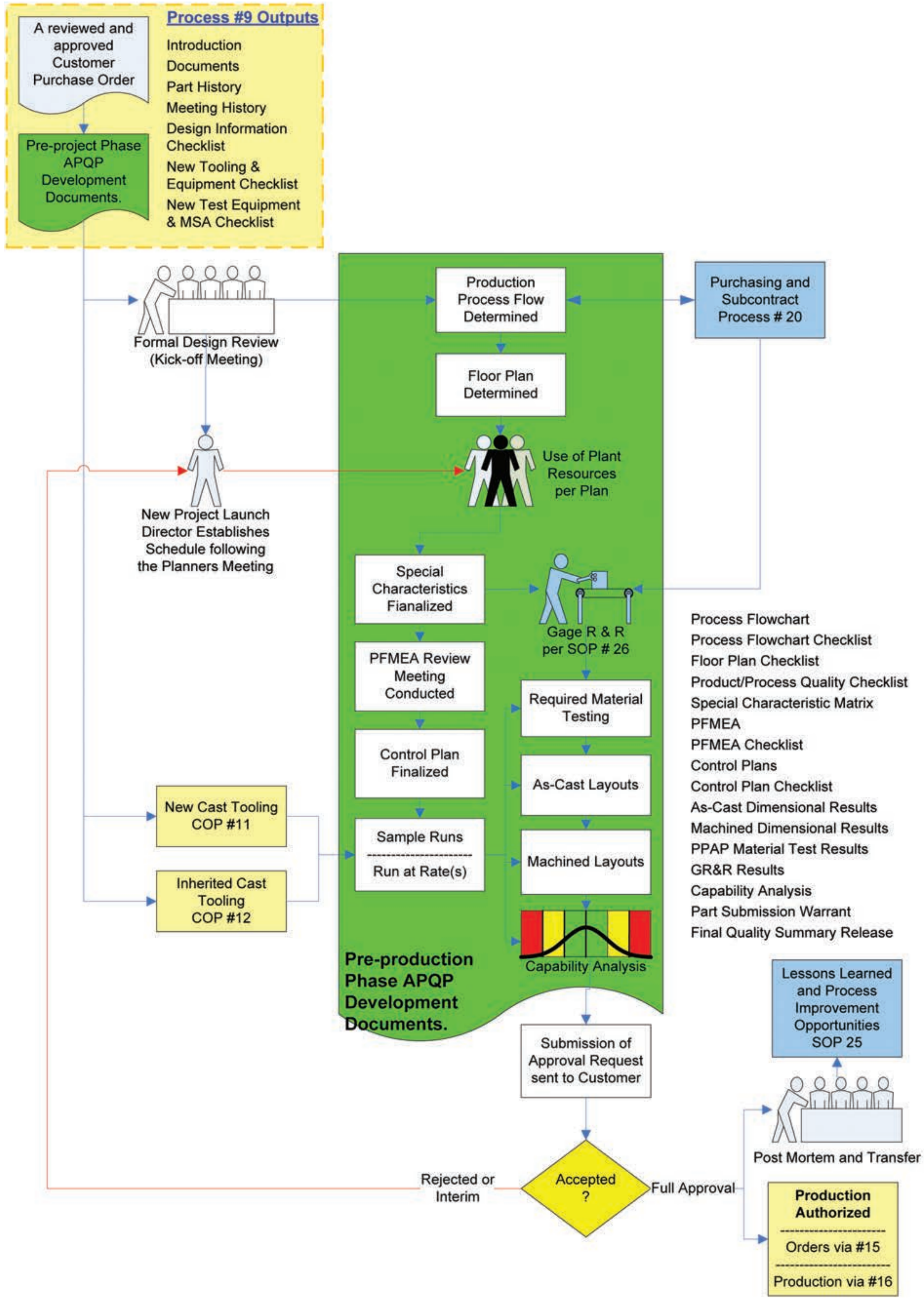


Figure 7-20: Example Advanced Product Quality Planning process flow chart.

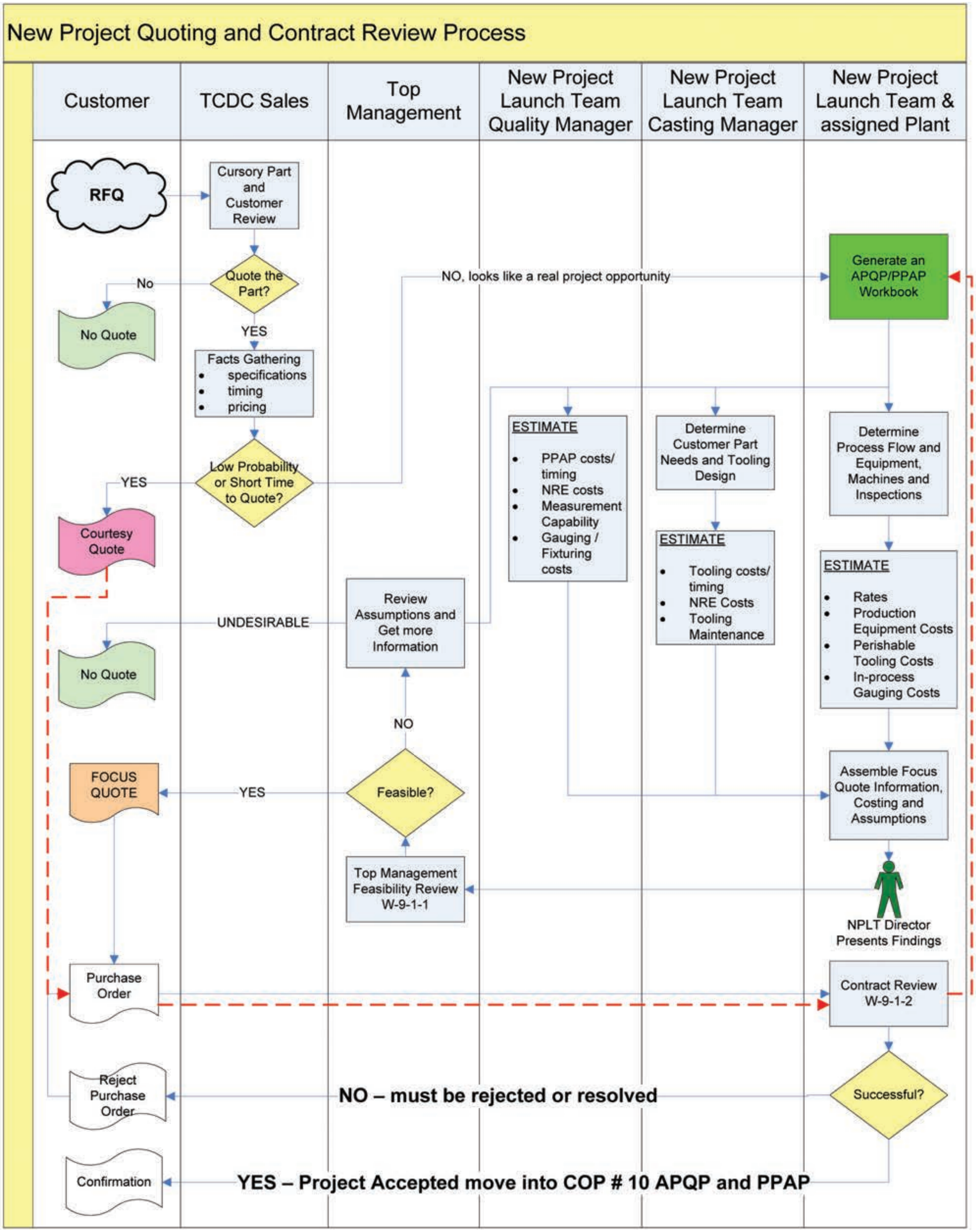


Figure 7-21: Example New Project process flow chart.

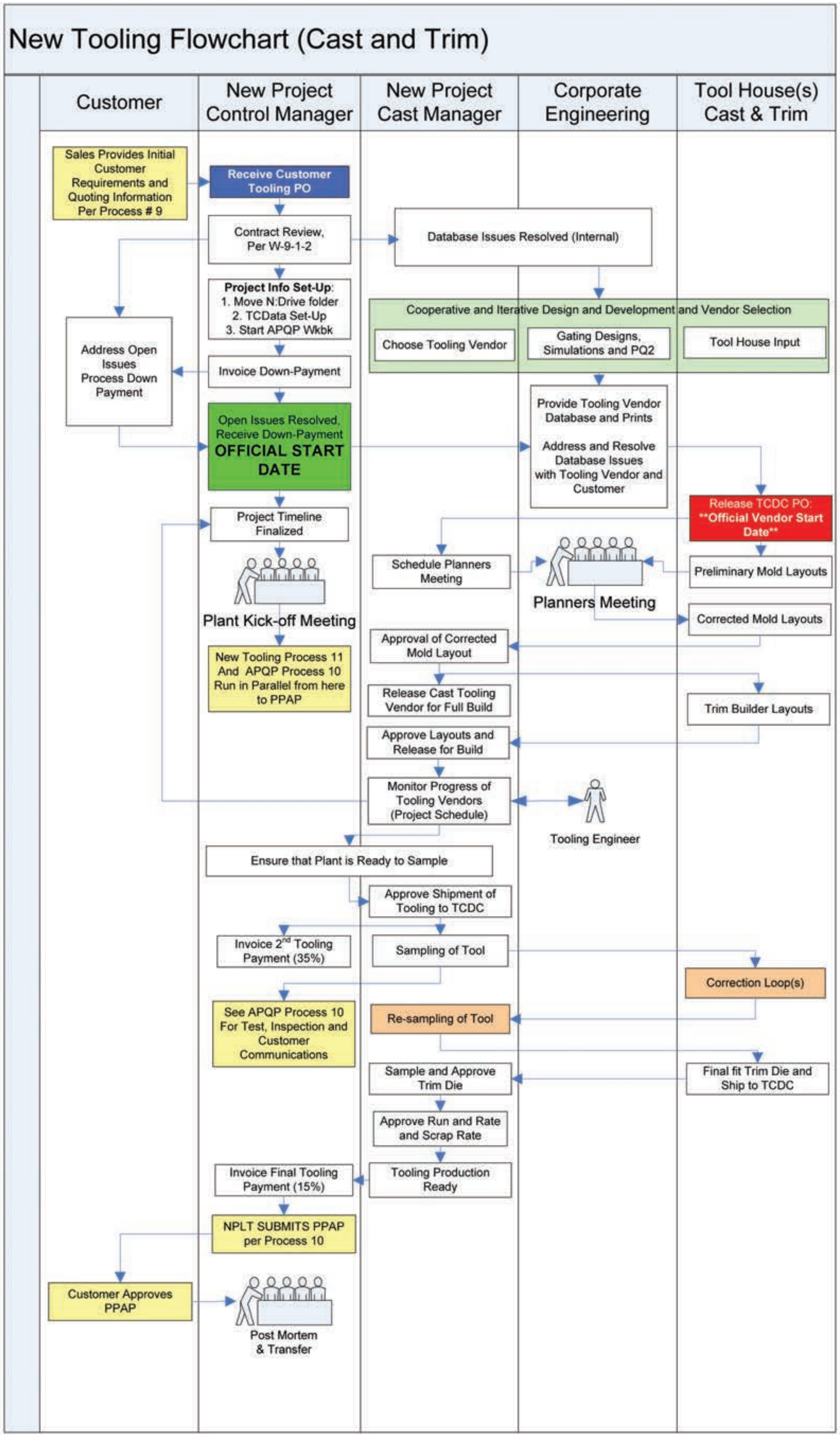


Figure 7-22: Example New Tooling processes flow chart.

Commercial Practices

SECTION 8

8

Commercial Practices

Frequently Asked Questions (FAQ)

1) Who owns the die cast die?
   See page 8-4, Die Ownership.
2) Are there checklists available that can be used for cast or finished specifications?
   See pages 8-14 and 8-15 for checklists.
3) How long do dies last?
   See page 8-5 and 8-6, Die Life, Maintenance, Repair and Replacement.
4) Are there any recommendations for creating CAD data files?
   See page 8-3, General Database Guidelines.
5) What is involved with die maintenance/repair/replacement?
   See page 8-5 and 8-6, Die Life, Maintenance, Repair and Replacement.

1 Introduction

In specifying die cast production, the purchase contract can be viewed as the purchase of a comprehensive engineering service from the die caster who will use the purchaser's tool to convert metal to the precise form desired by the purchaser.

The die caster will usually provide other important services, such as designing, constructing or maintaining the tool and performing machining and surface finishing operations on die cast parts. Sub-assembly services may also be provided.

The proposal and subsequent order for die castings sets forth a contract embodying the business practices governing a transaction in which custom engineered parts will be supplied on a continuing basis. Quality production of a high volume of custom parts, at the most economic level, involves a thorough understanding of the variables of the die casting process, its tooling requirements and related trimming, secondary machining and finishing operations.

The physical properties and constants of metals and alloys used for die castings are set forth in Alloy Data (Section 3 of this volume) and should be referred to with other accepted metallurgical specifications.

Aid in determining the detailed part design requirements to be specified for cost-effective production can be obtained from the Engineering and Design standards and guidelines in this volume (Sections 4, 5 and 6), together with other recognized engineering data. If geometric dimensioning is not being used on part prints, GD&T (discussed in relation to die cast parts in Section 5) is strongly recommended for optimizing quality and lowest costs.

Tooling (Section 2) and Quality Assurance (Section 7) should likewise be reviewed well before drawing up final product specifications.

Of equal importance to careful specification are the commercial arrangements which affect the buying of die castings. These trade customs have evolved from industry-wide production experience and have generally been accepted as good business practice. The commercial arrangements are normally found in the proposal and acknowledgement forms used by the North American die casting industry.

These specialized inter-relationships, among others, govern the ability of the custom producer to supply die castings to specifications on prearranged quantity schedules at competitive levels on a continuing basis. They are described in this section together with convenient die casting product specification checklists.

2 Using Die Casting Specification Checklists

The C-8-1 Checklist (Die Cast Product Specifications) and C-8-2 Checklist (Die Cast Surface Finishing Specifications), which appear at the end of this section, can help the purchaser to more clearly define the die casting requirements that will impact final costs. They can serve as a production guide to help provide accurate communication between the purchaser and the die caster, avoiding misunderstandings later. The die caster should review these specification levels with the purchaser to assure that the most cost-effective level is selected and, if necessary, provide samples of various specification levels.

2.1 Defining Quality Requirements

The checklists also mention the use of SPC and other inspection requirements. It is highly desirable to define such requirements so there is no question about record-keeping responsibilities. While most die casters use these techniques regularly, some purchasers have special requirements (ie. critical features) that must be defined early in the process.

When using statistical techniques for quality control, it is important for the purchaser to specify the parameters when requesting a price quotation. For example, general definitions of process capability, such as Cpk, can affect tooling dimensions that are built towards one side of the tolerance to allow for future die wear. These dimensions can vary in one direction only, as in the outside dimensions of a cavity (see "Moving Die Components" – Section 4). When applying general definitions in this situation, the tool will appear to be out of limits, while it is actually built to high quality standards for long life.

It is most important that agreement on procedures be reached prior to establishment of the quality standards. The costs for the quality level of a feature are calculated by the die caster during the quoting process, and any changes in standards at a later time may require a revision to the quotation.

