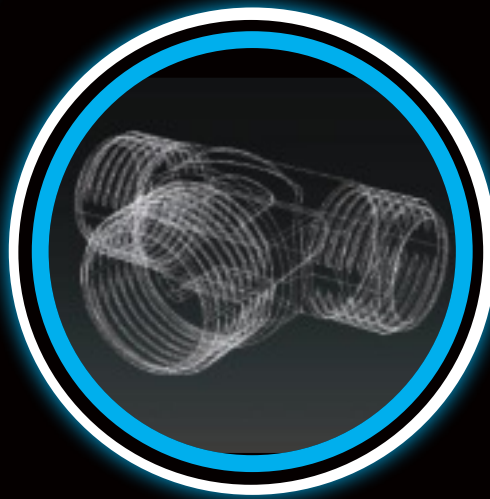
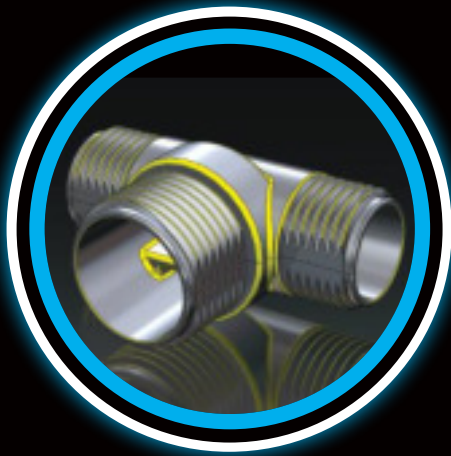


DESIGN AND DEVELOPMENT SOURCEBOOK

PRODUCT DESIGN FOR DIE CASTING



**in Recyclable
Aluminum,
Magnesium,
Zinc and
ZA Alloys**



**NADCA
DESIGN**

NORTH AMERICAN DIE CASTING ASSOCIATION

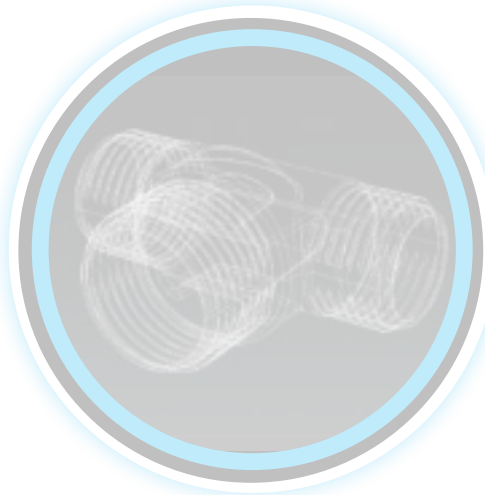
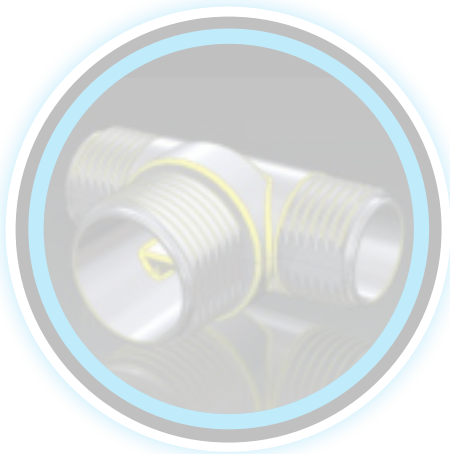
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Aluminum,
Magnesium,
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ZA Alloys**



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Casting Association



**NADCA
DESIGN**

NORTH AMERICAN DIE CASTING ASSOCIATION

PREFACE

Product Design for Die Casting was originally prepared and published for designers, engineers and specifiers through a cooperative effort of the die casting industry and the United States Department of Commerce. It was initially financed by contributing members of a marketing affiliate of the North American Die Casting Association (NADCA), and the U.S. Department of Commerce through a grant/cooperative agreement.

Acknowledgement is made to the selfless individuals, representing die casters, industry suppliers and engineers and managers, who spent many hours contributing, reviewing and verifying data. All known sources of published information on the die casting process as it applies to product design were researched.

Portions of the text and some of the illustrations in this manual were adapted from Product Design and Development for Magnesium Die Castings with the permission of the Dow Chemical Company. Several illustrations are reproduced with the permission of the International Lead Zinc Research Organization.

In addition to this book the North American Die Casting Association also provides die casting product design assistance through its NADCA Design program which consists of the following resources:

NADCA Design web site: www.diecastingdesign.org
NADCA Design seminars: www.diecastingdesign.org/seminars
Phone support: 847.279.0001
E-mail support: help@diecastingdesign.org

Designers, engineers and specifiers are also urged to consult NADCA Product Specification Standards for Die Castings, published by the North American Die Casting Association; these standards include standard and precision tolerances (including geometric dimensioning) for current production practices under varying manufacturing conditions. The standards also include Tooling, Alloy, Engineering & Design, Quality Assurance and Commercial guidelines.

For die casting produced with the semi-solid and squeeze casting processes the publication NADCA Product Specification Standards for Die Castings Produced by the Semi-solid and Squeeze Casting Processes is available.

Additional copies of this publication and other publications are available from the North American Die Casting Association:

North American Die Casting Association
www.diecasting.org
3250 N. Arlington Heights Rd., Ste. 101
Arlington Heights, IL 60090
Phone: 847.279.0001
Fax: 847.279.0002



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THE DIE CASTING OPTION

When functional products are designed for volume production, the high-pressure die casting process is one of the prime production options considered by product engineers.

Components can be cast at high speed from a range of durable metal alloys while faithfully capturing the most intricate design details. This ability to maintain close tolerances, often eliminating all machining, can make the process the optimum choice for lower volume production as well.

The introduction of new, higher-performing die casting alloys and process technology makes old design assumptions about the limitations of the process obsolete; dimensional specifications, draft angles, as-cast flatness, porosity reduction can be achieved to levels unheard of just a few years ago.

1.1 Die Casting's Advantages: Summary

This checklist summarizes the advantages of today's die casting process from the perspective of the product designer seeking to maximize product performance and minimize product cost.

- Modern process technology that insures consistent quality
- Freedom to design intricate configurations
- Net-shape casting economies, even at lower volumes
- Wide variety of available alloys and alloy properties
- The rigidity, look and feel of metal
- Meets moderate to high-strength performance needs
- Moderate to high impact and dent resistance
- Documented fatigue strength characteristics
- Pressure tightness for hydraulic and pneumatic components
- Bearing properties that often eliminate separate bearings
- Excellent sound damping properties
- Inherent EMI shielding for electronic applications
- High-quality surface finish for decorative applications
- Meets criteria for serviceability and recyclability

1.2 Advances in Die Casting Process Technology

The die casting process today has been well researched and systematically quantified in terms of thermodynamics, heat transfer and fluid flow parameters. This technology has been transferred to the die casting industry, where its use has made a significant improvement in the design of die casting dies, the die steel used in die construction, and in virtually all die casting production options.

Die casting machines today are being fitted with new, high-technology electronic systems that control production processes according to exact parameters and continuously monitor production output. Casting accuracy is greatly improved, variations from casting-to-casting are sharply reduced, and production costs are more closely controlled.

Today advanced die casting systems are producing castings with extremely close tolerances and reduced draft angles (in some cases zero draft) on selected features, eliminating finish machining operations. This casting precision has lowered the break-even point for die casting versus low-volume production processes and increased its economic advantages over high volume alternatives. The specific implications of these changes for the product designer are presented in this manual.

1.3 Developments in Die Casting Alloys

A wide range of alloys are used for die casting today. A separate section will deal in detail with the four families that currently account for most of the functional and decorative die castings produced in the United States: aluminum, magnesium, zinc, and ZA (zinc-aluminum). Copper, tin and lead are being die cast for certain specialized applications. Ferrous die castings are also being produced on a very limited basis.

Die casting alloys are precisely formulated to offer mechanical properties equivalent to medium-strength metals. They are generally several times as strong and many times more rigid than plastics, and the mechanical properties of the higher-strength die casting alloys compare favorably with powder iron, brass and low carbon steel. When compared with high-performance plastics or advanced composites, die casting alloys can often deliver the required product strength at a cost advantage.

New die casting alloys have been introduced and have proven their capabilities in full-scale production and field use. The methods now being used to produce them have been modified to reduce impurities, improve overall metal quality, improve product reliability, and reduce energy consumption.



Figure 1.1 Fog Light Housing

This die cast aluminum 383 fog light housing eliminated a two piece plastic and aluminum casting assembly. The reflective optics, pivot bosses and height adjustment features are included in one die cast part. The part is also leak proof and has thin weight reducing walls.

1.4 Die Casting's Range of Product Capabilities

Die castings are produced in a wide range of sizes and configurations, from precision components weighing less than one gram to a one-piece instrument panel for high performance automobiles. Integral housings for torque converters and automatic transmissions and intricate electronic components are typical of the size and complexity of die castings currently in production.