Many of the specifications, such as the quality of a surface finish or the severity of internal porosity, are subjective. The methods of establishing subjective standards can vary considerably, but it is always beneficial to spend the effort required to define the standards as closely as possible.

One way of defining subjective standards is to define borderline acceptable and acceptable samples, which should be retained as "limit" samples by the customer and the die caster. In addition, it is desirable to have pictures or a complete written description of the defects that would cause rejection. Such provisions can be improved upon during the initial production phase.

2.2 Specifying Tolerances

It is well known that the die casting process can achieve very high dimensional precision. The Engineering & Design Tolerance Standards for coordinate dimensioning of parts to be die cast (Section 4) are presented at two levels: as Standard Tolerance and as Precision Tolerance specifications. Most die casters can improve on the Standard Tolerances, but a cost penalty in increased cycle times will often be the trade-off.

Tolerance improvements are most directly related to part shape. If tolerance requirements are clearly discussed in advance with the die caster, precision tolerances can often be maintained for a cast part with significant improvements in product performance and reduced secondary machining and finishing operations.

Machining processes should also be considered well before any order for the tooling is released. A careful evaluation of machining requirements can lead to a redesign for net-shape die casting or near-net-shape production, with a reduced number of operations or setups.

2.3 General Database Guidelines

Computer Aided Design (CAD) databases usually consist of a two-dimensional drawing (2-D) and a three-dimensional model (3-D). To expedite communications, the die caster and customer should be aware of each other's CAD software capabilities early on in the project. In the event that the die caster and customer do not utilize the same software packages, universal file formats can be used to communicate. Although there are many available, the most common formats are DXF or DWG (for 2-D drawings) and IGES or STEP (for 3-D models). Translation software is needed to convert files into the appropriate format.

When databases are utilized for quoting purposes, these general guidelines apply:

1. If only a 2-D drawing is provided, it should contain dimensions and general views of the part and major features. Physical properties such as mass and part volume should be included as well.

2. If only a 3-D model is provided, the die caster should be able to retrieve dimensions and properties from the model.
3. Secondary operations, such as machining, can be included in the database or supplied separately.

Some general requirements when databases are being utilized for tool construction:

1. When only a 2-D drawing is provided:
   1.1. Drawing should contain complete dimensions of all features.
   1.2. Parting line, draft, radii, datums and tolerance (dimensional and geometric) requirements should be clearly defined.
   1.3. Secondary operations that are to be performed on the part and other requirements should be clearly stated.
2. When only a 3-D model is provided:
   2.1. All necessary draft, parting line and radii should be included in the model. Ideally the 3-D model will indicate machined surfaces.
   2.2. Lines and surfaces of the model should be connected within 0.001".
   2.3. The 3-D model should be accompanied by a limited dimension part print that contains all tolerancing information and shows any secondary machining to be performed.

An incomplete database could result in an inaccurate quote and possibly require considerable database manipulation, which leads to additional cost and extended lead-time. The die caster and customer should also indicate whether the 2-D drawing or the 3-D model controls the project.

3 Die Casting Dies and Production Tooling

Any die casting can be produced in a number of different ways and every die casting plant possesses different equipment and utilizes a range of production techniques. Optimum economy and maximum efficiency for the production of any die casting, therefore, must be considered in the light of the particular equipment with which it will be produced. The experience, technology, skill and ingenuity of the die caster are all involved in selecting the method of production on which the proposal is based.

Each die caster sells die casting dies, trim dies and specialized production tooling on its own individual terms and conditions. Normally, these terms provide for an advance payment for dies with the balance paid upon receipt of, or approval of, a sample produced from the dies and tools. Length of time for approving parts to be 30 days if not otherwise agreed upon between die caster and customer.

3.1 Die Ownership

Generally, the purchaser of die castings will retain ownership of the die casting die, even though the die remains with the die caster. It has also been the custom that the design and construction of the die casting die are performed by the die caster to its own specifications, even though the purchaser owns the die. The custom generally works to everyone's advantage.

The practice has developed because most purchasers lack the extensive experience and expertise required to design and build a die casting die that will produce acceptable castings. There are also a number of features of the die that need to precisely match the die casting machine selected by the die caster.

These die construction and ownership practices are generally being maintained today, although other options are available for the purchaser. The increasing technical capacity of designers is making it possible for a knowledgeable purchaser to contract for the design and construction of a die from a tooling vendor, then select a die caster to run the tool. However, this procedure can potentially create a number of serious conflicts with the eventual die caster. For example, if the castings are of low quality, who is responsible? The problem could stem from die design, die construction or production operations.

Consequently it is preferable for the die caster to be responsible for die design and construction. In addition to eliminating questions of responsibility, this procedure also ensures that the die will match the casting equipment. In addition, the die caster has a vested interest in building a high-quality die that will give few problems in production.

Commercial Practices

The die casting die, usually owned by the purchaser, is housed and maintained at the die caster. The die caster will be responsible for loss or damage to the die and tooling while housed at the die caster's facility. Some die casters offer the option of joint ownership of the die. In either case, there are some considerations that should be addressed during the purchasing discussions.

An ownership record should be established by both parties, which will include a description of the die and all additional components of the die. Each die should have a method of identification, which is best done with engraving (tags can come off). Typically a number is assigned to the die by the die caster, which is engraved on the die, slides and cores and included in the purchaser's record of the die.

All components purchased originally with the die should be noted in the record, such as shot sleeves or extra slides or cores. These components usually wear out much more rapidly than the rest of the die and they may be worn out and unavailable if the die is claimed by the purchaser.

The question of Tool Ownership as well as Replacement is often overlooked when general discussion begins at the start of a possible new project. Since there are multiple types of tools available for the die cast process the following descriptions for tooling and ownership is to provide a starting point for those decisions.

New tools are generally paid for by the Customer, the Die Caster is responsible for normal maintenance and care (as the caretaker), the customer (as the owner) for major component replacement, full die replacement, major repairs and refurbishment. It is the responsibility of the die caster to inform the customer of any atypical maintenance or care required. If the customer elects not to follow the maintenance advice of the die caster the quality of the part could suffer. In the following cases an example will be given as to typically who owns what portion of the tool.

1) Rapid Tooled projects frequently use a tool (mold base) that is owned by the die caster and becomes a type of Universal Holder for Die Cavity inserts (for multiple customers). The inserts that are used to make the part configuration are owned by the customer and frequently will have a shorter tool life than Production made tooling.
2) For Unit Dies, the Master or Universal Holder (as above) is usually owned by the Die Caster and the individual units and their inserts are owned by the Customer. As long as a Unit Die is the equivalent of an Industry standard it should be able to move to a new die caster if needed without major cost factors involved.
3) Dies by themselves are owned by the Customer and may have different shot life attached to them based on part design and function.

Replacement is sometimes limited to the cavity inserts but could be the entire die. The die caster is generally expected to monitor the tool condition and notify the customer that the replacement or repair may be needed so that enough time is allowed to get the replacement funds approved and to allow the tooling components to be approved before the original tool wears out. Sometimes, however, it is not possible to fully predict when a tool may need to be replaced. This can be paid for at the time of construction of the replacement or in cases of a very high volume part an amortization account may have been set-up. This type of account allows for a small amount to be added to the part price that will cover the cost of the replacement when needed. It becomes the Die Caster's responsibility to manage tool replacement and to notify the Customer when new replacements are submitted for approval.

Tooling Amortization must be started at the time of the fist part being produced for sale so that the account can cover the cost of replacement start and the balance due at approval. If it is not started at this time the tool may have to be pushed beyond normal life to pay for a new tool and to not interrupt Customer production. This usually results in added operations to the part which can increase costs. This process does not work with inherited tooling because of questions concerning actual shot count on the tool but can be applied after the first replacement is completed. Either the Customer or the Die Caster can be holder of the amortized funds for replacement but usage terms need to be clearly defined.

The Die Caster and the Customer need to agree on both the initial tool and replacement plans (as needed) and payment terms at the start of the project so that on-going needs are met and ownership is clear.

3.2 Die Life

The purchaser should be aware that the life of a die can be unpredictable. Die life is a function of many factors. Among them are part design, part configuration in the die, part quality expectations, release quantity, type of tool steel used for the die, the heat treatment of the die and the type of alloy being die cast.

Even when the die caster makes every effort to extend die life, early failure is still possible. It is also possible for a die to have an unpredicted very long life. An understanding of expected die life should be discussed in the initial phases of a project.

Progressive die casters can provide tool steel specifications and heat treat specifications that have been developed through extensive NADCA research programs. It is recommended that the purchaser reference these specifications for the building and heat treating of the casting die. The specifications include recommendations for stress relief during machining, the removal of the "white layer" after EDM operations and a number of other considerations.

When tooling is procured through a reputable die caster, tooling costs may be somewhat higher than if a purchaser dealt directly with the tool builder. The die caster will be closely involved in evaluations and decisions that will translate the product design into the optimum die casting die for successful production. The increased costs almost always represent a bargain in terms of overall costs during the life of the die.

An inexperienced purchaser who purchases tooling purely on a cost basis will find that the costs over the life of a die are significantly higher because of a lower-quality tool, although this will not be immediately apparent when the tool starts running. It cannot be emphasized too strongly that good quality tooling will cost more in the beginning but pay for itself many times over in the life of a typical die casting die.

3.2.1 Die Maintenance, Repair and Replacement

The responsibility and criteria for maintaining tooling, on the one hand, and replacing the tooling, on the other, should be understood. In some cases, the die replacement cost is requested to be amortized into the piece price. The most common way of structuring this portion of the contract is for the die caster to provide minor maintenance, and the purchaser to provide major repair and replacement.

Minor maintenance is generally described as "run-to-run" maintenance of a serviceable die to maintain die casting production. Major maintenance would cover the replacement or rebuilding of an entire die cavity, die section, or complex core slide that makes up a significant percentage of the casting detail, tool steel, the coatings applied to the die, or major die resurfacing or refurbishment. Most die casters have a preferred way of handling maintenance and it should be made clear.

The rapid wear components should be covered in the die maintenance understanding between the purchaser and the die caster. These components are frequently replaced by the die caster, although each purchaser should expect to make an individual agreement for each casting. If the components are replaced by the die caster, ownership usually remains with the die caster, although this can vary for individual agreements.

The purchaser should review the die maintenance practices of the die caster and agree on the expected maintenance. For example, if the purchaser expects the die to be stress relieved after a certain number of shots, then the die caster should be aware of this requirement so that it can be included in the costs.

Die preheating practices, gating design and die temperature control are particularly important to long die life. Reviewing these practices may be difficult, but there are some steps a purchaser can take.

1. The purchaser should ascertain the die preheating practices of the die caster. The best results are achieved by preheating dies to a specified temperature, depending on the alloy being cast, before the first casting is made.
2. Smooth metal flow at the correct velocities from a carefully designed gate is important to reduce the die erosion at the gate, as well as having a significant effect on casting quality. Die erosion can be repaired by welding, but the onset of welding significantly reduces the ultimate life of the die.

Note: Computer software is available for flow simulation, thermal and distortion analysis.

3. The die caster should be able to discuss the use of good die design practices with the purchaser. A die caster using trial and error without calculations for gating will have many more problems with die erosion and part quality than one who uses calculation techniques developed by NADCA or other authorities.
4. Die temperature control, involving careful cooling line control and proper cooling line placement, will influence casting cycle time and have an important effect on casting quality. Working with a quality die caster assures the purchaser that all aspects of die design and construction follow practices that maximize production as well as die life.

3.3 Credit

The die caster generally reserves the right to change his terms of payment if a change in the customer's financial condition requires it. Such changes are usually requested in writing and, when necessary, may require the die caster to stop design and/or construction pending agreement.

3.4 Changes or Cancellations

If any changes are required by the purchaser to finished die casting dies or production tooling which deviate from the original print and/or model provided for the dies and tooling at the time of quotation, the die caster reserves the right to requote the quality, expected die life, cost and delivery of the tooling. Any changes to the order must be agreed to by the die caster, in writing.

The die caster will usually require some payment for cancelled orders. Payment is necessary to compensate the die caster for costs of work in process to the date of cancellation and commitments made by the die caster for purchases relating to the order.

3.5 Die Retention and Removal

It is customary for the die caster to retain control and possession of die casting dies and production tooling. Since the full cost of engineering, designing, obtaining, and maintaining the die casting dies and production tooling is not fully reflected in the charges to the purchaser for these items, an additional charge may be necessary for these unreimbursed costs if the die casting dies and production tooling are removed prematurely from the die caster's plant.

It is also customary to allow die casting dies and production tooling which have not been used for three consecutive years for production of die castings to be scrapped following proper notification to the purchaser by the die caster.

Rules for the accessibility of the die should be established. If the die is to be claimed by the purchaser, it should be available after notice has been provided, and all outstanding invoices due the die caster are paid in full.

3.6 Insurance

It is customary for the insurance of die casting dies and production tooling to be the responsibility of the purchaser, unless specifically agreed upon, in writing, to the contrary.

Die casters normally have liability insurance protection against fire and theft or vandalism. However, fire insurance usually excludes tools, which do not burn, except for the clean-up costs following a fire. Insurance should be reviewed in each case, and business interruption in case of fire may need to be considered. Die casters will provide worker's compensation insurance as required by law.

3.7 Gaging

Good gaging is critical to obtaining good quality parts, both during the process and at final acceptance, and can also help reduce part cost, especially if a casting is heavily machined. It is important that this aspect be discussed early in the project.

The die caster can be expected to furnish standard gages. The purchaser is expected to furnish any special gages needed in the inspection process, such as those required for determining conformance to feature and location specifications and any gages needed for functional or statistical requirements.

All gages and gaging methods should be agreed upon in advance by the purchaser and die caster, including any need for duplicate gages. This will aid in both part function and fit, in instances where the die casting will be mated or assembled with other parts not manufactured by the die caster.

3.8 First-Piece Acceptance

After the first die cast samples are received from a die casting die, the die caster or purchaser will usually be required to measure the samples and verify that they meet specifications. Modifications from the original print which have no effect on part function or appearance can be discussed at this time to ensure that high production rates can be maintained and premature die maintenance avoided.

Procedures for handling changes in the print specifications for the die casting should be agreed upon. Any costs and delivery delay incurred by such changes should be quoted by the die caster immediately after they are received. Authorization for the changes should be given by the purchaser in writing on each change order.

4 Die Cast Production Part Orders

The commercial terms of the contract items and conditions between the purchaser and the die caster for die cast part production are discussed below. Note that the trade customs outlined represent the historic and customary practices prevailing in the die casting industry. Contract forms of individual die casters will vary in some details. A model of terms and consitions can be found at www.diecastingdesign.org/terms/

4.1 Metal and Metal Pricing

Quality metal is the foundation for good castings. Even a chemical analysis does not fully define all the metal quality specifications that are necessary for good die casting. Low-cost, low-quality metal cannot be expected to meet all die casting requirements.

For example, when aluminum or magnesium alloy does not meet established criteria, machining may be more difficult or surface corrosion accelerated. When zinc alloy does not meet established criteria, mechanical properties will be progressively and seriously reduced in use with time.

Metal price is commonly established from quotations from an approved metal supplier, or based on known industry indicators such as the daily American Metal Market, the London Metal Exchange, Platts or other major markets. If the purchaser elects to use an industry indicator, he may forfeit the advantage of spot metal buys at lower than market price.