Figure 1.2 Rearview Mirror and Sensor Mount
The zinc No. 5 rearview mirror mount shown here is ready to ship immediately after dropping out of the die casting die and requires no additional processing. This die casting was designed around a humidity sensor and allows the mounting of the sensor, related wiring, and harnesses in the smallest possible footprint. Zinc No. 5 was used for its wear resistance, tensile strength and ability to cast thin-wall sections.



Products from nearly every manufacturing industry make use of die castings:

- Agricultural Machinery
- Automotive Vehicles
- Building Hardware
- Electrical and Electronic Equipment
- Hand Tools
- Home Appliances
- Industrial Products
- Instrumentation
- Lawn and Garden Equipment
- Office Furniture
- Office Machines
- Recreational Equipment
- Portable Power Tools

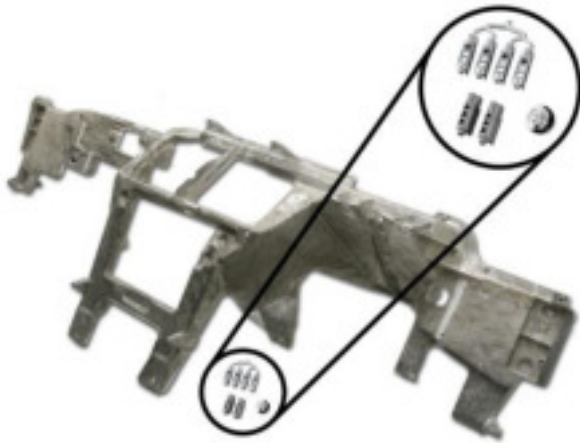


Figure 1.3 Example Size Range of Die Castings

The large magnesium 12.5 lb (5.7 kg) die casting shown here is an instrument panel that spans the entire area under the dash board of a vehicle. The four small zinc die castings shown in the foreground and magnified in the upper right corner are wire connectors weighing 0.096 oz (2.7 g) each. Coin shown: United States Mint Image

The following product capabilities highlight the qualities that can make die casting production the optimum product choice.

Intricate contours

The die casting process allows freedom to create extremely intricate contours with varying wall thicknesses over various sectors of the product. Where strength requirements are minimal, high-tech die casting processes are now producing components with ultra-thin walls. With die castings as opposed to plastics or stampings, the designer has much more latitude to design relatively thick walls for strength in some areas, and very thin walls for conserving material in others.

Rigidity

Component rigidity is analogous to strength; it is a function of both the modulus of elasticity of the material and the configuration of the component. Large size die castings that are designed primarily for rigidity, which is essential to minimize noise and vibrations, are being used for clutch and transmission housings in passenger cars and light trucks. On the other end of the scale, a die cast carrier for a high-speed computer printer was selected over filled plastics because it maintained precise alignment under high G-loads, at a weight of three ounces (85g).

Product strength

The product strength equation contains two key factors: material strength and product configuration. Die casting alloys offer a wide range of as-cast materials strengths, ranging as high as 64,000 ksi (440 MPa) ultimate tensile.

The designer can usually develop sufficient strength in critical features simply by providing adequate wall thickness in the die casting. Where additional strength is required, reinforcing features such as ribs, flanges, and locally thickened sections can be accurately computed and precisely cast.



Figure 1.4 Fishing Reel Frame

The die cast magnesium AZ91 fishing reel frame shown here replaced plastic and aluminum parts allowing a reduced weight while having exceptional density and surface quality and the ability to create complex geometry with varying wall thickness, while maintaining tight tolerances for mating components.

Surface finish

A variety of surface treatment processes are available to provide decorative, protective, or wear resistant surfaces for all die casting alloys. Zinc die castings can be economically electroplated to achieve a bright decorative chrome finish. The economics of electroplating, low die maintenance required to maintain a high-quality surface, and relatively high strength create many hardware applications for zinc die castings.

Impact and dent resistance

The impact and dent resistance of large die castings has been proven in the rugged drivelines of four-wheel drive vehicles. Medium-size die castings display similar properties in hand operated portable power tools. Small die castings, such as model cars and trucks, routinely survive impacts that are totally unpredictable!

Dent resistance is the ability of a component to withstand an impact load without undergoing permanent deformation. The moderate-to-high yield strength and low (compared with iron and steel) modulus of elasticity of die casting alloys allow the designer to develop die castings with surprisingly high dent resistance.

Fatigue strength

Die castings can be successfully used in fatigue applications by following appropriate design procedures, most of which apply to all materials. Fatigue strength has been documented for most die casting alloys. Published values are usually conservative and allow for casting variables such as porosity. High-tech die casting processes may improve component fatigue performance by minimizing the minor casting defects that initiate fatigue.

Pressure tightness

Significant progress has been made in the improvement of die casting process technology and in metal distributions systems (gates and runners of the die casting dies). This technology enables the die caster to greatly reduce the amount of entrapped gas porosity, which can affect machined or pressure tight castings. Inexpensive impregnation processes that seal surface porosity are also available to insure pressure tightness in die castings.

Bearing properties

Some die casting alloys offer very good bearing properties. Die castings made from aluminum alloy 390 are replacing iron in applications that require resistance to abrasion and wear. ZA alloys are being used to incorporate bearings into components, eliminating the need for bearings that are fabricated separately and inserted.

Sound damping

New studies indicate significant sound damping properties in zinc alloy, particularly ZA, die castings. The sound damping properties of magnesium alloy die castings has been demonstrated in automotive driveline components.

*Figure 1.5 Motorcycle Lower Crankcase
This aluminum die casting for the lower crankcase of a high performance motorcycle engine functions as the case for the crank, gear box and oil pumps, and is an integral part of the motorcycles frame. The final design eliminated costly secondary machining operations, and additional engine parts.*



EMI shielding

Die casting alloys have a level of electrical conductivity that provides inherent shielding from EMI and RFI (electromagnetic interference and radio frequency interference). This property gives die castings an economic advantage over plastics in many electronic applications. Plastics require expensive additions of metal powder fillers to their formulations or the use of special paints, coatings, fabricated metal or foil barriers, or multi-layer electroless nickel plating to provide EMI/RFI shielding.

1.5 The Economic Equation

Die casting holds a significant niche in the marketplace for the cost-effective production of components in large quantities. It can also prove economical at relatively low production levels when the as-cast part eliminates machining or several parts can be combined into a single die casting. The total cost of fabrication, installation, fastening and joining can often be significantly reduced. At the same time, die casting's high precision allows multiple die cast components to be accurately mated into a single larger end-product, without the costly machining that might otherwise be required.

One of the most important, but often overlooked, factors in the economic equation is the proven track record of die casting alloys, backed by several decades of continuous use and testing. In many cases, twenty-year data are available. This documentation enables the designer to predict the long-term performance of die castings with a significant level of confidence. Warranty costs may be accurately predicted, or virtually eliminated, as desired. Product liability may also be sharply reduced.

1.6 The Benefits of Designing for Manufacturing

Design management is increasingly adopting the approach that calls for early consultation with the most likely production resources for a give product. The procedure is not new, but now goes under many new names such as design for manufacturing, concurrent engineering, process-driven design, and simultaneous engineering. The meaning is the same: for optimum results, manufacturing process requirements should be fed into the design of the product at the preliminary design stage.

The traditional method of designing first and letting manufacturing considerations come later has had consequences which are no longer being tolerated: quality problems, delays in product introduction and serious product shortcomings. Product designers who work closely—and early—with their custom die caster are maximizing material and process benefits. Process consultation early in the design program is the key.

1.7 Miniature, Heat Treated, High Vacuum, Squeeze & Semi-Solid Metal Casting

Miniature Die Casting

Miniature die casting is similar to conventional hot-chamber die casting, but capable of much faster cycle times, tighter tolerances and minimal secondary operations. The process is capable of producing castings ranging in weight from fractions of an ounce up to 16 ounces. Tolerances less than .002 of an inch with virtually no “part-to-part” dimensional variation are routinely achieved.

Flash-free, net-shape components of complex design can be produced as miniature die castings from a variety of metals, specifically zinc, zinc-aluminum and magnesium. Zinc die casting components are often used “as cast” with no further secondary finishing. Various surface finishes can be applied, however, to increase corrosion resistance, provide aesthetic appeal, and/or improve mechanical properties. It is not uncommon for finished miniature die castings to cost as little as a few cents per part. One-time tooling charges range from \$7,000 to \$35,000, depending on the complexity of the part and cavity configuration.

A complete discussion of the miniature die casting process appears in the NADCA Product Specification Standards for Die Casting publication, Section 4.

Heat Treated Die Castings

The vast majority of die castings are used in the as-cast condition. The reason is due to gasses entrapped in the castings, which tend to expand and cause surface blistering when the castings are heated to elevated temperatures during heat treatment. However, recent research has shown that under certain conditions die castings can be heat treated to improve strength and ductility. A more complete discussion of heat treating die castings is provided in Chapter 4 of this publication.