4.2 Acceptance of Orders & Reorders

4.2.1 Acceptance of Orders

Proposals for the production of die castings are prepared on the basis of the specifications and prints known at the time of estimating. Die casting proposals are, therefore, for immediate acceptance on the basis specified. Similarly, since orders are accepted on the basis of the requirements known at the time of the order, changes from the original proposal on which the order is based may result in the need for price adjustment for the parts. The die caster reserves the right to review all orders before acceptance.

The proposal, the order and its acceptance, signed by an authorized representative of the die caster, constitute the entire contract with the exception that, when any provisions of the order conflict with the proposal, the proposal and acceptance always prevail. Modifications, changes, additions, cancellations or suspensions of an order are not binding upon the die caster, unless accepted in writing by an authorized representative of the die caster and upon terms that will indemnify him against all loss.

4.2.2 Reorders

Reorders for die castings are covered by the same conditions as was the original order, provided no revised proposal and acceptance has intervened. Pricing of reorders will, of course, be affected by quantity, alloy, labor and other costs prevailing at the time the reorder is placed.

4.3 Changes, Cancellation and Errors

4.3.1 Changes or Cancellation

Any changes to the order deviating from the original basis upon which the order was accepted must be agreed to, in writing, by the die caster. These changes may result in the adjustment of prices. Changes could include, but are not restricted to, delivery dates, quantities, release dates, part prints, etc.

The die caster usually will require some payment for cancelled orders. Payment is necessary to compensate the die caster for costs of work in process to the date of cancellation and commitments made by the die caster for purchases relating to the order, including dedicated equipment specifically acquired for a cancelled project.

Any change to the delivery schedule or release dates beyond 90 days must be subject to negotiation between the die caster and the customer.

4.3.2 Errors

Clerical errors are, of course, subject to correction regardless of whether they favor the buyer or the seller and enforceable if discovered within a period of one year.

4.4 Credit, Payment Terms and Taxes

4.4.1 Credit

The die caster generally reserves the right to change terms of payment if changes in the customer's financial condition requires it. Such changes are usually requested in writing and, when necessary, may require the die caster to stop production or suspend shipment pending agreement.

4.4.2 Terms of Payment

Each die caster sells its products on its own individual terms and conditions. Shipments are generally FOB (or EXW) the city in which the die casting plant is located. Payment is normally net 30 days with provision for metal market and escalation clauses.

4.4.3 Taxes and Duties

Sales or use taxes, excise taxes, taxes on transportation, other direct taxes and applicible duties are the responsibility of the purchaser whether such taxes are federal, state or local.

4.5 Packaging and Delivery

4.5.1 Shipping Tolerances

Since the die caster cannot determine in advance the exact loss factor in a particular run, it is generally recognized that he may manufacture and ship 10% over or 10% under the number of die castings ordered or released. If no deviation is to be allowed, with pricing affected accordingly, this should be so specified in the purchasing agreement.

4.5.2 Packaging

Die castings are generally packed in bulk as the most suitable and economical method. Any special requirements, such as specifying layer packed, separated or cell-packed shipments, must be communicated to the die caster in the RFQ; otherwise a price change may be required later. If recyclable packaging is required, it should be carefully spelled out in the quoting phase. While this type of packaging can have a positive impact on pricing, it may increase up-front costs. The die caster and customer should discuss responsibilities associated with recyclable packaging.

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4.5.3 Deliveries

Unless otherwise specified, deliveries of die castings generally begin as soon as the die caster's schedules permit and, in the case of a new die, after approval of samples. Deliveries are made at a rate approximately equal to the capacity of the tools until orders are completed. The purchaser selects the method of delivery and, unless otherwise specified on the purchaser's order, the die caster will use his best judgement in routing the shipment and seeing that deliveries are effected as specified. Acceptance of the goods by the carrier shall constitute a delivery. Any charges in connection with postponement or cancellation of delivery are the responsibility of the purchaser. The purchaser will also be responsible for any additional costs of expedited or other special transportation as result of changes in delivery schedules not caused by die caster.

Penalties upon the die caster for delayed delivery, whatever the cause, are not normally acceptable unless agreed upon at the time the order is being placed.

Many die casters today can provide an electronic connection to high volume purchasers to facilitate placing orders, as well as provide bar coding. It is frequently desirable to anticipate emergencies and provide for backup tooling, a small amount of emergency inventory or some other way of addressing the catastrophic failure that can occur in any volume production process based on sophisticated tooling.

4.5.4 Lot Size versus Cost

Because of the cost of setup, die casting is usually a high-volume process where the cost of a small lot is significantly increased by setup costs. It is therefore imperative that lot sizes be considered in the discussions of the purchasing contract. Each die caster will have his own costs for setup, so the break-even point for minimum lot sizes will vary among die casters. Some purchasers use consignment inventory agreements to address the reality of die setup costs and tooling life factors that are adversely affected by the short runs.

Lot size should be considered in the early stages of determining the tooling requirements. For example, in some cases fewer cavities on a smaller die will result in lower tooling costs, lower setup costs and a smaller economical lot size. This may be more desirable even though the piece-price may be slightly higher.

If small lot sizes are required often, quick setup aids, such as quick-disconnects, can be built into the tooling. Advising the die caster of small lot requirements at the time of quotation will enable him to optimize the use of these aids.

It is desirable for the purchaser to take time to explore the options of economical lot size, costs of maintaining inventory and tooling options during the tooling quotation phase. Since there may be many options, it is suggested that the purchaser provide the die caster with those considerations that are important for the project and let the die caster propose several options. This will allow the die caster to maximize the efficiency of the equipment available in his plant and provide the most economical quote to the purchaser.

4.6 Limitations on Inspection Procedures

4.6.1 Prints and Approved Samples

Die castings may not be rejected because of variation from print dimensions if they are made to, and are unchanged from, approved samples with respect to dimensions, finish and analysis. When the purchaser has specified or approved the design, failure with regard to function or fitness for use shall be the purchaser's responsibility. If sample die castings have not been approved and conflicting models and prints have been submitted, the basis of acceptance shall be agreed to in writing.

4.6.2 Accuracy

Die castings may not be rejected if they vary from finished sizes or dimensions within limits agreed upon. Where a very close tolerance or particular dimensional accuracy is specified, the permissible variations shall be agreed upon before die work is begun. In the absence of applicable standards, tolerances will be subject to the commercial variations generally prevailing in the industry.

4.6.3 Inspection and Sampling Procedures

If specified and specifically acknowledged and agreed to by the die caster, die castings can be inspected on the basis of statistical quality control or other sampling procedures.

Use of statistical quality control standards and other related procedures require specific detailing by prior mutual agreement on all aspects involved.

4.7 Compliance with Laws

Die caster will comply with applicable laws, rules and regulations of the country where the casting is made. Die caster will provide customer with material safety data sheets and, upon request, provide other information reasonably required in order to comply with applicable laws.

5 Purchased Components

Innovation in the design of die castings and flexibility in the industry's manufacturing process have led to the use of purchased components for insertion or assembly by the die caster. The procurement and subsequent responsibilities for the delivery and quality of such components lies with the purchaser of the die casting unless otherwise agreed upon and included in the quote and the order. These components may be "insert cast" as an integral part of the die casting or may be assembled to the die casting in a separate operation.

5.1 Cast-in-Place Inserts

If the finished casting contains cast-in-place inserts, the responsibility of providing them to the proper specifications should be clearly defined. The design of the purchased component is the responsibility of the die casting purchaser and is subject to approval by the die caster. In many cases the clearances in the die will require that the insert tolerances be tighter than the purchaser would normally supply for the required end use. If the purchaser is supplying the inserts, provision must be made to ensure that all supplied inserts are within tolerance. An out-of-tolerance insert can seriously damage the die.

5.2 Inventory Costs

Regardless of who purchases an additional component, there must be consideration given for in-process spoilage and rejects. As a result, the quantities of purchased components will always exceed the number of die castings purchased. It is understood that there are costs associated with handling, storing, counting and inspecting of purchased components. Inventory of purchased components required to meet the die casting purchaser's delivery schedule are the responsibility of the die casting purchaser. The labor cost for inserting or assembling the component is normally included in the quoted piece price.

6 Price Adjustments

Because of the job-shop nature of production and the variation in product design and specifications, the prices for die castings are determined by the use of price estimating formulas.

Each die caster employs an individual pricing formula constructed in accordance with their individual methods and costs. All price estimating formulas contain a number of factors which may require adjustment, upward or downward, because of conditions beyond the control of the estimator. Significant unexpected increases in the cost of either natural gas and/or electricity may result in negotiated energy surcharges per mutual written agreement.

Commercial Practices

6.1 Quotations and Metal Market Pricing

6.1.1 Order Quotations

Order quotations for die cast products, and die casting dies and production tooling necessary to make the die cast products, are normally valid for a fixed period of time. After this time has expired, the die caster reserves the right to requote based upon price adjustment provisions as discussed above.

To establish a uniform basis of comparison, the estimated weight and monthly and/or yearly quantity requirements should be specified when soliciting quotations, and it should be requested that the material cost be itemized.

6.1.2 Metal Market Pricing

Prices for die castings are based on the die caster's prevailing cost for the alloy specified on the day the estimate is prepared. In some instances, the die caster's quotation may make reference to various published alloy prices or other indicators. The cost for the alloy is subject to fluctuation beyond the control of either the purchaser or the die caster and the actual price charged for the die casting will reflect the changes required to adjust for all metal market variations. Similar adjustments may be made on each release and/or reorder.

6.2 Labor and Operating Costs

6.2.1 Labor Costs

Many die casting dies are in production over extended periods, often over many years. For this reason, the piece-part labor cost may change over the life of the order. If piece-part labor costs change after the date of the original price estimate, it is generally necessary to change the piece-part price for future deliveries.

Customer schedules often are expanded and sometimes require production beyond the normal schedules of the die caster.

Since all die casting prices are estimated on the basis of production at straight-time rates, an adjustment is generally required if premium labor rates are necessary to meet the customer's expanded needs.

Die casting price estimates and quotations reflect labor costs based on continuous operation for the quantity specified for any delivery release. Reductions in scheduled deliveries or production interruptions by the customer, may affect labor and other piece part costs. In such cases, a price adjustment may be necessary.

6.2.2 Operating Costs

Costs of outside services (such as painting, plating and machining), or of purchased supplies and components (such as inserts, packing materials and fasteners), or action of governmental or regulatory agencies may cause periodic increases in the costs of manufacturing. These added costs must be reflected in changes to quoted prices. Also, changes in acceptance criteria by the customer may significantly affect the die caster's operating costs, making an adjustment to the part price necessary.

7 Patent Obligations

Die casting is essentially a conversion process by which metal shapes are produced for a purchaser. Therefore, if a die casting infringes, or is claimed to infringe on any letters patent or copyright, the purchaser must assume the responsibility involved.

While the die caster does provide input into the design of the customer's component for die casting manufacturing feasibility, the die caster is not responsible for the design or functionality of the customer's product or device or for the design of the die casting as part of such product or device. The purchaser of die castings is liable for his own product or device and for all patent infringement claims relating to it or any of its parts.

Die casting proposal and acknowledgment forms generally include clauses which provide that the die caster shall be indemnified and held harmless of and from all expenses arising from all such claims. When patents, design or otherwise, are involved, they should be specifically called to the attention of the die caster.

8 Intellectual Property

Die Caster is not required to provide any intellectual property used to produce parts for the purchaser. Purchaser has the right to use parts in purchaser's product.

9 Warranties Covering Die Castings

9.1 Extent of General Warranty

Die casters, like other responsible manufacturers, stand behind their product. However, it should be understood that the die caster in assuming this proper responsibility focuses its engineering efforts upon the die cast manufacturing feasibility of the component, rather than the component's product function which is the responsibility of the purchaser.

In general, die casters agree, at their option, to correct, replace or issue credit for, defective die castings, subject to specific limitations and exceptions. Reference NADCA Terms and Conditions for more details on warrenties.

9.2 Limitations on Warranty

9.2.1 Processing After Delivery

No warranty attaches to a die casting which has been altered, machined or finished after delivery to the purchaser by the die caster.

9.2.2 Reasonable Time

No claim for defective die castings will be recognized unless made in writing within 90 days (or as agreed upon between die caster and purchaser) after delivery.

9.2.3 Returns

Die castings claimed to be defective are not to be returned to the die caster without specific approval and inspection by the die caster. Returned goods accepted by the receiving department of the die caster are not exempted from the right of the die caster to inspect the die castings or to determine the extent, if any, of his liability.

9.2.4 General Limitations

Losses, damages or expenses arising from the use of a die casting, or labor costs or other charges incurred outside of the die caster's plant, or transportation costs, as well as losses due to other causes, are not acceptable basis for claims against die casters under the warranty provisions. The Warranty as stated in paragraph 8.1, above, is limited to the repair or replacement of defective die castings or the issuance of credit for their return as stated.

10 Product Liability

Die casters cannot be expected to have technical knowledge relating to the end product of the many industries they service. While they may freely offer design services to make a product easier to manufacture, at no time does this imply a knowledge of the strengths, stresses or other forces that may be induced in the product's end use. This must be exclusively the liability of the buyer and design suggestions are offered by the die casters with this understanding.

The die casting industry has always maintained the position that a die caster is not liable for the failure of a die casting in a buyer's product, if the part furnished to the buyer meets the prescribed specification.

Die casters accept the responsibility of manufacturing a part to the buyer's specifications within the agreed acceptance level. This means the buyer will accept a percentage of parts that do not conform to the specifications. Die casters cannot be held liable for any failure in the end product because of the decision on the part of the buyer to perform a limited incoming inspection or to forgo an incoming inspection altogether.

If a buyer approves a sample for production of parts that do not meet specification in any way, this approval constitutes a change in specification and the die caster's responsibility is then altered to only meet this altered specification.

It is anticipated that the buyer will indemnify and defend the die caster from any damages or claims arising from the use of die castings or other goods produced to the buyer's specifications.

11 Production and Finishing Specification Checklists

The C-8-1 Checklist (Die Cast Production Specifications) and C-8-2 Checklist (Die Cast Surface Finishing Specifications) appear on the following pages.

It is recommended that, prior to final quotations, and always before any die design commences, the casting requirements defined by these checklists be reviewed with the die caster, together with the specifications and procedures listed in Section 7, "Quality Assurance." All of these items impact final costs and should be thoroughly discussed to assure accurate communication between the purchaser and the die caster.

This checklist is for use in consultation with your die caster prior to estimating production costs. Use in combination with the Finishing Checklist C-8-2. Also review Checklists T-2-1A and T-2-1B, for Die Casting Die Specification, in Section 2.

Casting Production Specifications

To be used in consultation with your caster (Use in combination with Checklist C-8-2)*

Checklist for Die, SSM and Squeeze Casting Production Part Purchasing

This Production Checklist provides a convenient method for assuring important factors involved in purchasing cast parts are evaluated and clearly communicated between the purchaser and the caster.

It should be used as a supplement to the essential dimensional and alloy specifications detailed on part prints submitted for quotation, since the listed factors directly affect the basis on which the casting quotation is made. The checklist may be reproduced for this purpose. Your caster will clarify any item requiring further explanation.