High Vacuum Die Casting, Squeeze Casting and Semi-Solid Metal Casting (SSM)

The high vacuum, squeeze and semi-solid metal casting processes represent a new range of machine casting technologies that combine the near-net-shape benefits associated with traditional high-pressure die casting with innovative approaches to produce highly dense, heat-treatable, light alloy parts.

With high vacuum die casting, the fast injection speed used by conventional die casting is maintained, but powerful vacuum systems reduce the air pressure in the die cavity and shot sleeve to 50 milli-bar or less (1/10 of an atmosphere), so there is little gas remaining in the cavity to become trapped in the castings. Therefore, high vacuum die castings can be heat treated to maximize properties.

Squeeze and semi-solid casting are different, as they employ relatively slow ingate velocities to minimize turbulence during die filling, and high pressures are applied to the castings throughout solidification to consistently cast high integrity parts capable of solution heat treatment. By preventing gasses from being trapped during the die filling process, high vacuum, squeeze and SSM casting can produce parts which can be welded or joined by other fusion methods without blistering or outgassing. The resulting castings allow cost-effective conversions from many parts produced by traditional premium shaping processes such as forging, permanent mold casting, sand casting and high-strength fabrication.

Unlike low pressure sand, investment or permanent mold casting processes, it is unusual to find micro porosity in squeeze or SSM cast parts. This lack of micro porosity, together with a finer microstructure, means that these castings typically exhibit superior mechanical performance compared with these manufacturing processes.

Squeeze casting process begins with molten metal, which is injected into the cavity at low speeds and held in the casting die, under high pressure, until solidification is complete. Aluminum components are being produced by squeeze castings varying in size from around 4 oz. (112 g) to 30 lb. (14 kg).

SSM casting begins with a semi-solid mass of metal. Since it is already half solidified at the time of casting, high production rates can be achieved. Aluminum SSM parts are being produced from less than 0.1 oz. (2g) to more than 20 lb. (9 kg).

High vacuum die casting, squeeze casting and SSM casting are described in more detail in Chapter 5 of this book, while a complete discussion of these high integrity die casting processes appears in the NADCA Product Specification Standards for High Integrity and Structural Die Casting Processes.

1.8 Serviceability & Recycling

Serviceability and recycle-ability are often required to be integrated into a products design, die castings offer extra capabilities in these areas. The energy-saving advantages of recycling aluminum are well-known, but unlike many engineering plastics, all die castings are inherently recyclable, and have a long established reclamation record in the metal recycling stream.

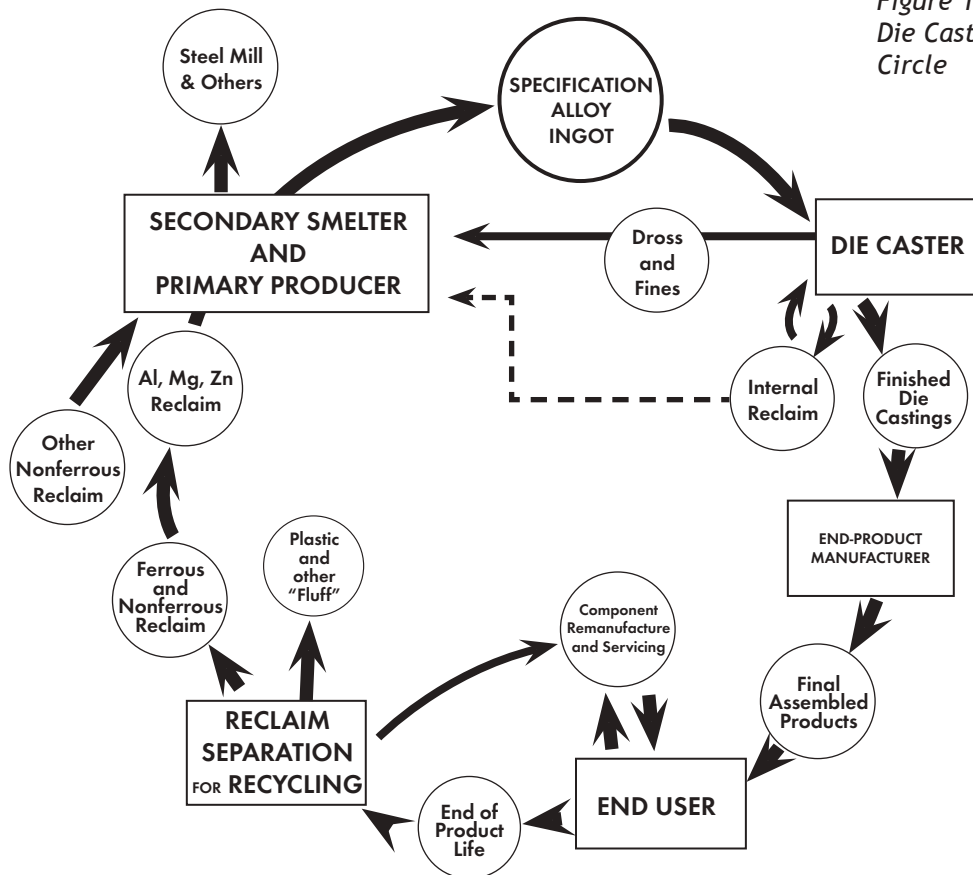


Figure 1.6
Die Casting Recycling Circle

In selecting materials and manufacturing processes which meet environmental concerns, the product designer should ask these questions:

- Does material allow for efficient and economical disassembly, maintenance, repair, refurbishing, or remanufacturing of the product to extend its life, where this is a design benefit?
- Is the material readily recyclable at the end of its useful life?
- Can the material be recovered and reused in high-performance applications?
- Is the necessary infrastructure in place to make recycling of the reclaimed material a practical reality?

Increasingly product designers are considering their material/process choice based on the important factors of recycling and serviceability.



PRODUCT DEVELOPMENT

Developing an optimum product design is similar, in most respects, for any material/process combination. In capitalizing on today's advanced die casting processes, however, specific attributes of die casting alloys and the die casting process offer opportunities for distinct product advantages and cost reductions that require somewhat different tactics. These should be applied when a totally new product is being developed, and are critical when an existing product made from another material or process is being redesigned for die casting.

When a design is started from a clean sheet of paper, the designer must disassociate the design constraints from the materials and processes traditionally employed. This is the path to the optimum cost-effective results. Three principles are helpful:

- Think function, before traditional form.
- Performance must be sufficient, not equal.
- Match material properties to performance specifications.

These principles can be implemented by following a systematic assessment procedure.

1. Function Before Traditional Form

In many cases form does not reflect function, but is instead determined by the traditional material and process employed. Therefore, it is essential to think of the function(s) that the component is to perform, and disregard the traditional or previous process form. For example:

- A powdered metal part may have relatively thick walls in structural areas, with through holes to remove excess material. A die casting typically achieves maximum structural properties by utilizing thin walls with corrugated sections or rib reinforcements.
- An injection molded plastic component may be attached with through bolts and nuts, which are required because the viscoelastic (relaxation) behavior of the plastic makes it necessary to apply only compression loads. Or it may utilize metal inserts. A die casting with superior creep and relaxation properties can employ tapped threads to an advantage.
- A billet machined part may have block like features to obtain functions, for example: square pockets, sharp edges, flat and cylindrical surfaces. The same part designed as a die casting may obtain function with smooth filleted pockets, generously radiused edges and contoured and shaped surfaces.

Figures 2.1 and 2.2 illustrate the application of the “function before traditional form” principle to die casting product design.



Figure 2.1 Appliance Pulley

The small pulley on the left for a home appliance was produced from 1-in. (25 mm) diameter bar stock on automatic screw machines. The diameter is controlled by the need for a tapped hole which receives a set screw. The die cast version on the right uses a smaller diameter hub with a raised boss which accommodates the set screw.

The function before traditional form principle can often be applied to die castings made a few years ago. In many cases, wall thicknesses have been dictated by the limitations of then existing casting technology, so that the component was over designed in terms of functional and structural criteria. Yesterday’s die castings can often be redesigned and produced by today’s advanced die casting technology with thinner walls, reduced draft, and closer tolerances that more nearly reflect the functional criteria.

It is important to note that the definition of form in “function before traditional form” is the traditional shape that is required by specific manufacturing processes. This is not to be confused with a purposely designed form or shape that may provide value or function to the product design. The die casting process easily produces complex design shapes that may be difficult, costly or impossible to produce with other manufacturing processes. Figure 2.2 illustrates the capability of the die casting process to create complex design shapes that are visible on the outside of the radio housing shown.

2. Performance Must Be Sufficient, Not Equal

Components are often over designed because the dimensions of structural features are governed by economics or manufacturing constraints, rather than design criteria. A die cast alternative must, of course, be designed to develop properties that clearly meet product standards. It is not necessarily required, however, that a die casting match the performance of an existing over designed component. For example:

- Cast iron was formerly the material of choice for automotive drivetrain components because of its strength and rigidity. Aluminum, magnesium and ZA die castings, employing carefully calculated wall thicknesses and rib reinforcements, are replacing cast iron at substantial weight reductions.
- Oil impregnated sintered bronze bushings, which offer good bearing properties, are often selected for bearing applications. However, die casting alloys, particularly the ZA group, are now being used for components that were redesigned to incorporate the bearing into the die casting itself, eliminating separately fabricated bearings.