This checklist provides a numbering system in which the lowest numbered description for each requirement can be met at the lowest production cost, as follows:

	No.	Cost Effect
☐	1	Most economical basis for production
☐	2	Involves additional work which may affect cost
☐	3	Additional work which may increase cost
☐	4	Special Requirements which may increase cost

Part # ___________________________

A	Casting Cleanliness	☐ 1 Some residue and chips not objectionable ☐ 2 Shop run — blown reasonably free of chips but not degreased ☐ 3 Clean, dry and free of chips ☐ 4 Special requirements ___________________
B	Cast Surface Finish	☐ 1 Mechanical quality — finish is not significant ☐ 2 Painting quality — streaks and chill areas coverable with paint ☐ 3 Highest quality — for electroplating, decorative finishing, O-ring seats
C	Metal Extension (Flash) Removal *Parting Line External Profile*	☐ 1 No die trimming — break off gates and overflows ☐ 2 Die trimmed to ___________________ of die casting surface *(See NADCA Guideline G-6-5)* ☐ 3 Hand filed or polished — flush with die casting's surface ☐ 4 Customer defined requirements (such as thermal, tumble or vibratory deburring, or shot or grit blasting)
D	Metal Extension (Flash) Removal *Cored Holes*	☐ 1 Flash not removed ☐ 2 Flash trimmed ___________________ of die casting surface ☐ 3 Flash to be machined or otherwise completely removed
E	Metal Extension (Flash) Removal *Ejector Pins*	☐ 1 Not removed *(See NADCA Guidelines G-6-4)* ☐ 2 Crushed or flattened *(See NADCA Guidelines G-6-4)* ☐ 3 Removed from specific locations ___________________
F	Pressure Tightness	☐ 1 No requirement ☐ 2 Pressure-tight to agreed-upon psi (kPa). Testing medium: ___________________ ☐ 3 Other arrangements to be agreed upon
G	Flatness	☐ 1 No requirement ☐ 2 To NADCA "Standard" specification tolerances (S-4-8) ☐ 3 Critical requirement — to NADCA "Precision" specification tolerances (P-4-8) ☐ 4 Customer defined requirements
H	Dimensions	☐ 1 Normal: per NADCA "Standard" specification tolerances ☐ 2 Semi-critical: "Precision" tolerances on specified dimensions, others "Standard" ☐ 3 Critical: Special tolerances to be agreed upon
I	Customer's Receiving Inspection	☐ 1 No unusual inspection requirements — no Statistical Quality Control ☐ 2 Statistical quality control: Acceptable at Cpk 1.33 or higher (or AQL over _________________) ☐ 3 Statistical quality control: Acceptable at Cpk 2.0 or higher (or AQL over _________________)
J	Packaging	☐ 1 Not critical — bulk packed ☐ 2 Layer packed, with separators, or weight restriction ☐ 3 Packed in cell-type separators or individually wrapped ☐ 4 Customer defined requirements ___________________ ___________________

** The specification provisions and procedures listed in Section 7, "Quality Assurance," should also be addressed.*

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Commercial Practices

CHECKLIST

This checklist is for use in consultation with your die caster prior to estimating production costs. Use in combination with the Finishing Checklist C-8-2. Also review Checklists T-2-1A and T-2-1B, for Die Casting Die Specification, in Section 2.

Casting Surface Finishing Specifications

To be used in consultation with your caster (Use in combination with Checklist C-8-1)*

Checklist for Finished Die, SSM and Squeeze Casting Part Purchasing

No. Cost Effect

- ☐ 1 Most economical basis for production
- ☐ 2 Involves additional work which may affect cost
- ☐ 3-4 Additional work which may increase cost
- ☐ 5 Most difficult surface to cast on a production basis

Part #______________________________

This Finishing Checklist provides a convenient method for assuring that important factors involved in the surface finishing of cast parts are evaluated and clearly communicated between the purchaser and the caster.

It should be used as a supplement to the essential dimensional and alloy specifications detailed on part prints submitted for quotation, since the listed factors directly affect the basis on which the casting quotation is made. The checklist may be reproduced for this purpose. Your caster will clarify any item requiring explanation.

This checklist provides a numbering system in which the lowest numbered description for each requirement can be met at the lowest production cost, as follows:

K	Casting Insert	☐ 1 No insert used in cast part ☐ 2 Inserts required, to be supplied by customer at 10% overage ☐ 3 Inserts required, to be supplied by caster
L	Parting Lines	☐ 1 Polishing not required ☐ 2 Polish only where marked on drawing ☐ 3 Polish all parting lines (except as noted)
M	Surface Preparation	☐ 1 No buffing required ☐ 2 Mechanical (burnishing, tumbling, etc.) Specify: ____________________ ☐ 3 Buff as indicated on drawing
N	Plating, Anodizing or Other Special Finish	☐ 1 Protective Only — Specify: ____________________ ☐ 2 Decorative Paint — Specify: ____________________ ☐ 3 Severe Exposure Protection — Specify: ____________________
O	Painting	☐ 1 Heavy Paint, Protective Only — Specify: ____________________ ☐ 2 Decorative Paint — Specify: ____________________ ☐ 3 Application requires base coat or special treatment: ____________________ Specify: ____________________
P	Environmental	☐ 1 Normal interior use only ☐ 2 Exposure to weather — Specify: ____________________ ☐ 3 Exposure to unusual chemistry — Specify: ____________________
Q	As-Cast Surface *See NADCA Guidelines G-6-6*	☐ 1 Utility Grade — surface imperfections acceptable, nondecorative coatings ☐ 2 Functional Grade — slight, removable surface imperfections, heavier coatings ☐ 3 Commercial Grade — removable imperfections ☐ 4 Consumer Grade — no objectionable imperfections, as agreed upon, when viewed under normal lighting conditions at ________________ feet viewing distance ☐ 5 Superior Grade — specified average surface finish value of ____________ microinches, per print
R	Special Requirements	For special flash removal requirements, see *Checklist* C-8-1, items C & *E* For special packaging/weight restrictions, see *Checklist* C-8-1, item *J*

** The specification provisions and procedures listed in Section 7, "Quality Assurance," should also be addressed.*

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High Vacuum, Squeeze and Semi-Solid Casting Examples

Section
9

Section Contents Page

High Vacuum Casting

Part Name:	Right/Left Hand Bracket
Application:	Automotive
Part Weight:	0.75 lbs.
Alloy:	Aural-2
Heat Treatment:	T5
Special Requirements:	–
New Part or Substitution:	Converted from low pressure permanent mold, which required extensive machining.
Customer:	BRP Skidoo

High Vacuum Casting

Part Name:	Engine Base Bracket
Application:	Automotive
Part Weight:	6.2 lbs.
Alloy:	ADC3SF
Heat Treatment:	–
Special Requirements:	High strength, low weight, net shape
New Part or Substitution:	Replaced stamped steel assembly (reduced components from 16 to 1 piece)
Customer:	Honda

High Vacuum Casting

Part Name:	Composite Engine Sub-Frame
Application:	Automotive
Part Weight:	13.5 lbs.
Alloy:	ADC3SF
Heat Treatment:	–
Special Requirements:	High strength, weldable
New Part or Substitution:	Replaced stamped steel assembly (reduced components from 48 to 16 pieces)
Customer:	Acura

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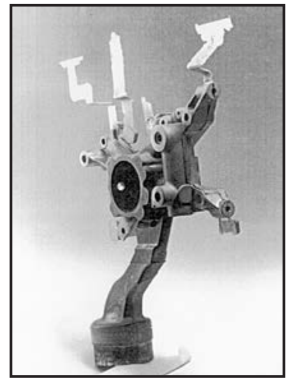
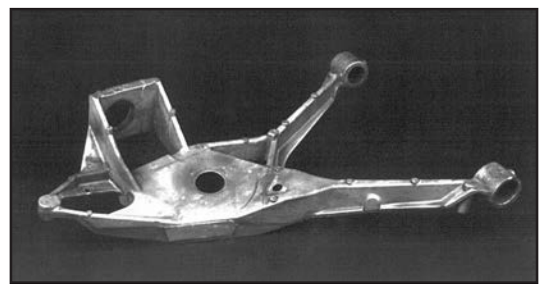
Squeeze Castings

Part Name: Oil Pump Housing
Application: —
Part Weight: —
Alloy: ADC-12(383)
Heat Treatment: —
Special Requirements: Pressure tightness, net shape
New Part or Substitution: —
Customer: Lexus



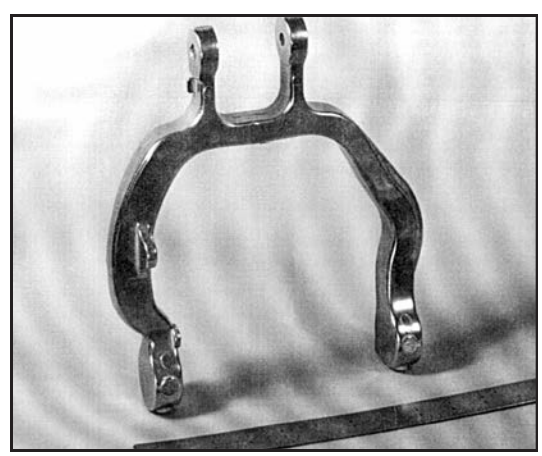
Squeeze Castings

Part Name: G-Car Trailing Arm
Application: Automotive Trailing Arm
Part Weight: 15.5 lbs.
Alloy: —
Heat Treatment: —
Special Requirements: High strength/low mass.
New Part or Substitution: New; consolidated a proposed 6 piece ferrous weldment to a single aluminum casting
Customer: Oldsmobile, Buick



Squeeze Castings

Part Name: Upper Control Arm
Application: Automotive Suspension
Part Weight: 2.2 lbs.
Alloy: A356.2 Strontium modified
Heat Treatment: T6
Special Requirements: Fatigue life greater than two piece forging
New Part or Substitution: Conversion from ductile iron
Customer: Cadillac

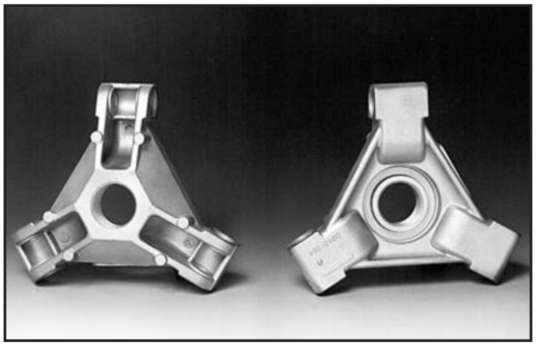


Squeeze Castings

Part Name:	Pulley
Application:	Automotive
Part Weight:	1.3 lbs.
Alloy:	390
Heat Treatment:	T6
Special Requirements:	High integrity, light weight, wear resistance
New Part or Substitution:	Replaced iron castings
Customer:	—

Squeeze Castings

Part Name:	Clutch Spider
Application:	Snowmobile Clutch Spider
Part Weight:	1.1 lbs.
Alloy:	356
Heat Treatment:	T6
Special Requirements:	Wear resistance
New Part or Substitution:	Substituted for a high pressure die casting, results a average life span doubled
Customer:	—



Squeeze Castings

Part Name:	Lower Control Arm
Application:	Automotive
Part Weight:	5.1 lbs.
Alloy:	A356
Heat Treatment:	T6
Special Requirements:	Safety critical component-must see strength, impact & fatigue requirements
New Part or Substitution:	Conversion from D4512 ductile cast iron
Customer:	Volvo

Squeeze Castings

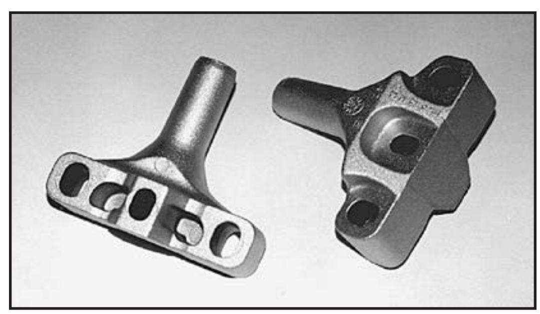
Part Name: Front Steering Knuckle
Application: Automotive
Part Weight: 6.0 lbs.
Alloy: A356
Heat Treatment: T6
Special Requirements: Safety critical component- must meet strength, impact & fatigue requirements
New Part or Substitution: Conversion from D4512 ductile cast iron
Customer: Ford

Squeeze Castings

Part Name: Engine Mount
Application: Automotive
Part Weight: 1.0 lbs.
Alloy: GS-AlSi13Fe
Heat Treatment: None
Special Requirements: Better fatigue resistance than conventional die casting
New Part or Substitution: New Part
Customer: Volkswagen/Audi

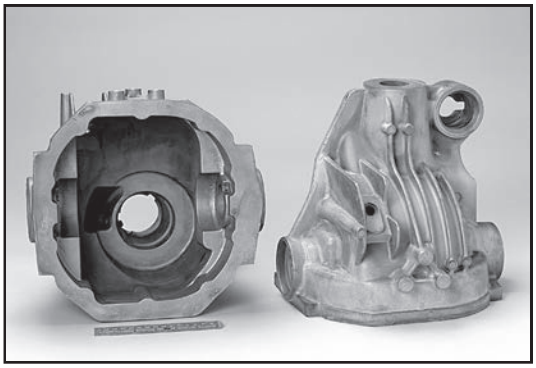
Squeeze Castings

Part Name: Rocker Arm
Application: Automotive engine valve actuator
Part Weight: 0.2 lbs.
Alloy: AlSi12CuNiMg
Heat Treatment: T6
Special Requirements: Better fatigue resistance than conventional die casting
New Part or Substitution: New Part
Customer: Mercedes



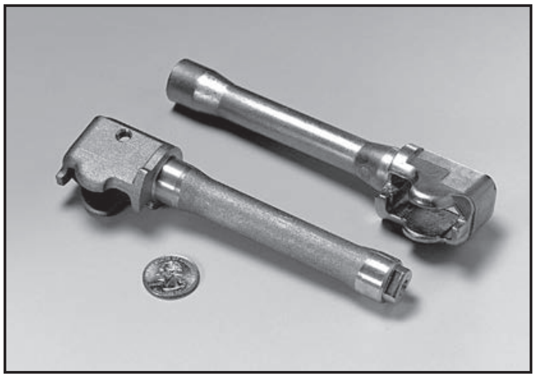
Squeeze Castings

Part Name:	Differential Carrier
Application:	Independent Rear Suspension
Part Weight:	16.5 lbs.
Alloy:	ADC-12
Heat Treatment:	T6
Special Requirements:	—
New Part or Substitution:	Converted from an iron casting
Customer:	Visteon Corporation



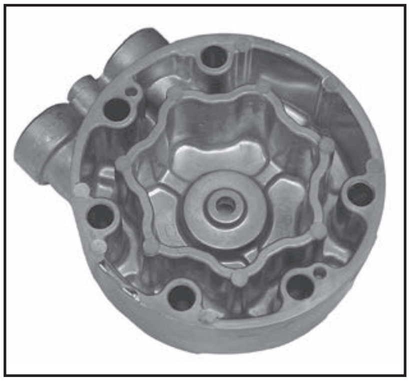
Squeeze Castings

Part Name:	Shift Actuator
Application:	Steering Column
Part Weight:	0.25 lbs.
Alloy:	MKC Sweries TK
Heat Treatment:	—
Special Requirements:	—
New Part or Substitution:	Converted from a steel investment casting
Customer:	Delphi Corporation



Squeeze Castings

Part Name:	GQ Cylinder Head
Application:	Vehicle Air Conditioner Compressor
Part Weight:	1.37 lbs.
Alloy:	A356.2
Heat Treatment:	—
Special Requirements:	Leak test with gas medium. Ports and bolt hole to be porosity free
New Part or Substitution:	New Part
Customer:	Sanden International (USA), Inc.