Figure 2.2 Radio Housing
The radio housing shown here incorporates functions required in an ergonomic way taking advantage of the design options provided by the die casting process.

3. Match Material Properties to Performance Specifications

The material properties apparently suggested by performance criteria are not always relevant. For example, a component required to withstand minor impacts without denting, such as a gravel impingement, may seem to suggest a material with high impact strength. However, impact strength applies when the material is forced through the plastic range to rupture, whereas dent resistance implies minimal or no yielding.

Yield strength and modulus of elasticity are the properties critical to dent resistance. The moderate to high yield strength and relatively low modulus of elasticity of die casting alloys often make die cast products equal or superior to products made from cast or wrought ferrous alloys when dent resistance is required.

4. A Procedure to Assess Alternatives

The following procedure will help the designer to assess the optimum material/process alternative.

State Objectives

Begin with a concise, descriptive statement of product objectives. The example die casting designs found throughout this book, which illustrate the unusual and innovative as well as the traditional in die casting applications, will be helpful. Also documented are the techniques for reducing the application at hand to the optimum form for die casting.

Review Product Constraints

The following section presents a guide to systematic assessment of the working environment, which helps to interpret product constraints in the context of the operating environment. Subsequent information on economic assessment directly compares die casting with alternate materials and processes, and is helpful in assessing economic constraints.

Configure for the Material/Process

During the preliminary design phase it is important to configure the product for the material/process combination to be employed. Information presented later on product design, alloys and the die casting process offers a comprehensive guide to developing the optimum configuration for die casting. Guidelines on structural criteria, bearing applications, fastening and joining, finish machining, and surface treatment are useful in this phase of the program.

Involve the Die Caster Early

The die caster should be involved in the product development by the time the program reaches the preliminary design phase. In some cases, involvement should begin sooner. Key information will be presented in this manual to build a working knowledge of the die casting process as a sound basis for interacting with the die caster.

Verify the Design

When the preliminary design is complete, it is usually necessary to verify it by finite element analysis (FEA) or fabricating and testing prototypes. A review of applicable prototyping strategies will assist the designer in developing a strategy that is appropriate to the die casting process and the application under development. It also identifies properties that are and are not evaluated in the selected prototyping process.

Produce and Test

The procurement and testing of production samples normally completes the product development process. At this point the prototyping strategy should be reviewed to determine which of the properties of the end product were or were not adequately reviewed during the prototyping phase.

2.1 Working Environment

This section presents a systematic plan for assessing the working environment of a proposed or existing product to determine if advanced die casting processes will produce cost-performance benefits.

A vast combination of materials and processes are available that may be applicable to any product. The number of combinations will continue to proliferate as new materials and processes are developed. The entire spectrum can be reduced to a matrix of workable size by a systematic analysis of the working environment. This analysis will also identify opportunities for die castings that would not otherwise be apparent.

The analysis may be divided, for convenience, into seven categories:

- Operating temperatures
- Applied loads
- Assemblies
- Electrical/electronic requirements
- Thermal conductivity
- Corrosion
- Unexpected and unquantifiable conditions

1. Operating Temperatures

The temperature at which the component is expected to operate is often a limiting factor in material/process selection. A systematic assessment of environmental temperature may indicate that a die casting can function satisfactorily even though the temperature appears to be prohibitive. Three criteria should be considered:

- Cyclic versus steady state
- Continuous or transient
- Internal and external

Cyclic versus steady state

The maximum temperature in a cyclic environment does not necessarily indicate the temperature that the component will reach. For example, aluminum and magnesium pistons function in gasoline engines at cyclic temperatures with maximums in excess of 3000°F (1648°C), while gas turbine wheels require special high temperature alloys to operate at 2200°F (1204°C). The 3000°F (1648°C) piston exposures are a brief portion of each cycle, while the turbine wheels are exposed to a continuous flow of hot gases and reach the indicated gas temperature.

Continuous or transient

Transient temperatures, or “spikes,” are also relatively brief and occur periodically or seldom. They typically occur when a heat-generating device, such as a furnace or internal combustion engine and its cooling equipment, is shut down and the environmental temperature rises briefly while the heat is dissipated by free convection. When the maximum, or spike, temperature is used as the design criterion, the component may be over designed, or a viable material/process option excluded. Either may contribute to excessive cost.

Internal and external

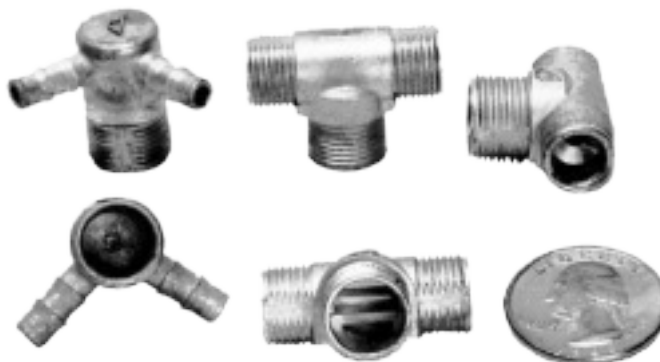
Steady state external temperatures may only partially indicate the true operating temperature of a component. For example, automotive fuel pumps are located under the hoods of vehicles where the operating temperature frequently reaches 220°F. The pump is also exposed to flowing fuel on the inside which is at a much lower temperature. The actual operating temperature of the pump is between the two, and is substantially lower than the under hood air temperature.

The components shown in Figure 2.3 illustrate an application where die castings did not reach the temperature of the external environment. In some cases a prototyping program is useful or necessary to optimize the design or verify alloy selection.

2. Applied Loads

Applied loads must be assessed in terms of the stress levels or the deflections they produce. Conventional methods for calculating stresses and deflection, ranging from rudimentary stress formulas to finite element analysis, can be applied to die castings. Four types of load should be assessed.

*Figure 2.3 Diesel Engine Fuel Fittings
Two zinc die cast fittings (shown in different positions) for a diesel engine injection system require no finish machining operations. Engine fuel produces a cooling effect which maintains metal temperatures below that of the engine environment.*



- Long term or continuous, which may induce creep or stress corrosion cracking.
- Short term, applied relatively few times. Data on mechanical properties can usually be directly applied.
- Cyclic, repeated thousands or millions of times, inducing fatigue failure.
- Impact, applied once or very few times, causing gross distortion or fracture.

Information presented later on strength, rigidity and endurance gives guidelines for applying the mechanical properties of die casting alloys to all four load types. The mechanical properties of die casting alloys vary widely. In general, they are superior to plastics. The higher-strength alloys are equivalent to mild iron, steel, and brass alloys, and all are lower than specially alloyed or heat treated iron and steel alloys.

3. Assemblies

Assemblies present major opportunities for a die cast product advantage. In many product applications, the individual parts of a multiple part assembly can be combined into one die cast part. Combining multiple part assemblies into one die cast part leads to reduced cost and often improved reliability. Replacing multiple parts assemblies with a single die casting is one of the most powerful design advantages provided by die castings.

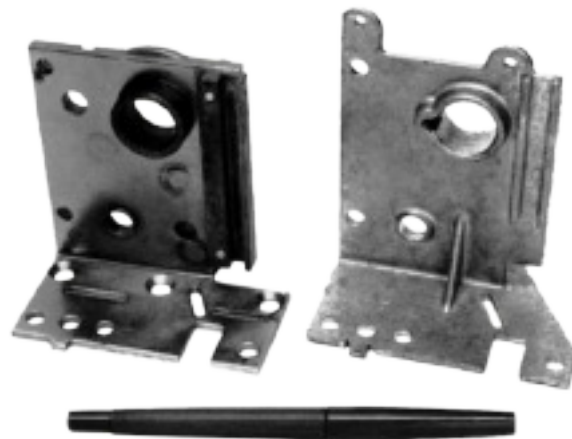
Due to the unique capability of combining multiple parts into one part, die castings are often placed in contact with other stationary and moving parts. These mating parts often consist of other die castings and parts made of dissimilar materials.

Three characteristics must be considered when using die castings with mating parts in an assembly.

- Dissimilar materials may require special design measures, especially at attachment points, if there is sufficient difference in coefficients of thermal expansion and operating temperatures vary widely. Dissimilar materials may also have the potential for galvanic corrosion.
- The optimum method of attachment may depend on the materials. For example, the creep properties maybe prohibit or permit the use of tapped threads and press-fit inserts. Ductility may prohibit or permit crimping, staking, and swaging.
- Mounting surfaces may require more or less dimensional precision, depending on the stress response in both the casting and interfacing member, and the effects of long-term stresses on them.

Figure 2.4 Bearing Brackets

The single die cast bracket on the right replaced the seven part stamped steel bracket assembly on the left. The steel bracket consisted of: two steel stampings, two sintered bronze bushings, a guide, and two guide screws. All seven part features were integrated into one single die cast bracket design shown on the right, which requires only one finishing operation, reaming the bushing bores.



4. Electrical/Electronic Requirements

The proliferation of electronic devices in commercial, business, industrial and consumer products, particularly those that generate high frequencies, has caused problems from electromagnetic interference (EMI, formerly called radio frequency interference or RFI). The problem has resulted into the adoption of military, foreign and ASTM standards, and action from the Federal Communications Commission. In addition to shielding the devices that generate EMI, those devices that may be adversely affected by externally generated EMI should also be shielded to ensure operating integrity.

A very effective and practical way to achieve EMI shielding is enclosing the device within a conductive cover. When EMI impinges on a conductive cover, ohmic currents are induced in it, and dissipated as heat. EMI requirements have added substantial cost to plastic enclosures, which must add shielding fabricated from foil or mix metal particles into the plastic formulation to develop conductivity. The inherent electrical conductivity of die casting alloys is usually sufficient to meet EMI standards on enclosures designed to meet impact and strength criteria.

5. Thermal Conductivity

The thermal conductivity of die castings may be used to advantage when thermal energy needs to be transferred or dissipated. Die castings are frequently used as heat sinks; often adding the heat sink function to already existing features of the product design. Gear cases, transmission housings and other enclosures for mechanical systems often benefit from the thermal transfer properties of die casting alloys resulting in lower operating temperatures and therefore longer fluid and mechanical component life. In many cases, the as-designed geometry of the die casting is enough to provide adequate thermal transfer. For higher performance thermal transfer, fins may be added to the die casting.

6. Corrosion

Die casting alloys are subject to two types of corrosion: atmospheric and galvanic. Atmospheric corrosion is caused by the chemical action of substances in the atmosphere—primarily water and pollutants—on the surface of the component. The process usually forms a coating on die castings that tends to retard further action.

Figure 2.5 Microwave Radio Enclosure
As is demonstrated by this enclosure, die castings offer advantages over plastics in isolating EMI interference in electrical and electronic enclosures. Die casting alloys are electrical conductors, which is essential to EMI shielding. The Dimensional precision and stability of die castings makes it possible to maintain a close fit between adjacent parts preventing EMI leakage. The thermal conductivity of die casting alloys allows the die cast part to function as a heat sink, often eliminating the need for cooling fans that would be required with plastic or steels.



Therefore, die castings require no corrosion protection in many applications. Where corrosion protection is required, a variety of corrosion protection systems, described in this manual, are available.

Galvanic corrosion is an electrochemical reaction occurring at the interface of dissimilar metals in the presence of an electrolyte (liquid capable of conducting electricity). Aluminum, magnesium, and zinc are active metals and sometimes require measures to prevent galvanic corrosion. The measures are usually simple to achieve and do not add significantly to the cost of the component. Typical measures are:

- Select alloys that are galvanically compatible
- Design to eliminate features that trap and retain moisture
- Provide a moisture proof barrier at the interface

Detailed information on galvanic corrosion is given in chapter 3 Assemblies.

7. Unexpected and Unquantifiable Conditions

The product engineer must try to foresee unusual conditions that may occur, and give them proper attention to ensure product integrity. Such conditions occur when interacting components fail, operating temperatures go out of design limits, maintenance is not adequate, or the component is improperly used or modified. Some conditions that cannot be quantified produce beneficial effects. For example, the oil film that forms on components in the engine compartment of a vehicle affords protection from corrosion.

Conditions that might contribute to failure must be evaluated and a reasonable level of protection (margin of safety) established. Where possible, the system should be fail-safe. That is, it should fail in a manner that produces a safe, rather than unsafe condition. Where this is not possible or practical, failure should at least not be catastrophic.

Some conditions, such as stone damage and environmental pollutants, cannot be quantified, and design parameters must be determined experimentally. Published values of mechanical and physical properties are included in this manual to provide a qualitative guide for evaluating these conditions.

2.2 Structural Criteria

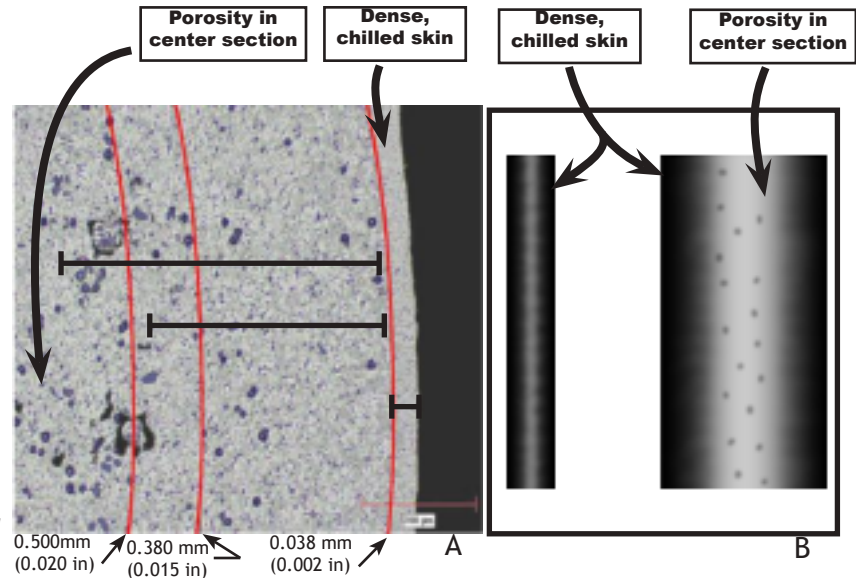
Die castings are designed to meet structural criteria in many applications. Conventional formulas for stress and strain and computerized technology such as finite element analysis (FEA) are commonly employed to optimize product designs. Although analytical methods can often predict product performance accurately, they are not usable when inputs are not quantified. Such methods also may be unjustified when the components is unusually complex and a cycle of testing and modification is relatively simple.

Mechanical properties of die casting alloys are compiled from tests performed on specially prepared specimens. The properties of the specimens may vary from the actual die castings, primarily because of solidification patterns. Metal at the surface of a die casting solidifies most rapidly, forming a dense, fine-grained structure with higher strength than underlying metal (sometimes called “skin effect”). See Figure 2.6.

This dense surface is also free from porosity, which may occur in the interior of the section. Therefore, design parameters such as wall thicknesses and changes in mass of contiguous features may cause the mechanical properties of the die casting to vary somewhat from tabulated data and from other features in the same casting.

Figure 2.6 Skin Effect

Due to rapid solidification in the die, a die casting's outer skin has a dense, fine grained structure with a higher strength than underlying metal. According to Borland and Tsumagari (2006), 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 shown in micrograph A. and as portrayed in pictorial image B.⁶



1. Stiffness, Strength, Fatigue and Impact Performance

The structural performance of a die casting usually depends on four mechanical properties: modulus of elasticity, tensile strength, fatigue strength and impact strength.

- The modulus of elasticity is not affected by casting parameters. Therefore, analytical methods for computing stress and deflections to the yield point can be applied to die castings.
- Ultimate tensile strength and yield strengths may be affected by casting parameters, and some alloys are more affected than others. Designing die castings to published stress levels is not usually recommended unless the design anticipates that wall thicknesses will be increased in critical areas and allows for the die casting die to be modified as needed. Where strength of a feature is critical, it is essential to work with the die caster to establish the levels of performance that can be achieved and agree on the test and inspection procedures from maintaining the required strength.
- Die casting alloys do not reach a distinct endurance limit as do steel alloys. Published values for endurance limit specify a very high number of cycles of fully reversed loading, typically 5×10^8 , beyond which there is very little decline in stress level at failure. Fatigue is affected by porosity; minute cracks that initiate fatigue failure begin more readily at individual pores. Die casting process controls that reduce porosity improve fatigue performance.
- Impact failures are very difficult to predict by analytical methods, usually because the inputs cannot be quantified. Published values of impact strength are primarily used to predict the relative performance of two alloys in a given application.

Stress, strain and fatigue in die castings can be handled by conventional formulas and computerized programs. A publication addressing specific stress calculations and deflections in zinc die castings is available through zinc research, see References 1,4 at the end of this chapter.

2. Creep and Dent Resistance

Two other categories of structural performance relevant to die castings, which are not readily handled by standard methods are creep (and relaxation) and dent resistance.