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Squeeze Castings

Part Name: Steering Knuckle

Application: Automotive

Part Weight: 5.1 lbs.

Alloy: A356.2

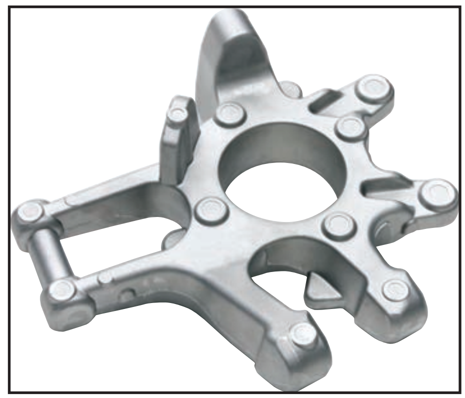
Heat Treatment: T6

Special Requirements: Maintain minimum property levels

New Part or Substitution: Substitution for traditional manufacturing processes of forging and/or iron-steel castings, resulting in lighter weight

Customer: Jaguar Cars Ltd.

Squeeze Castings



Part Name: Rear Steering Knuckle

Application: Rear wheel and suspension support for a high performance sports car.

Part Weight: 5 lbs

Alloy: A356.2

Heat Treatment: T6

Special Requirements: Pressure tightness, net shape

New Part or Substitution: Substitution for cast and forged iron and aluminum

Customer: Jaguar

Squeeze Castings

Part Name: Rack & Pinion Steering Gear Housing

Application: Houses hydraulic fluid, rack and pinion to turn the wheels on a class 8 truck.

Part Weight: 8.2 lbs

Alloy: ADC12

Heat Treatment: –

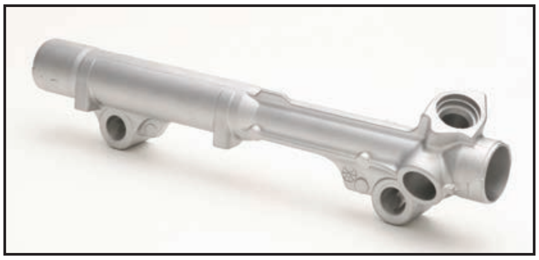
Special Requirements: Thick walls, contain high pressure fluid, machine to a very fine finish, lower weight

New Part or Substitution: Substitution for steel multi-pul part assembly

Customer: Freightliner

Squeeze Castings

Part Name:	Rack & Pinion Steering Gear Housing
Application:	Contain hydraulic fluid and steering components for a full size pickup truck
Part Weight:	9.2 lbs
Alloy:	ADC-12
Heat Treatment:	T6
Special Requirements:	Prevent distortion of rack, high burst limit, low porosity and lower weight
New Part or Substitution:	New Part
Customer:	Toyota

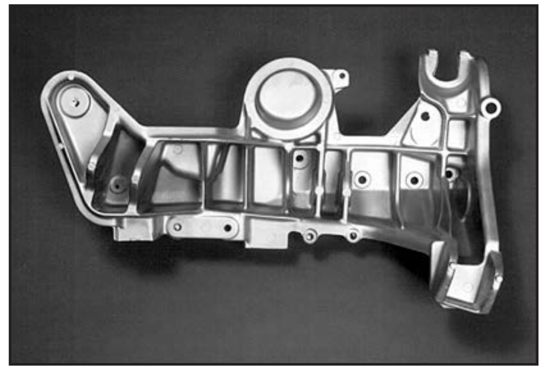


Squeeze Castings

Part Name:	End Head
Application:	To transfer and direct hydraulic fluid through many ports in a small area for many tasks such as: auto hoists, snow plows, dump trucks, and lifts
Part Weight:	3.8 lbs.
Alloy:	380
Heat Treatment:	None
Special Requirements:	Leak proof operation at high pressures, lower weight, reduced machining, allow performance similar to 6061 aluminum
New Part or Substitution:	Substitution for machined 6061 billet aluminum part
Customer:	Stone Hydraulic

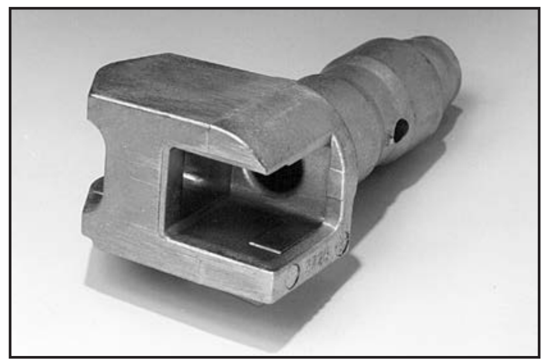
Semi-Solid Metal Castings

Part Name: Multi-Link
Application: Rear Suspension Support
Part Weight: 15.0 lbs.
Alloy: A356
Heat Treatment: T5
Special Requirements: Low weight, high strength
New Part or Substitution: New Part
Customer: Alfa Romeo



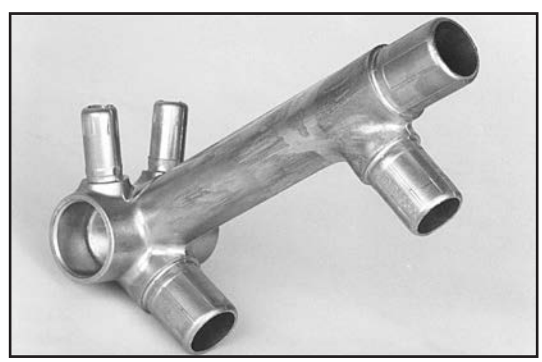
Semi-Solid Metal Castings

Part Name: Actuator Shaft
Application: Automotive Steering
Part Weight: .1 lbs.
Alloy: 356
Heat Treatment: T6
Special Requirements: High strength, low weight
New Part or Substitution: Converted from a steel investment casting
Customer: Porsche



Semi-Solid Metal Castings

Part Name: Lower Crank Housing
Application: Light Weight Bicycle
Part Weight: 1.1 lbs.
Alloy: A356
Heat Treatment: T6
Special Requirements: High strength, low weight
New Part or Substitution: Substitution for two squeeze castings, eliminating the joining operation. The squeeze casting process was unable to produce the different section thickness
Customer: —



Semi-Solid Metal Castings

Part Name: Control Arm

Application: Automotive Control Arm

Part Weight: .5 lbs.

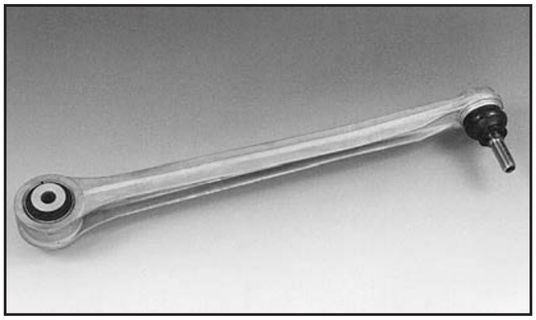
Alloy: A356

Heat Treatment: T6

Special Requirements: High strength, excellent impact resistance, low weight

New Part or Substitution: New Part

Customer: Porsche



Semi-Solid Metal Castings

Part Name: Fuel Rail

Application: Automotive

Part Weight: .8 lbs.

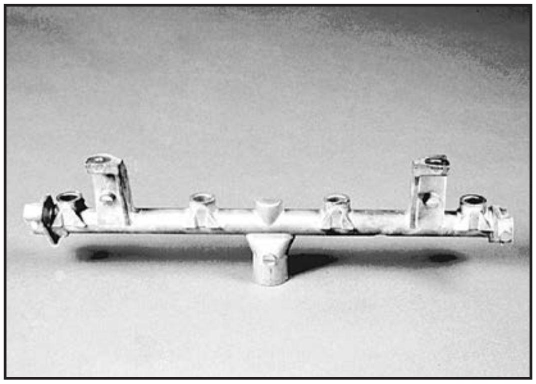
Alloy: 356

Heat Treatment: T5

Special Requirements: Pressue tightness, low weight, corrosion resistance

New Part or Substitution: New Part

Customer: Visteon Powertrain Control Systems



Semi-Solid Metal Castings

Part Name: Upper Fork Plate

Application: Motorcycle

Part Weight: 1.8 lbs.

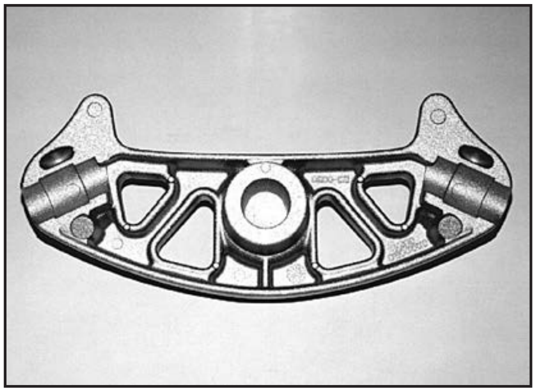
Alloy: 357

Heat Treatment: T5

Special Requirements: —

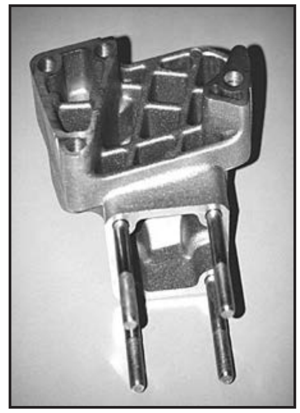
New Part or Substitution: Substitution of gravity pour aluminum

Customer: Derbi (Spain)



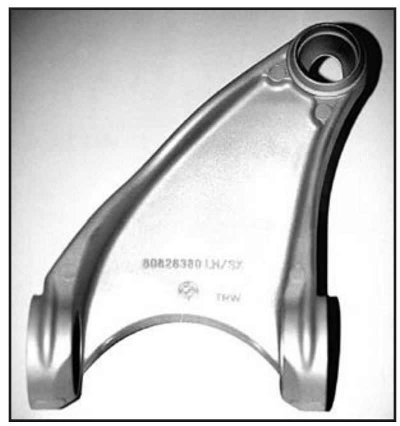
Semi-Solid Metal Castings

Part Name: Transmission Belt Cover
Application: Automotive
Part Weight: 2.8 lbs. (assembled)
Alloy: 357
Heat Treatment: T5
Special Requirements: Net Shape
New Part or Substitution: New Part
Customer: FIAT Auto



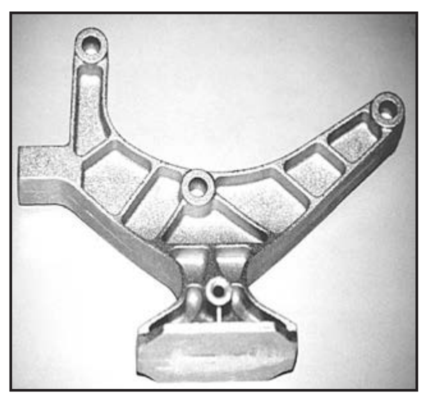
Semi-Solid Metal Castings

Part Name: Front Suspension Arm
Application: Automotive
Part Weight: 1.3 lbs.
Alloy: A356
Heat Treatment: T6
Special Requirements: Near net shape
New Part or Substitution: Substitution of forged part
Customer: TRW



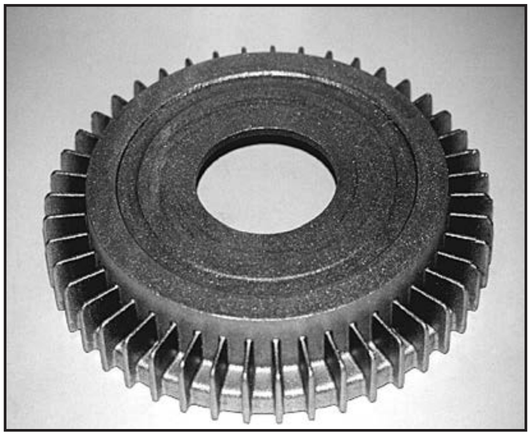
Semi-Solid Metal Castings

Part Name: Engine Mount
Application: Automotive
Part Weight: 1.8 lbs.
Alloy: A357
Heat Treatment: T5
Special Requirements: Net Shape
New Part or Substitution: New Part
Customer: FIAT Auto



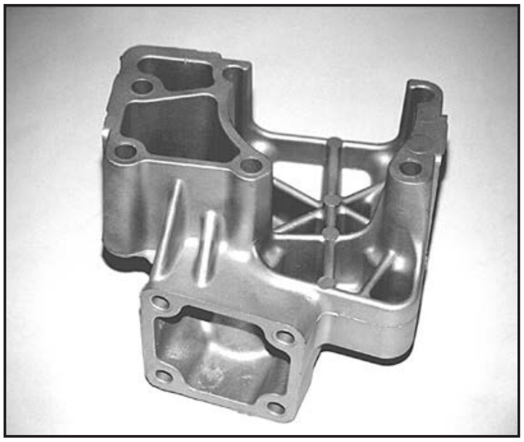
Semi-Solid Metal Castings

Part Name:	Brake Drum
Application:	Automotive
Part Weight:	3.7 lbs.
Alloy:	A390
Heat Treatment:	T5
Special Requirements:	Low weight, wear resistance
New Part or Substitution:	Substitution of cast iron
Customer:	FIAT Research Center



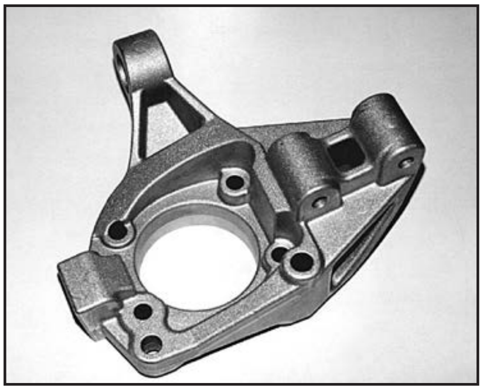
Semi-Solid Metal Castings

Part Name:	Transmission Belt Cover
Application:	Automotive
Part Weight:	3.3lbs.
Alloy:	A357
Heat Treatment:	T5
Special Requirements:	Net Shape
New Part or Substitution:	New Part
Customer:	FIAT Auto



Semi-Solid Metal Castings

Part Name:	Steering Knuckle
Application:	Automotive
Part Weight:	4.8 lbs.
Alloy:	357
Heat Treatment:	T5
Special Requirements:	Low weight, high strength
New Part or Substitution:	Substitution of cast iron
Customer:	Alfa Romeo



Semi-Solid Metal Castings

Part Name: Rear Door Hinge

Application: Audi model A2 rear door

Part Weight: 0.17 kg

Alloy: A357

Heat Treatment: T6

Special Requirements: Low weight, net shape, high strength

New Part or Substitution: New part

Customer: Audi

Semi-Solid Metal Castings

Part Name: Pulley

Application: Vehicle Power Steering Pump

Part Weight: 0.55 lbs.