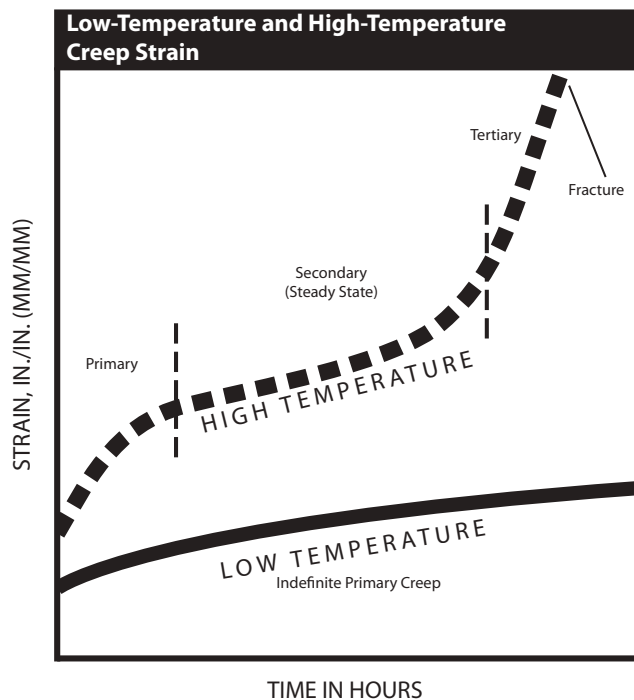
Creep

Creep is a very slow flow or shifting of material causing permanent shape change at stress levels below the yield point of the material at elevated temperatures. The temperature at which creep begins, and the rate at which it progresses, are generally indicated by the melting point of the alloy; the higher the melting point, the higher the threshold temperature and the slower the rate.

The deformation at higher temperatures progresses through three distinct phases: primary, secondary and tertiary. The three phases are shown schematically in Figure 2.7.

Figure 2.7

Low-temperature and high-temperature creep strain of a material on loading versus time at constant engineering stress and temperature. The curves are schematic, with the high-temperature curve depicting all three stages. The actual shape is determined by material, alloy variations, stress level and temperature. Primary and secondary creep are generally considered in design. Total creep decreases rapidly with reduced stress levels; in one alloy a 50% reduction in stress reduces creep deformation by 90%. The low-temperature curve describes aluminum and magnesium alloys at room temperature.⁷



At higher temperatures, primary creep—which is the shortest phase (in terms of time)—begins at a relatively fast, diminishing rate. The point at which the rate becomes constant is considered the end of the primary and the beginning of the secondary phase. Secondary creep, the longest phase, progresses at a constant rate. There is no loss of strength during the primary and secondary phases. The tertiary phase begins when the rate begins to increase. Its progress is comparatively rapid, and the rate continues to increase. The material loses strength during this phase until it permanently changes shape and failure occurs.

Creep must be considered when the following conditions occur.

- Applied loads are continuous, such as in swaged, riveted and threaded connections and in components such as clamps.
- Operating temperatures and stress levels are above the threshold continuously or for a long intermittent periods, such as internal combustion engines, lighting fixtures and industrial equipment.

Creep is not a consideration under the following conditions:

- Applied loads are short-term intermittent or reversing, such as hardware for office furniture, and door and window mechanisms.
- The operating temperature and stress do not reach the threshold for the alloy.
- The operating temperature and stress exceed the threshold for only short durations, such as the temperature spikes that occur when internal combustion engines and industrial equipment is shut down and latent heat dissipates while the cooling system is inoperative.

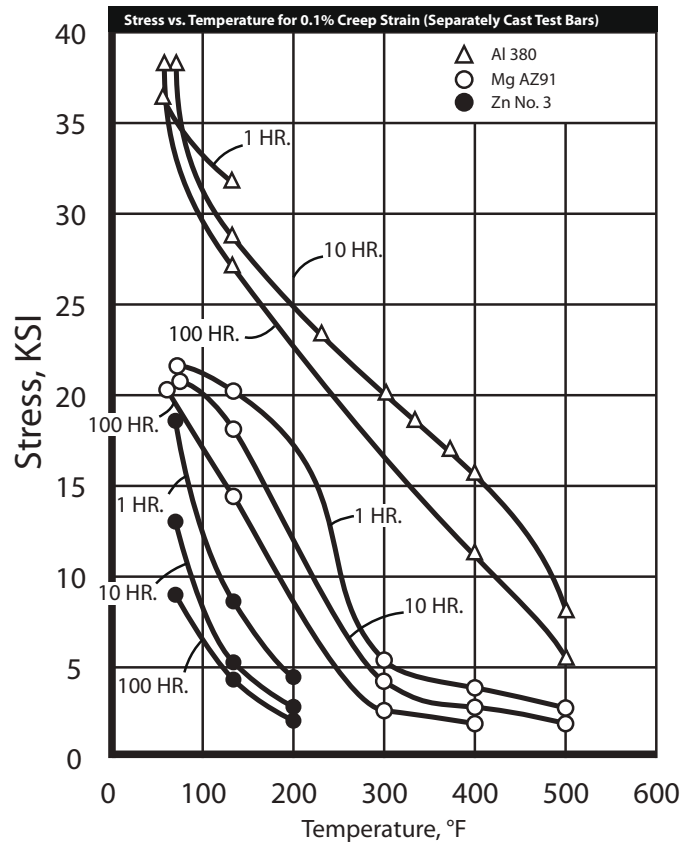
Creep is expressed as the stress required to produce a prescribed strain at a prescribed temperature over a prescribed time period. A reference point for secondary creep is 1% elongation at 100,000 hours (approximately 11.4 years). Data are usually taken on specimens subjected to uniform tensile stress and uniform bending moments. The data generated are difficult to apply quantitatively in real-world applications because they are based on pure loads with no variations in load or temperature. The data are useful for eliminating some alloys from consideration and for comparing the relative merits of several alloys in a given application. See Figure 2.8 for a comparison of creep profiles at varying temperatures for the most common aluminum, magnesium, and zinc die casting alloys.

Relaxation is a variant expression of creep. The term applies to conditions, such as interference fits and swaged joints, where stress (and consequently the retained load) diminishes while there is essentially no change in dimension.

Where an analysis of operating conditions indicates that creep can occur, the following design procedures will minimize the effects and often achieve an acceptable design.

- Design to reduce or eliminate bending, tension and shear and keep the material in compression. For example, through bolting with steel bolts, nuts and washers is preferable to bolts in tapped holes because the thread loads are in the steel rather than the die casting.
- Reduce stress levels in critical areas. For example, washers under nuts and bolt heads and increased depth and diameter of threads increase the area of load-carrying metal.
- Utilize additional methods of retention at joints, such as bonding or staking, where members are retained by press fits.

Figure 2.8
 Stress vs temperature to produce
 0.1% creep strain for aluminum 380,
 magnesium AZ91, and zinc no. 3.
 (separately cast test bars)³



Dent Resistance

Dent resistance indicates the ability of a component to withstand an impact without permanent deformation. A component resists denting by storing energy within the elastic range of the material. The amount of energy that can be stored is proportional to the stress and the strain at the elastic limit. Dent resistance is different from impact resistance in that stress levels do not exceed the yield point, whereas impact strength is based on deformation through plastic range to the point of rupture.

Since stress is proportional to strain in the elastic range of most alloys, the energy absorbed within the elastic range can be expressed in terms of the yield point and modulus of elasticity. For a given configuration with all other factors equal, the comparative energy absorbed by a material is proportional to:

$$\frac{Y_s^2}{(2E)}$$

Where: Y_s = yield stress
 E = Modulus of Elasticity

This factor should be used as a design guide, for comparative purposes only, for the following reasons:

- Tabulated stress data are generated at low strain rates. Impacts impose very high strain rates that develop higher stress levels at yield.
- In a comparative design of two different materials, all other factors are rarely equal.

In view of these restrictions, the data in Table 2.9 can serve as a useful guide in assessing the dent resistance of various material options.

When the anticipated accidental load involves dropping the product, material density should be factored into the comparison. For example, an aluminum die cast pulley will not weigh as much as a similar zinc die casting. The lower dent resistance of aluminum may be offset by the lower amount of energy absorbed in comparative drop tests.

Table 2.9 Properties Relating to Dent Resistance

Alloy	Yield Stress (ksi)	M.O.E. (ksi x 10⁻⁶)	ys²/2E
Die Casting Alloys			
380 aluminum	23	10.3	26
AZ91 magnesium	23	6.5	41
390 aluminum	52	11.8	52
ZA-8	41	12.4	68
Zinc 3*	31	6.3	79
ZA-27	57	11.3	143
Sheet Steel			
40 ksi	40	29.5	27
60 ksi	60	29.5	61
90 ksi	90	29.5	137
Powdered Iron			
FC-0205-45	50	19.5	64
FC-0508-60	70	17.5	140

*Based on the secant modulus at the yield point. Comparative performance in bending will be somewhat better than indicated because the stress-strain relationship is nonlinear.