Alloy: Ultralite™ metal matrix composite

Heat Treatment: None

Special Requirements: Light weight and wear resistance

New Part or Substitution: Substitution for ferrous component with comparable wear resistance

Customer: Prototype, Ford (potentially others)

Semi-Solid Metal Castings

Part Name: Vibration Damper Bracket

Application: Engine Bracket Component

Part Weight: 80 g

Alloy: A357

Heat Treatment: T5

Special Requirements: Strength, hardness, near net shape manufacturing

New Part or Substitution: New Part

Customer: Peugot

Semi-Solid Metal Castings

Part Name: Engine Transmission Cartridge Plate

Application: Non-automotive

Part Weight: 440 g

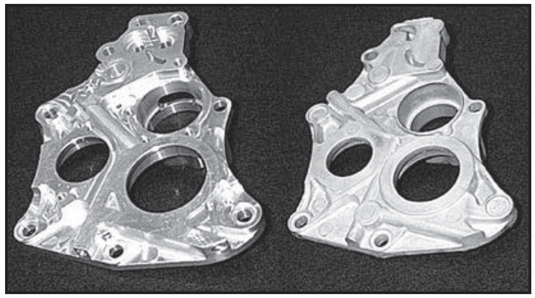
Alloy: A357

Heat Treatment: T5

Special Requirements: Light weight, high strength

New Part or Substitution: Substitution of cast iron

Customer: —



Semi-Solid Metal Castings

Part Name: Water Pump Housing

Application: Non-automotive

Part Weight: 135 g

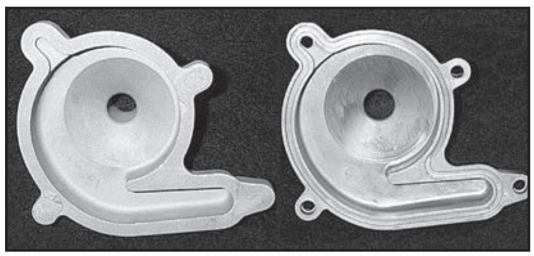
Alloy: A357

Heat Treatment: T5

Special Requirements: Light weight

New Part or Substitution: Substitution

Customer: —



Semi-Solid Metal Castings

Part Name: Multi Link Rear Suspension

Application: Daimler Chrysler Pacifica Automobile

Part Weight: 3.3 lbs.

Alloy: 356

Heat Treatment: T6

Special Requirements: —

New Part or Substitution: Conversion from aluminum forgings

Customer: Daimler Chrysler

Glossary

This glossary of terms is presented to aid the product designer and specifier in communicating with the custom die caster during product development and production. It includes definitions involved in product prototyping, the design and construction of the die casting die and trim die, die casting production and post-casting machining and surface finishing operations.

Abrasive blasting

A process for cleaning or finishing by which abrasive particles are directed at high velocity against a casting or work piece.

Acid pickle

A method to remove oxides and other contaminants from metal surfaces.

Aging

A change in the metallurgical structure of an alloy occurring over a period of time following casting, which affects the properties and dimensions. Heating accelerates aging.

Aging, artificial

A low temperature heat treatment meant to accelerate aging, generally applied to increase strength and/or to stabilize properties.

Aging, natural

Aging that occurs at room temperature.

Alloy

A substance having metallic properties and composed of two or more chemical elements, of which at least one is metal. Alloy properties are usually different from those of the alloying elements.

Alloy, primary

Any die casting alloy whose major constituent has been refined directly from ore, not recycled scrap metal.

Alloy, secondary

Any die casting alloy whose major constituent is obtained from recycled scrap metal. Nearly 95% of die castings provided in North America are made from secondary alloys.

Alloy, standard

Any die casting alloy that has been assigned an ASTM designation.

Alloying

The process of making a die casting alloy from its various constituents. The process usually consists of melting the major constituent and adding the others to the bath where they then dissolve. The molten metal is then cleaned of contamination by fluxing.

Amortization

A financial method to defer tooling cost and include the tooling cost with casting production on a prorated basis. For example, if tooling life is agreed to be 100,000 acceptable castings and the tooling cost is $100,000, the prorated cost is $1.00 per each acceptable casting shipped, and invoiced at shipment.

Anode

The electrode in a plating bath at which metal ions are formed, negative ions are discharged or other oxidizing reactions occur.

Anodic metal

Any metal that tends to dissolve, corrode or oxidize in preference to another metal when the metals are connected electrically in the presence of an electrolyte.

Glossary

Anodizing

To subject a metal to electrolytic action as the anode of a cell in order to coat with a protective or decorative film.

ANSI

American National Standards Institute.

AQL

Acceptable Quality Level, as agreed upon for the fulfillment of production orders.

As-Cast

Condition of a casting that has not been given a thermal treatment subsequent to casting. This is also termed as the "F temper."

ASQ

American Society for Quality.

ASTM

American Society for Testing and Materials.

Atmospheric corrosion

Surface corrosion caused by exposure in the environment to gasses or liquids that attack the metal.

Bailment

The voluntary transfer of property, such as dies, fixtures, gages, etc., in trust by the Bailor (customer) to the Bailee (vendor). This can be codified with a "Bailment Agreement".

Ball burnishing

The smoothing of surfaces by means of tumbling parts in the presence of hardened steel balls, without abrasives.

Barrel burnishing

The smoothing of surfaces by means of tumbling a part in rotating barrels in the presence of metallic or ceramic shot, without abrasives.

Barrel plating

Plating in which a part is processed in bulk in a rotating container.

BHN

Brinell Hardness Number, scale used to indicate hardness.

Biscuit

Excess metal left at the end of the injection cylinder of a cold-chamber die casting machine, formed at the end of the plunger stroke. Also called a slug.

Black chromium

Nonreflective, black chromium coating electrodeposited from a sulfate-free bath.

Black nickel

Nonreflective, decorative, black nickel coating having little protective value, produced by electroplating or simple immersion.

Blister

A surface defect or eruption caused by expansion of gas, usually as a result of heating trapped gas within the casting, or under metal which has been plated on the casting.

Glossary

Blow holes

Voids or holes in a casting that may occur due to entrapped air or shrinkage during solidification of heavy sections.

Bright finish

A finish with a uniform nondirectional smooth surface of high specular reflectance.

Bright nickel

Decorative nickel plate that is deposited in the fully bright condition.

Bright plating

A process that produces an electrodeposit having a high degree of specular reflectance in the as-plated condition. Abrasive particles are applied in liquid suspension, paste or grease stick form.

Buffing

Smoothing a surface with a rotating flexible wheel, to the surface of which fine abrasive particles are applied in liquid suspension, paste or grease-stick form.

Burnishing

The smoothing and polishing of a metal surface by rubbing or tumbling in the presence of metallic or ceramic balls and in the absence of abrasives.

Butyrates

Organic coatings based on butyric acid derivatives having excellent initial color and good resistance to weathering.

Cp

Capability index.

Cpk

Total process capability. A production process capability index of both a process dispersion and its central tendancy, taking into account the spread of the distribution and where the distribution is in regard to a specification midpoint.

CQI

Continuous Quality Improvement, an approach to quality management that builds upon traditional quality assurance methods by emphasizing the organization and systems. It focuses on "process" rather than the individual; recognizes both internal and external "customers"; and, promotes the need for objective data to analyze and improve processes.

Cadmium plate

A coating of cadmium metal applied to an aluminum or steel substrate for corrosion protection or improved solderability. Cadmium plate on zinc die castings requires an intermediate barrier layer of nickel.

Cass test

(Copper accelerated salt spray) An accelerated corrosion test for electroplated substrates (ASTM 368-68).

Castability

The relative ease with which an alloy can be cast; includes the relative ease with which it flows and fills out a die/mould cavity, and its relative resistance to hot cracking and tearing.

Casting rate

The average number of shots that can be cast during one hour of steady running.

Glossary

Casting section thickness

The wall thickness of the casting. Since the casting may not have a uniform thickness, the section thickness may be specified at a specific place on the casting. Also, it is sometimes useful to use the average, minimum or typical wall thickness to describe a casting.

Casting yield

The weight of casting or castings divided by the total weight of metal injected into the die, expressed as a percent.

Casting cycle

The total number of events required to make each casting. For die castings, the casting cycle generally consists of solidification time, machine movement and sequencing time and the operator's manual movements.

Casting drawing

The engineering drawing that defines the size, shape and tolerances of the casting. This is a detailed drawing of the casting only and not an assembly of the product in which the casting is included.

Casting, functional

A die casting that serves a structural or mechanical purpose only. It has no decorative value.

Casting thickness

See Casting section thickness.

Casting, thin wall

A term used to define a casting which has the minimum wall thickness to satisfy its service function.

Casting volume

The total cubic units (i.e. cu. in. or cu. mm) of cast metal in the casting.

Cathode

The electrode in electroplating at which metallic ions are discharged, negative ions are formed or other reducing actions occur.

Cathode robber

An auxiliary cathode so placed as to divert electrical current to itself from portions of the articles being plated which would otherwise receive too high a current density.

Cathodic metal

Any metal that does not tend to dissolve, corrode or oxidize in preference to another metal when the metals are connected electrically in the presence of an electrolyte.

Cavity

The recess in the die in which the casting is formed.

Cavity block

The portion of the die casting die into which most, if not all, the cavity is formed. There are usually at least two cavity blocks in each die set.

Cavity fill time

That period of time required to fill the cavity with metal after the metal begins to enter the cavity.

Center line shrinkage

Shrinkage or porosity occurring along the central thermal plane or axis of a cast part.

Glossary

Charpy

Name of an impact test in which the specimen, forming a simple beam, is struck by a hammer while resting against anvil supports spaced 40 mm apart.

Checking

See **Fatigue, thermal**.

Chemical cleaning

The removal of foreign material from a surface by means of immersion or spraying without the use of current.

Chromate

A conversion coating consisting of trivalent and hexavalent chromium compounds.

Chromating

The application of a chromate coating.

Chrome pickle

A chemical treatment for magnesium in nitric acid, sodium dichromate solution. The treatment gives some protection against corrosion by producing a film that is also a base for paint.

Chromium plate

A coating of electrodeposited chromium metal which affords superior resistance to tarnishing and abrasion.

Clamping capacity

The force a die casting machine is capable of applying against the platen to hold the die closed during metal injection.

Clamping force

Actual force applied by a die casting machine to a die clamp to keep the die closed. This may be less than the clamping capacity of the die casting machine.

Cold chamber

The molten metal chamber of a cold-chamber, die casting machine. This is a hardened tube (shot sleeve) through which the shot plunger moves to inject the molten metal into die. The cold chamber and plunger combine to form a metal pump. It is called the cold chamber because it is cold relative to the metal put into it.

Cold forming

Bending of a die casting without the application of heat to achieve a desired shape that is different than that as cast. Cold forming is frequently used to hold an assembled part to the die casting.

Cold shut

A lapping that sometimes occurs where metal fronts join during the formation of solidified metal that sometimes occurs in the formation of die castings which constitutes an imperfection on or near the surface of the casting.

Cold-Chamber machine

A die casting machine designed so that the metal chamber and plunger are not continually immersed in molten metal.

Color anodize

An anodic coating that is dyed before sealing with an organic or inorganic coloring material.

Glossary

Coloring

The production of desired colors on metal surfaces by appropriate chemical or electrochemical action, or light buffing of metal surfaces for the purpose of producing a high luster; also called Color Buffing.

Combination die

A die with two or more different cavities each producing a different part, also called a family die.

Composite plate

An electrodeposit consisting of two or more layers of metal deposited successively.

Compressive yield strength

The maximum stress that a metal, subjected to compression, can withstand without a predefined amount of yield (normally 0.2% for die castings).

Contraction

The linear change typically occurring in metals and alloys on cooling to room temperature.

Contraction Factor

A factor used to multiply casting dimensions to obtain casting die dimensions. It accommodates differences in Coefficients of Thermal Expansion of the die steel and alloy, and die operating temperatures.

Conversion coating

A coating produced by chemical or electrochemical treatment of a metallic surface that forms a superficial layer containing a compound of the metal; example: chromate coatings on zinc and cadmium, oxide coating on steel.

Cooling channel

A tube or passage in a die casting die through which a coolant (typically water, oil or air) is forced to cool the die.

Copper plate

A coating of copper deposited by electrolytic or electroless plating methods. Copper electroplated from a cyanide solution is generally used as the initial layer in plating zinc die castings. Acid copper is used as a leveling deposit under nickel-chromium plate.

Core

A part of a die casting die that forms an internal feature of the casting (usually a feature with considerable dimensional fidelity) and is a separate piece from the cavity block. A core may be fixed in a stationary position relative to the cavity block or may be actuated through some movement each time the die is opened.

Core pin

A core, usually of circular section. Core pins are hot work tool steel pins, usually H-13, used for a cored hole in a die casting and may be fixed or movable. A core is made from a core pin.

Core plate

The plate to which the cores are attached and which actuates them.

Core slide

Any moving core.

Core, fixed

A core that, as the die opens and closes, does not move relative to the cavity block into which it is mounted.

Glossary

Core, moving

A core that must move through some travel as the die opens or immediately after the die has opened, to allow the unrestricted ejection of the casting.

Corrodkote

An accelerated corrosion test for electroplated substrates (ASTM 380-65).

Corrosion

Degradation of a metal by chemical or electrochemical reaction with its environment.

Corrosion endurance

Resistance to corrosion as a function of time.

Cover gas

A mixture consisting of sulfur hexafloride, carbon dioxide and air, used to protect and minimize oxide formation on the surface of molten magnesium.

Cover; cover die

The stationary half of a die casting die.

Covering power

The ability of a plating solution, under a specified set of plating conditions, to deposit metal on the surfaces or recesses of a part, or in deep holes.

Creep

Plastic deformation of metals held for long periods under stresses less than the normal yield strength.

Creep strength

The constant nominal stress that will cause a specified amount of creep in a given time at a constant temperature.

Current shield

A nonconducting medium for altering the current distribution on an anode or cathode.

Damping

Ability of material to dampen vibration in components and thus lower noise levels.

DOE

Design of Experiments

Deburring

The removal of burrs, sharp edges or fins by mechanical, chemical, electrochemical or electrical discharge means.

Decorative finish

A plated, painted or treated surface having aesthetic qualities and the ability to maintain those qualities in service.

Defect

Imperfections in a cast part - such as pores, inclusions, cracks, cold shuts, laps or the like.

Deflection

The bending or twisting of a die casting or a tool when a load is imposed on it. Deflection is normally used to describe elastic strain (i.e., the item will return to its original shape when the load is removed) rather than permanent (plastic) deformation.

Glossary

Deformation, plastic

Bending or twisting of a die casting or a tool by a load that is beyond its elastic limits, and the casting or tool does not return to its original shape when the load is removed.

Degasifier

A substance that can be added to molten metal to remove soluble gases that might otherwise be entrapped in the metal during solidification.

Degassing

(1) A chemical reaction resulting to remove gases from the metal. Inert gases are often used in this operation. (2) A fluxing procedure used for aluminum alloys in which nitrogen, chlorine, chlorine and nitrogen and chlorine and argon are bubbled up through the metal to remove dissolved hydrogen gases and oxides from the alloy. See also **flux**.

Degreasing

The removal of grease and oils from a surface.

Dendrite

A crystal that has a tree-like branching pattern most evident in cast metals slowly cooled through the solidification range.

Deoxidizing

(1) The removal of oxygen from molten metals through the use of a suitable deoxydizer. (2) Sometimes refers to the removal of undesirable elements other than oxygen through the introduction of elements or compounds that readily react with them. (3) In metal finishing, the removal of oxide films from metal surfaces by chemical or electrochemical reaction.

Dichromate process

A chemical treatment for aluminum, magnesium and zinc alloys in a boiling dichromate solution, resulting in a surface film that resists corrosion.

Die

A metal block used in the die casting process, incorporating the cavity or cavities that form the component, the molten metal distribution system and means for cooling and ejecting the casting.

Die block

The large block of steel that forms the base for one half of a die casting die. All other components of the die are attached to or mounted on the die block.

Die cast skin

The metal on the surface of a die casting, to a depth of approximately 0.020 in. (0.8 mm), characterized by fine grain structure and freedom from porosity.

Die casting

A process in which molten metal is injected at high velocity and pressure into a mold (die) cavity.

Die halves

A die casting die is made in two parts, the cover and the ejector. These are called the "halves" of the die.

Die insert

A removable liner or part of a die body.

Glossary

Die life

(1) The number of usable castings that can be made from a die before it must be replaced or extensively repaired. (2) The distance, in inches or millimeters, measured in the direction of the trimming action that a die cast trimming die is fitted to the casting. As trim dies are repeatedly sharpened, die life distance is reduced. When the die life is completely sharpened off, the die steels must be replaced.

Die release

Die coating to improve casting surface quality and facilitate removal from die.

Die or steel safe

A technique employed in close-tolerance die casting in which exterior surfaces of the casting are deliberately made slightly under size, and interior surfaces slightly over size. After a trial casting run, all dimensions are brought within specified tolerances. This technique ensures that all final die modifications, no matter how slight, are made by removing, rather than adding, metal.

Die temperature

A die casting die has a very complex pattern of temperatures across its parting surface and through its thickness. The expression "die temperatures" is usually used to mean die surface temperatures.

Die temperature control

The use of thermocouples in the die casting die to regulate flow rate of the cooling fluid through the die, keeping die temperature within preset range.

Die weight

The mass (weight) of a die. The weight is stamped on the die so individuals handling it can select the proper lifting equipment.

Die, miniature

Die casting dies for making die castings that weigh less than two ounces (55 grams) are usually considered to be miniature die casting dies.

Die, multiple-cavity

A die having more than one casting cavity.

Die, single cavity

A die casting die that has only one cavity.

Dimension, critical

A dimension on a part that must be held within the specified tolerance for the part to function in its application. A noncritical tolerance is specified for weight saving or for manufacturing economy, and is not essential for the product's function.

Dimension, linear

Any dimension to features of the die casting that are formed in the same die component (half). Any straight line dimension on a part of die print.

Dimension, nominal

The size of the dimension to which the tolerance is applied. For example, if a dimension is 2.00 ±0.02, the 2.00 is the nominal dimension and the ±0.02 is the tolerance.

Glossary

Dimension, parting line

A dimension on a casting, or in a die casting die cavity, that is parallel to the direction of die pull and crosses the die parting line.

Dimensional stability

Ability of an alloy to retain its size and shape unchanged with time.

Discontinuity

Any interruption in the normal physical structure or configuration of a part, such as cracks, laps, seams, inclusions or porosity. A discontinuity may or may not affect the utility of the part.

Dolomite

A mineral made up of calcium and magnesium carbonate.

Double-Layer nickel

An electroplated, double-layer nickel coating, of which the bottom layer is semi-bright nickel containing less that 0.005% sulfur and the top layer is bright nickel containing more than 0.04% sulfur; the thickness of the bottom layer is not less than 60% of the total nickel thickness, except on steel where it is not less than 75%.

Dowel pin

A guide to ensure registry between two die sections.

Draft allowance

The maximum angle of the draft that is allowed by the casting's specification.

Draft

The taper given to cores and other parts of the die cavity to permit easy removal of the casting.

Drag-Out

The solution that adheres to the objects removed from cleaning and plating baths.

Dross

Metal oxides in or on the surface of molten metal.

Dull finish

A finish virtually lacking both diffuse and specular reflectance.

Eject

To push the solidified casting out of the cavity of the die casting die.

Ejection, accelerated

A system, usually within the die casting die, that causes selected ejector pins to move faster and further than the others during the final portion of the ejection travel. Also called **Secondary Ejection**.

Ejector marks

Marks left on castings by ejector pins, frequently including a light collar of flash formed around the ejector pin.

Ejector pin

A pin actuated to force the casting out of the die cavity and off the cores.

Glossary

Ejector plate

Plate to which the ejector pins are attached and which actuates them.

Ejector; ejector die

The movable half of a die casting die containing the ejector pins.

Electrolyte

A substance, usually liquid, in which the conduction of electricity is accompanied by chemical decomposition. An electrolyte is one of the factors required for electrolytic corrosion to occur.

Electromotive series

A list of elements arranged according to their standard electrode potential.

Electroplate

An adherent metallic coating applied by electrodeposition on a substrate for the purpose of improving the surface properties.

Electropolishing

The improvement in surface finish of a metal effected by making it anodic in an appropriate solution.

Elongation

Amount of permanent extension in the vicinity of the fracture in a tensile test, usually expressed as a percentage of original gage length.

Engraved finishes

Designs etched on die cavity surfaces by chemical dissolution to produce specified patterns in the as-cast part.

Entrained air

Air or other gases that are mixed with the flowing molten metal as the die cavity is filling.

Epoxies

Organic coatings applied to parts, having superior corrosion resistance and adhesion.

Erosion

A damaged condition in the die cavity or die runners caused by the impingement of the molten metal during injection.

Expansion, thermal coefficient of

A numerical value of the unit change in length of a substance with each degree of temperature change. These values are arrived at by experimentation and are tabulated in reference books.

Extractor

In die casting, a mechanical apparatus that enters the space between the two halves of the opened die casting die, grips the cast shot, pulls it free from the ejector pins and removes it from the die space.

FAIR

First Article Inspection Report

FMEA

Failure Mode and Effect Analysis

FEA

See Finite element analysis.

Glossary

Fatigue

The phenomenon leading to fracture under repeated or fluctuating stresses that have a maximum value less than the tensile strength of the material.

Fatigue, thermal

The cracking (or crazing) of the die cast die cavity surface. This is caused by the expansion and contraction of the cavity surface which happens every time molten metal is injected into the die.

Feedback

A process control principle in which information about the actual performance of a machine, tool, die or process is inputted into the machine control system for the purpose of possible machine adjustments to correct any inaccurate variable.

Feeding

The process of supplying molten metal to the die cavity to compensate for volume shrinkage while the cast part is solidifying.

Ferric nitrate treatment

Process for producing a bright, corrosion-resistant finish on magnesium.

Fillet

Curved juncture of two surfaces; e.g., walls that would otherwise meet at a sharp corner.

Fin

See Flash.

Finish machining

(1) The last machining operation on the cavity of a die casting die before the hand work (benching or polishing) is started. (2) Machining operations on a part that has been die cast to bring the part to final specified tolerances, where die casting to net-shape was not economically feasible.

Finish

The smoothness of the surface of a die casting or a die casting die cavity. The finish quality of a cavity surface may be specified as the grit size to be used in the final polishing, microinch RMS value or SPI/SPE finish standard number.

Finite element analysis

A numerical simulation procedure that can be used to obtain solutions to a large class of engineering problems including stress analysis, fluid flow, heat transfer and many more.

Fit

The preciseness or accuracy with which two parts must be fitted together. The clearance or interference between two interconnected parts. When a die casting must be made to unusually close tolerances to achieve a specified fit, it may impose a higher cost on its manufacture.

Fixture

Any apparatus that holds a part, such as a die casting, firmly in a predetermined position while secondary operations are being performed on the part.

Flash (metal extension)

The thin web or fin of metal on a casting occurring at die partings, air vents, and around movable cores. The excess metal is due to the working pressure and operating clearances in the die.

Flash, clearance

In die casting dies, spaces deliberately provided between parts of the die for the formation of flash. In trim dies and other secondary tooling, spaces provided for the positioning of the casting flash.

Flash, trimmed

The excess material that has been trimmed from a die casting that will be remelted and used over again.

Flow lines

Marks appearing on the surface of a casting that indicates the manner of metal flow.

Flow pattern

The pattern with which the molten metal progressively fills the cavity of a die casting die.

Flow rate

The volume per unit time of molten metal entering a cavity in a die casting die. Flow rates are expressed in cubic inches or cubic millimeters per second.

Fluid bed coating

A process in which the metal to be coated is heated and inserted into the powdered resin which is fluidized in air.

Fluidity

Having fluidlike properties. In die casting: the distance the molten metal will travel through a channel before it freezes, at a given temperature.

Flux

A substance such as halide salts used to protect and minimize oxide formation on the surface of molten metal. Also used to refine scrap metals.

Form

The shape of a die casting.

Forming, cold

Any of several processes in which a die casting is reshaped by a tool or fixture, usually in a power press, without the application of heat. Spinning, which generates some localized heat, is still considered a cold forming operation. Heat staking, which utilizes heated punches, is not a cold forming operation.

Fracture test

Breaking a specimen and examining the fractured surfaces to determine such things as composition, grain size, soundness or presence of defects.

Freezing range

That temperature range between liquidus and solidus temperatures in which molten and solid constituents coexist.

GD&T

Geometric Dimensioning and Tolerancing

Gage

A fixture or apparatus that checks the dimensional accuracy of a produced part such as a die casting. A gage performs no work on the part.

Glossary

Gaging

The process of using a gage to determine if a part is dimensionally usable.

Galling

Tearing out of particles from a metal surface by sliding friction.

Galvanic corrosion

Corrosion associated with the current of a galvanic cell consisting of two dissimilar conductors in an electrolyte or two similar conductors in dissimilar electrolytes.

Gas, trapped

A defect in a die casting where gases (such as air, steam, hydrogen and gases from the decomposition of the parting material) have become entrapped within the casting and have formed one or more voids.

Gate erosion

Die damage induced by the long term high-temperature and high-velocity metal stream from the die inlet gate(s).

Gate runner

The runner in a die casting die that is directly adjacent to the gate. The transition from gate opening to runner cross-section.

Gate

(1) The passage connecting a runner or overflow with a die cavity. (2) The entire ejected content of a die, including the casting or castings and the gates, runners, sprue (or biscuit) and flash.

Gate, center

A gating arrangement in a die casting die that causes the injected metal to enter the cavity from the center of the part instead of along an outer edge. The casting must be open in the center, like a wheel or bezel, to be center gated.

Gating system

The passages, except the cavity, in a die casting die through which the injected metal must flow. The gating system includes the sprue or biscuit, main runner, branch runners (if any), gate runners, approach, the gate, overflows and vents.

Geometric characteristics

Geometric characteristics refer to the basic elements or building blocks which form the language of geometric dimensioning and tolerancing. Generally, the term refers to all the symbols used in form, orientation, profile, runout and location tolerancing.

Globular microstructure

A microstructure in which the primary phase is globular, rather than dendritic. This is the typical microstructure for semi-solid castings after heating to the semi-solid forming temperature. See also degenerate dendrites.

Gooseneck

In hot-chamber die casting, a spout connecting a metal pot or chamber with a nozzle or sprue hole in the die and containing a passage through which molten metal is forced on its way to the die.

Glossary

Grain

A region within a solidified metal where the crystalline structure of the atoms is relatively perfect. The entire structure of the metal is made up of such grains. During cooling the grains are formed by growing larger from chance joining of atom pairs or from an impurity. As the grains grow they meet each other and the crystalline structure ends at these boundaries.

Grain refinement

The manipulation of the solidification process to cause more (and therefore smaller) grains to be formed and/or to cause the grains to form in specific shapes. The term "refinement" is usually used to mean a chemical addition to the metal, but can refer to control of the cooling rate.

Grain structure

The size and shape of the grains in a metal.

Grit blasting

Abrasive blasting with small irregular pieces of ferrous or ceramic material.

Growth

(1) Volumetric increase of a casting as a result of aging, intergranular corrosion or both. (2) Growth is the opposite of shrinkage.

Hard anodizing

A variation of the sulfuric acid anodizing process using lower temperatures and higher voltages.

Hard buffing

Procedure for cutting down rough surfaces using buffs made with a high thread count and an aggressive compound.

Hard chromium

Chromium that is plated for engineering rather than decorative applications, and is not necessarily harder. It provides a wear-resistant surface and can be used to salvage worn or undersized parts.

Hard spots

Dense inclusions in a casting that are harder than the surrounding metal.

Hardware finish

An especially smooth, as-cast surface requiring no polishing and little buffing in preparation for plating.

Heat checking

See Fatigue, thermal.

Heat sink

(1) Feature of a die casting die designed to remove heat from the die or from a specific region within the die. Water channels are the most common type of heat sink. However, high thermal conductivity materials are also used. (2) A die casting designed to function as a heat sink in an assembly.

Heat transfer coefficient

The rate a material will transfer heat energy per unit time through a distance due to a temperature difference. The heat transfer coefficients for different materials are given in Btu/hr-ft-°F and W/m-°C. Also called the Coefficient of Thermal Conductivity.

Hiding power

The ability of a paint to hide or obscure a surface to which it has been uniformly applied.

Glossary

Hole, cored

In a die casting, any hole that is formed by a core in the die casting die. A cored hole is distinguished from a hole that is added after the casting has been made (as by drilling).

Hot-chamber machine

A die casting machine designed with the metal chamber and plunger, or metal pump, continually immersed in molten metal, to achieve higher cycling rates.

Hot cracking

A rupture occurring in a casting at or just below the solidifying temperature by a pulling apart of the soft metal, caused by internal thermal contraction stress.

Hot short

Brittle or lacking strength at elevated temperatures.

Hot shortness

A tendency for some alloys to separate along grain boundaries when stressed or deformed at temperatures near the melting point. Hot shortness is caused by a low melting constituent, often present only in minute amounts, that is segregated at grain boundaries.

Hot tear

A fracture formed in a metal during solidification because of hindered contraction. Compare with hot crack.

ISIR

Initial Sample Inspection Report

Impact strength

Ability to absorb shock/energy, as measured by a suitable testing machine.

Impression

(1) A cavity in a die. (2) The mark or recess left by the ball or penetrator of a hardness tester.

Inclusions

Particles of foreign material in a metallic matrix. The particles are usually compounds (such as oxides, sulfides or silicates), but may be of any substance that is foreign to (and essentially insoluble in) the matrix.

Ingate

The passage or aperture connecting a runner with a die cavity.

Ingot

A pig or slab of metal or alloy.

Injection

The act or process of forcing molten metal into a die.

Injection profile

The preprogrammed change in speed with time of the injection ram. Speed is often changed during the injection stroke to minimize air entrapment and die filling time.

Glossary

Insert

A piece of solid material, usually metal, that becomes an integral part of the casting. Inserts are commonly set in the die so that metal is cast around that portion left exposed in the die cavity. Alternatively, inserts are often applied subsequent to casting. (Note: inserts become a part of the casting, whereas die inserts are a part of the die.)

Intergranular corrosion

A type of corrosion that preferentially attacks the grain boundaries of a metal or alloy, resulting in deep penetration.

Izod

Name of an impact test and testing machine in which the specimen is clamped at one end only and acts as a cantilever beam when struck by the hammer.

Jewelry finish

The highest-quality, defect-free, electroplated decorative finish for a die cast part.