3. Effects of Temperature

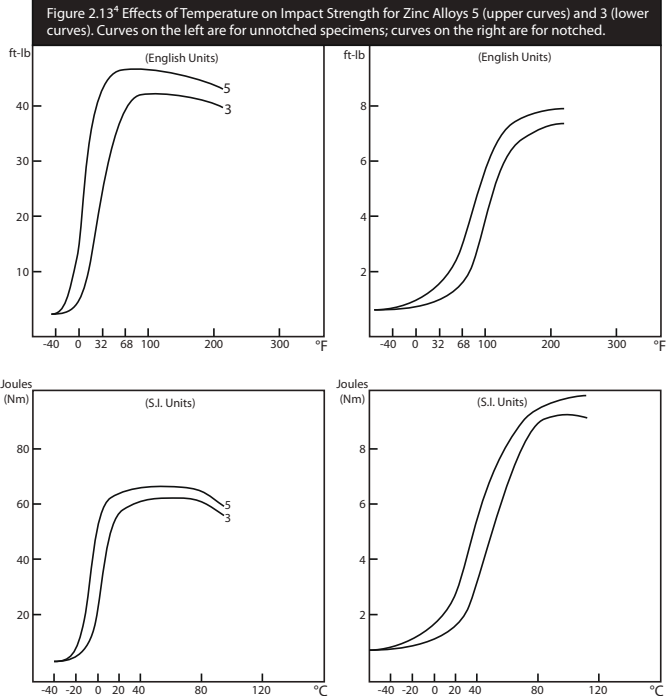
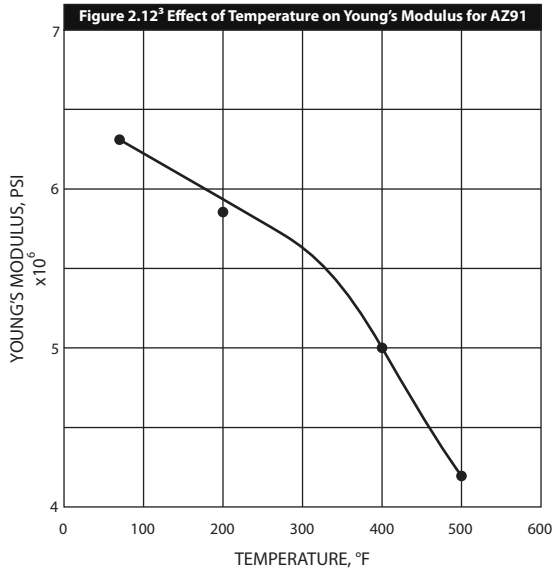
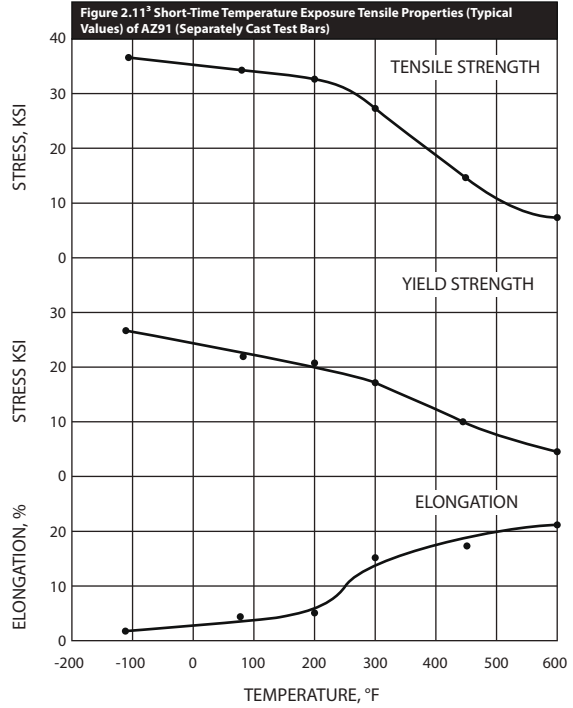
Die castings often operate at temperatures that affect mechanical properties to some extent. Temperature effects on die casting alloys are usually greater than on brass, iron and steel, an important consideration when die castings replace brass, iron, or steel components. Conversely die castings are usually less affected by temperature than injection-molded plastics, so that designs may often be simplified when converting from those materials. Temperature effects on die casting alloys are not generally prohibitive, provided that they are addressed adequately in the design. The effect of temperature on the mechanical properties of aluminum, magnesium and zinc and ZA alloys have been documented and published. (See Table 2.10² and Figures 2.11³, 2.12³, 2.13⁴, and 2.14⁴)

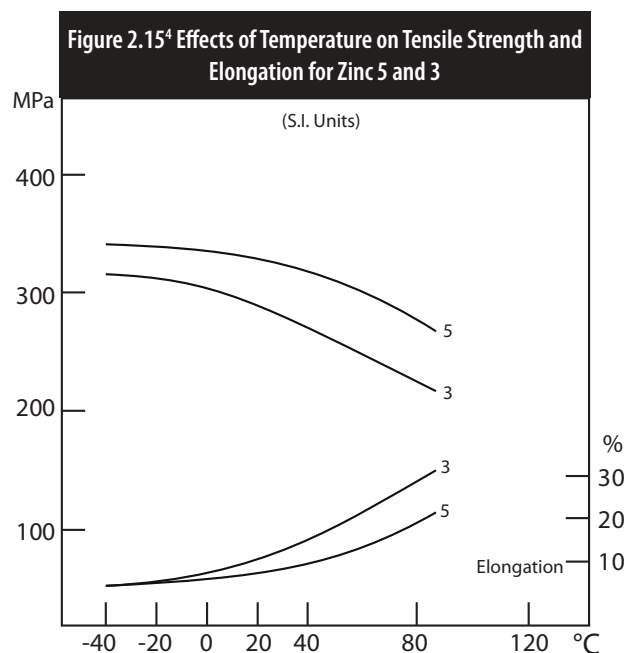
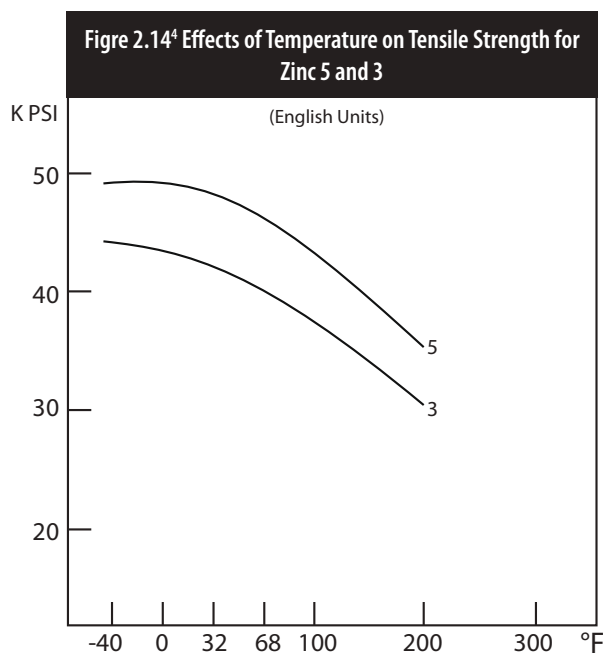
The following summary indicated the general effects of temperature changes on mechanical properties of die casting alloys. The amount of change depends on the alloy composition. If the anticipated change in properties is significant, product performance should be verified by test.

- Tensile and yield strengths generally increase slightly as temperatures are reduced. As temperatures increase, they decrease at a progressive rate.
- Modulus of elasticity is generally more stable than strength, with some decrease expected at elevated temperatures. The decrease has been documented for AZ91 magnesium alloy.
- Ductility decreases uniformly with decreasing temperature and increases with increasing temperature.
- Impact strength decreases with decreasing temperature and increases with increasing temperature. The effect for some alloys is not uniform, but concentrated over a relatively narrow temperature range.
- Creep does not occur below the threshold temperature. The rate, in terms of per cent elongation over a specified time period, increases progressively with increasing temperature.

Table 2.10² As-Cast Properties of Aluminum Die Casting Alloys at Various Temperatures

Alloy	Temperature °F	Temperature (°C)	Tensile Strength ksi	Tensile Strength (MPa)	Yield Strength ksi	Yield Strength (MPa)	Elongation %
360	75	(24)	47	(325)	25	(170)	3
	212	(100)	44	(305)	25	(170)	2
	300	(150)	35	(240)	24	(164)	4
	400	(205)	22	(150)	14	(95)	8
	500	(250)	12	(85)	7.5	(50)	20
380	-18	(-28)	49	(338)	24	(165)	3
	75	(24)	48	(330)	24	(165)	3
	212	(100)	45	(310)	24	(165)	4
	300	(150)	34	(235)	22	(152)	5
	400	(205)	24	(165)	16	(110)	8
390	100	(38)	--	--	37	(260)	--
	200	(95)	--	--	41	(285)	--
	300	(150)	--	--	38	(265)	--
	400	(205)	--	--	30	(210)	--
	500	(250)	--	--	18	(125)	--
413	-18	(-28)	44	(303)	21	(145)	2
	75	(24)	43	(295)	21	(145)	2.5
	212	(100)	37	(255)	20	(140)	5
	300	(150)	32	(220)	19	(130)	8
	400	(205)	24	(165)	15	(105)	15
500	(250)	13	(90)	9	(60)	30	





4. Principles for Application of Design Data

The following guidelines will assist the designer in applying tabulated values of mechanical properties to the design of die castings.

Aluminum alloys

Aluminum alloys offer the best properties at elevated temperature and the best creep resistance of the four alloy groups of die casting alloys.