Knock-Out; loose piece

A core positioned by, but not fastened to, a die and so arranged as to be ejected with the casting. The knock-out is subsequently removed and used repeatedly.

Lacquer

A coating composition which is based on synthetic thermoplastic film-forming material dissolved in organic solvent and which dries primarily by solvent evaporation.

Laminated object manufacturing (LOM)

A method of rapid prototyping for producing a prototype part which uses CAD data to position a laser beam over a sheet of heat-activated, adhesive-coated paper, bonding each layer on top of the last.

Leveling electroplate

An electroplate that produces a surface smoother than the substrate.

Logo (logotype)

A symbol used to identify a company, often cast into a die cast part.

Lot size

The number of pieces made with one die and machine setup.

Metal distribution ratio

The ratio of the thickness of metal upon two specified areas of a cathode.

Metal extension (flash)

The thin web or fin of metal on a casting occurring at die partings, air vents and around movable cores. The excess metal is due to the working pressure and operating clearances in the die.

Metal saver

A core used primarily to reduce the amount of metal in the casting and to avoid sections with excessive thickness.

Glossary

Metal, hot delivery of

The practice of transferring molten metal from the smelting plant to the die casting plant. Hot-metal delivery results in considerable energy and dross savings since the metal does not have to be remelted at the die casting plant. Metal may be transported in the molten state for several hundred miles.

MHD Casting

Magneto-Hydro Dynamic casting is a casting process in which the metal is vigorously stirred by a magnetic field during solidification.

Microthrowing power

The ability of a plating solution or specified set of plating conditions to deposit metal in fissures, pores or scratches.

Moving core mechanism

The parts of a die casting die that hold and move a moving core. These may include gibs, locking wedge, angled pins, dogleg cams, racks, pinions and/or hydraulic cylinders.

NADCA

North American Die Casting Association, consolidation of the Society of Die Casting Engineers and the American Die Casting Institute.

NADCA Product Standards

Die casting product standards originally published by the American Die Casting Institute, which this publication supersedes. ADCI and SDCE (the Society of Die Casting Engineers) merged to become NADCA, the North American Die Casting Association.

Net casting yield

See Casting yield.

Nickel plate

A coating of nickel, deposited by electrolytic or electroless plating methods, for decorative purposes and corrosion resistance. It is usually coated with a chromium flash plate for greater resistance to tarnish and wear.

Nitric acid pickle

A pre-pickle for the ferric nitrate treatment of magnesium.

Nitriding

A heat treating process for increasing the surface hardness of tool steels by diffusing nitrogen into the surface.

Nozzle

The outlet end of a gooseneck or the tubular fitting that joins the gooseneck to the sprue hole.

Operation, secondary

A manufacturing operation, or step, that is performed on, or to, a die casting after the casting is produced but before it is shipped to the customer or assembled into the finished product.

Overflow

A recess in a die, connected to a die cavity by a gate, remote from the entrance gate (ingate).

Overflow gate

A passage or aperture connecting a die cavity to an overflow.

Oxidation

A reaction in which electrons are removed from a reactant, as in the formation of ions at the anode surface in electrolysis. The combination of a reactant with oxygen or an oxidizing agent.

Oxide coating

A coating produced on a metal by chemical or electrochemical oxidation for the purpose of coloring or providing corrosion and wear resistance.

PPAP

Pre-Production Approval Process

PPM, Parts per Million

The acceptance level for the fulfillment of a production order based on the number of defective parts permissible per million parts shipped.

Part print

An engineering drawing (sometimes a reproduction of the engineering drawing) showing the part design. Usually “part print” refers to the drawing of a die casting rather than a die, tool or machine.

Parting face

The surface of a die casting die half that closes against a mating surface on the opposite die half. See Surface, parting.

Parting line

The junction between the cover and ejector portions of the die or mold. Also, the mark left on the casting at this die joint.

Parting line, stepped

A condition on a die casting where the parting line changes abruptly from one level to another.

Passive stirring

Another process for producing the feed material for semi-solid casting. The liquid metal is forced through restrictive channels as it cools, breaking up the dendrites.

Phosphate coating

A conversion coating applied to metal surfaces for the purpose of improving paint adhesion and corrosion protection.

Phosphoric acid pickle

A treatment to remove surface segregation from magnesium die castings and improve corrosion resistance.

Pickling

Removing surface oxides by chemical or electrochemical reaction.

Pin

A core, usually of circular section, normally having some taper (draft). Also, a dowel (or guide pin) to ensure registry between two die sections.

Pitting

The appearance of small depressions or cavities produced during solidification or as a result of corrosion and cavitation.

Platen

Portion of a casting machine against which die sections are fastened, or of trim presses against which trim dies are fastened.

Glossary

Plating rack

A frame for suspending parts and carrying current to articles during plating operations.

Plunger

Combination of tip and rod that forces metal into the die.

Polishing

The smoothing of a metal surface by means of the action of abrasive particles attached by adhesive to the surface of wheels or endless belts usually driven at a high speed.

Porosity

Voids or pores, commonly resulting from solidification shrinkage; air (primarily the nitrogen component of air) trapped in a casting or hydrogen exuded during electroplating.

Porosity dispersion

The degree to which the porosity is spread throughout the casting, as opposed to being all in one place.

Porosity, internal

Porosity that is completely encased within the die casting.

Porosity, surface

Porosity in a die casting that is open to the surface of the casting.

Port

Opening through which molten metal enters the injection cylinder of a hot-chamber machine or is ladled into the injection cylinder of a cold-chamber machine.

Pouring hole/slot

Port through which molten metal is ladled into the cold-chamber of a die casting machine.

Powder coating

This method involves electrostatically spraying a premixed granulated powder onto a workpiece and then curing at an elevated temperature to obtain final coating properties. Powder coating has many advantages, including the absence of organic solvents, a wide choice of coating materials for many service conditions, minimal material waste, and easy handling.

Preheating

The process of heating a die casting die prior to making castings to minimize the thermal shock from the first few castings. Also applies to die heating prior to die placement in the machine, for more rapid die changing and onset of production.

Press, trimming

A power press (either mechanical or hydraulic) used to trim the flash, runners and overflows from die cast parts after casting.

Pressure tightness

A measure of the integrity of a die casting in which a fluid under pressure will not pass through the casting. The method of testing and the pressure used must be specified.

Process capabilities

The range, or variation, of critical casting quality parameters (such as dimensional tolerances) within which a particular die and machine combination will operate.

Quench

The cooling of a die casting from its ejection temperature to room temperature.

Quench, water

The cooling of a die casting from its ejection temperature to room temperature (or to nearly room temperature) by placing it in water.

Quick-Change

(1) Any construction for a tooling component that allows the component to be replaced without removing the tool or die from the machine in which it is operated. (2) Die casting die features and procedures, such as preheating, which enable dies to be changed on die casting machines with a minimum of interrupted production. Such features usually add cost to the original construction of the tool or die, but can save considerable machine downtime costs.

R&R

Repeatability and Reproducibility.

Radiograph

A picture produced on a sensitive surface, as a photographic plate, by electromagnetic radiation of wavelength less than 500 angstrom units. The most common is the X-ray. X-ray pictures of die castings can often reveal flaws inside the castings.

Radius

A convex arc blending two surfaces on a die casting or on the model from which a die casting is to be made. See **Fillet**.

Rapid prototyping

Production of a full-scale model of a proposed design more quickly and inexpensively than by traditional methods like single-cavity prototype die casting, gravity casting or machining. See also: Stereolithography, Selective laser sintering, Laminated object manufacturing.

Reclaim

The process of smelting trimmings, scrapped parts, dross and machine turnings back to original alloy specifications.

Refine

In magnesium melting practice, the removal of magnesium oxide and other suspended non-metallic matter by use of flux that preferentially wets the impurities and carries them to the bottom of the pot as sludge.

Reflective defect

A casting surface defect that “reflects” an undesirable surface condition of the die cavity steel. For example, fatigue or heating checking of the die steel may manifest itself as cracks and craters in the steel. This will leave raised features on the casting that “reflect” the die surface condition.

Release agent

A material that is applied to the surface of the die cavity to keep the casting from sticking to the die. Such materials are usually applied frequently, sometimes every cycle, and are usually applied by spraying. To facilitate the spraying, the material is mixed with water or a mineral solvent which evaporates from the cavity surface.

Remelt

Sprues, gates, runners and as-cast defective castings returned directly to the melting pot.

Glossary

Rheocasting

Another term for semi-solid metal casting.

Rib

A wall normal to a second wall or surface to strengthen or brace the second wall or surface.

Robber

See **Cathode robber**.

Runaround scrap

See **Remelt**.

Runner

A die passage connecting the sprue hole or plunger hole of a die to the gate or gates where molten metal enters the cavity or cavities.

Salt fog test

An accelerated corrosion test in which specimens are exposed to a fine mist of a solution usually containing sodium chloride.

Satin finish

A surface finish that behaves as a diffuse reflector, which is lustrous but not mirror-like.

Scale

A build-up of material that forms on the die cavity surface during the operation of the die casting die. The build-up material is usually a combination of the oxide of the metal being cast and the parting material. The scale leaves an imprint on the casting and in extreme instances can even change dimensions on the casting.

SDCE

Society of Die Casting Engineers, which merged with the American Die Casting Institute to become the North American Die Casting Association (NADCA).

Sealed chrome pickle

A treatment for magnesium consisting of a chrome pickle, followed by sealing in a dichromate solution.

Sealing of anodic coating

A process which, by absorption, chemical reaction or other mechanism, increases the resistance of an anodic coating to staining and corrosion, improves the durability of colors produced in the coating or imparts other desirable properties.

Section, heavy

Any place in a die casting where the thickness is significantly greater than (at least double) that of the majority of the casting.

Segregation

Non-uniform distribution of alloying elements, impurities, or microstructures.

Selective laser sintering (SLS)

A method of rapid prototyping which uses a modulated laser beam on specialized powders to transform CAD data into full size prototypes in polycarbonate, nylon, or investment wax.

Semi-bright nickel

Nickel plate, containing less than 0.005% sulfur, that requires polishing to give full brightness or is used as-plated for the bottom layer in a double-layer nickel plate.

Glossary

Shield

A nonconducting medium for altering current distribution on an anode or cathode.

Shot

Die filling or part of the casting cycle in which molten metal is forced into the die.

Shot peening

The procedure of impacting a metal surface with a high-velocity stream of metal shot or glass beads for the purpose of (1) cleaning or (2) improving resistance to stress corrosion by producing a compressive stress.

Shot size

The cubic volume of a die cast shot or the cubic volume of die casting alloy that a die casting machine is capable of injecting into a die. Shot sizes are sometimes expressed in weight or mass units.

Shrink mark

A surface depression, often called a shadow mark, that sometimes occurs at a thick section that cools more slowly than adjacent sections. Also known as a sink.

Shrinkage factor

See **Contraction factor**.

Shrinkage pits

A condition on a die casting where the solidification shrinkage has resulted in small holes on the surface of the casting. These holes are sometimes called "heat holes." When they form along the gate, they are called "gate holes."

Shrinkage, internal

Condition during the solidification of a casting where volumetric shrinkage results in the formation of a void inside the casting.

Shrinkage, solidification

Volume reduction that accompanies the freezing (solidification) of metal in passing from the molten to the solid state.

SIMA

(Strain Induced, Melt Activated) A wrought process for producing feed material for semi-solid metal casting. The metal is generally hot extruded and cold drawn.

Skin

See Die cast skin.

Sleeve, shot

The molten metal chamber of a cold-chamber die casting machine. This is a hardened steel tube through which the shot plunger moves to inject the molten metal into the die. See **Cold chamber**.

Slide

Portion of a die generally arranged to move parallel to the parting line. The inner end forms a part of the die cavity wall and sometimes includes a core or cores.

Slug

See **Biscuit**.

SMED

Single minute exchange of dies, a technique from Lean Manufacturing disciplines to reduce die set up times.

Glossary

Soldering

The sticking or adhering of molten metal to portions of the die following casting.

Solidification shrinkage

See **Shrinkage, solidification**.

Solution heat treatment

Heating an alloy to a suitable temperature, holding at that temperature long enough to allow one or more constituents to enter into solid solution and then cooling rapidly enough to hold the constituents in solution.

SPC, statistical process control

Statistical techniques to measure and analyze the extent a process deviates from a set standard.

Sprue

Metal that fills the conical passage (sprue hole) that connects the nozzle or hot chamber to the runners of a hot-chamber machine. (Most cold-chamber machines form a biscuit and have no sprue.)

Sprue pin

A tapered pin with rounded end projecting into a sprue hole and acting as a core to keep the casting in the ejector portion of the die.

Sputter coating

The formation of a deposit by the condensation of atoms or particles formed by ejection from a surface subjected to high-energy ion bombardment.

SQC, statistical quality control

Statistical techniques to measure and improve the quality of a given process.

Staking

A cold forming operation to a die casting. Staking is usually performed in a power press to bend tabs or swage heads onto studs.

Stereolithography

A method of rapid prototyping which converts 3-D CAD data into a series of very thin slices and uses a laser-generated ultravioliet light beam to trace each layer onto the surface of a vat of liquid poly-mer, forming and hardening each layer until the complete, full-size prototype is formed.

Strength, ultimate tensile

The maximum tensile (pulling) stress a metal can stand before rupturing.

Strength, yield

The stress at which a material exhibits a specified limiting permanent strain or permanent deformation.

Stress corrosion cracking

Cracking due to the combined effects of stress and corrosion. Usually this type of failure occurs as a fine hairline crack that propagates across the section without any exterior sign of corrosion.

Stress

Force per unit area. When a stress is applied to a body (within its elastic limit) a corresponding strain (i.e., change in shape) is produced, and the ratio of strain to stress is a characteristic constant of the body.

Glossary

Stress, thermal

Stress induced into a material when a temperature change causes a force trying to change the size or shape of the part, but the part is restrained and cannot re-spond to the thermally induced force.

T&T

Taper and Tolerance.

TQM

Total Quality Management.

Unit system

A die casting die built to a standardized design and dimensions. Also, a series of units, for a variety of castings, that are installed and run in the die holder as the need for various castings dictates.

Vacuum

A space completely devoid of matter, even gases. Shrinkage voids in a die casting can be a vacuum. It is not necessary for a void to include entrapped air.

Vacuum assist

The action of voiding the die casting die of gasses during or prior to the flow of molten metal to form the casting.

Vent

A thin narrow passage that permits air to escape from the die cavity as it is filled with metal.

Vibratory finishing

A process for deburring and finishing mechanically by means of abrasive media in a container subjected to high-rate oscillations.

Void

A large pore or hole within the wall of a casting usually caused by solidification shrinkage or gas trapped in the casting. Also, a blow hole.

Water line

See **Cooling Channel**.

Wet blasting

A process for cleaning or finishing by means of a slurry of abrasive in water, directed at high velocity against the parts being processed.

Wire brushing

The method of burr removal, edge blending and surface finishing by contacting the work surface with a variety of rotating wire brushes.

Yield

See **Casting yield**.

ZA

A designation followed by a number, which is used to designate a group of three zinc based casting alloys. The number indicates the approximate nominal aluminum content.

Zamak

An acronym for zinc, aluminum, magnesium and copper, used to designate the zinc alloys 2, 3, 5 and 7.

Glossary

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