Computerized methods such as FEA accurately predict stress levels, deflections, and vibrations in aluminum die castings. The techniques are frequently used to redesign cast iron housings in automotive drivelines as aluminum die castings. Where strength is critical, stress levels should be limited to 60 to 70% of tabular values, depending on wall thicknesses. When indicated stresses are above these levels, provision should be made to increase wall thicknesses or otherwise strengthen the critical area as indicated by test results, such as by adding ribs or gussets.

Magnesium alloys

The strength, deflection and vibration response of magnesium die castings can be predicted by FEA in magnesium die castings as well as in aluminum. The excellent casting characteristics of magnesium alloys allow the latitude to design thin and closely spaced ribs and gussets with minimum draft to achieve strength and rigidity. These properties have made magnesium a viable alternative when redesigning from cast iron.

The mechanical properties of magnesium die castings at elevated temperatures are generally below aluminum and above zinc and ZA. AS41 alloy may be specified where creep resistance is critical. AM60 alloy is specified when impact resistance or ductility is critical.

Figure 2.16

When aluminum die castings replace iron castings in automotive driveline applications, such as this differential housing, deflections must be minimized to maintain critical running clearances between gears. Finite element analysis is being extensively used to optimize the die cast housings for maximum rigidity with minimum material.



Zinc alloys

The zinc alloy group (commercially known as Zamak alloys) can closely approximate tabulated mechanical properties in thin-wall castings when casting parameters, particularly porosity, are closely controlled. Experience with FEA is limited because these alloys are not yet generally used in large structural components. The zinc industry is currently adapting FEA to zinc and ZA alloys.

The mechanical properties of the zinc alloys at elevated temperatures are the lowest of the four groups. The creep threshold in tension, even at low stress levels, is below room temperature, so creep should be addressed when operating conditions (enumerated above) indicate it is a factor.

ZA alloys

Currently there are very little data directly comparing test results with strength predictions based on tabulated alloy properties. Where ZA alloys have been substituted for aluminum or zinc alloys, the increased performance has met or exceeded expectations. The zinc industry is adapting FEA to ZA alloys, as noted above.

The performance of ZA alloys at elevated temperatures and their creep resistance are superior to the zinc alloys. Some creep may be expected under tensile loads at room temperature at stresses above 10 ksi (69 MPa). Creep should therefore be addressed when operating conditions (enumerated above) indicate it is a factor.

2.3 Manufacturing Economics

This section presents an overview of the economic factors involved in selecting the optimum material and manufacturing process to execute a product design. These factors center on the following:

- Material Costs, including net material cost and component material volume
- Processing Costs
- Tooling Costs
- Post-processing Costs

The cost of manufacturing a product is determined by the net cost of material and the process costs associated with fabricating the material into a finished product. Material costs are moving generally upward in a pattern that is sometimes erratic, with discontinuities which may last as long as several years. Processing costs follow a long-term inflationary trend occasionally interrupted by reduction related to a technological break-through.

It is not practical or necessary for the product engineer to maintain detailed knowledge of all factors that determine product production costs for alternative manufacturing processes; the final product cost is ultimately determined from supplier price quotations. However, a general overview of the factors governing manufacturing cost will give a good first approximation of the economic viability of die casting versus other product processing options. It will also make it possible to efficiently design economy into the product from the very beginning of the design process.

1. Material Costs

The real material cost is the product of two factors.

- Net material cost per unit of volume
- Component material volume

Five factors determine the net material cost per unit of volume

- Purchase price of material per unit of weight
- In-plant processing and handling cost
- Cost of recycling in-house scrap
- Value of scrap sold outside the plant
- Scrap generated by finish machining operations

A. Purchased price of material per unit of weight

Materials are purchased on a per-pound basis, but employed on a per-cubic-inch basis. Cost per cubic inch offers a good first approximation when the comparison is restricted to die casting alloys. When comparing with other materials that have significantly different properties, material forms, and manufacturing methods, cost per cubic inch must be considered with several other factors. The purchase price of die casting alloys per cubic inch is generally higher than cast iron; equivalent to comparable foundry alloys, powdered iron, sheet steel, and lower priced plastic; and lower than copper alloys and higher-priced engineering plastics.

Figure 2.17 Die Casting Alloy Ingots

Ingots are one of the common material forms that die casting alloys are purchased in before being melted to produce die castings. Die casting alloys are purchased on a per pound basis. The cost per pound of die casting alloys is just one of the material costs associated with die castings.



B. In-plant processing and handling cost

The major in-plant processing cost associated with die casting alloys is the energy required to melt them. Melting costs are generally equivalent to comparable foundry alloys. Energy costs are lower for those alternate processes that require heating without melting, such as powdered metal, and processes that require no heating such as stamping and automatic screw machining.

C. Cost of recycling in-house scrap

In-house die casting scrap consists of rejected castings and the metal that solidifies in the metal distribution system of the die casting die (runners, overflows, and the entry channels called sprues and biscuits), which is subsequently trimmed off and returned to the melting furnace. The die casting process benefits from the ability to reprocess virtually 100% of its scrap. The reprocessing cost, primarily the cost of energy required to remelt, typically adds five to ten percent to the material cost for die castings. Foundry alloys and some thermoplastics incur similar costs. Scrap from thermosetting plastics and stamping processes usually cannot be recycled in-house. Powdered metals generate essentially no material scrap. Screw machining will generate significant amounts of scrap and is discussed below.

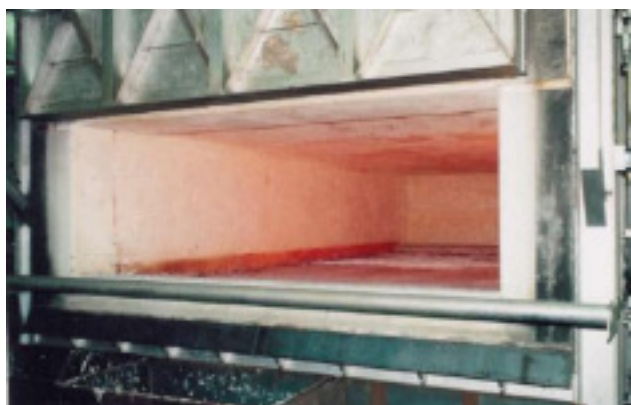


Figure 2.18 Furnace Using Energy to Melt a Die Casting Alloy

Die casting alloys must be melted before use. In addition, the metal distribution system used to feed the die cast part will be re-melted. Energy used for melting is the major in-plant cost associated with die casting alloys.

D. Value of scrap sold outside the plant

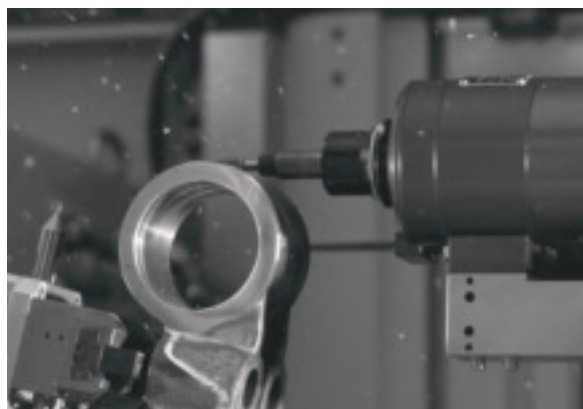
Scrap that is not recycled within the plant is sold outside. Although this is a deduction against material cost, the scrap price is usually only a small fraction of the purchase price. Most die casting scrap is recycled in-plant as noted above. Scrap from most other processes is generally sold at a very low return.

E. Scrap generated by finish machining operations

Die castings usually require very little metal removal by finish machining operations. They are equivalent in this respect to powdered metal, stamped, and precision molded plastic components. Some features of foundry casting require substantial finish allowances, and automatic screw machining generates large amounts of scrap, sometimes exceeding the volume often product produced. Scrap from machining operations brings a very low return. (Brass is an exception; brass chips bring a substantial return.)

Figure 2.19 Machining Operation

Although many die castings require minimal machining, the scrap chips produced during finish machining operations yield a very low cost return.



F. Component material volume

The volume of material in a component varies with the manufacturing process. High precision and thin-wall capabilities of die casting process offer the latitude to design according to performance requirements rather than being restricted by process constraints. Die castings can often be made with very thin walls and carefully located reinforcing features (such as ribs and webs) which develop the required structural properties with less material than most alternative processes.

The volume of material in a die casting is usually much less than an injection molded plastic component. The difference is attributed to the superior mechanical properties of die casting alloys, particularly stiffness.

2. Processing Costs

The die casting processing cost consists of labor and equipment costs. Labor intensity varies with the amount of automation employed. Each die casting machine and its supporting equipment represents a substantial capital investment. The cost per casting increases with press size due to lower production rates and higher machine cost per hour.

Machine cycle time is controlled to a lesser extent by factors that can be addressed in the design of the product.

- The time required for metal to solidify usually depends on the most massive feature of the component. Massive product features should be avoided in favor of thinner walls reinforced with gussets, ribs and webs.
- The press opening and closing events require additional time when more complex moving members, such as core slides and staged come retractors, are employed. Die castings should incorporate features requiring these die components when their use allows thinner walls and reduces or negates subsequent machining operations. The die casting should otherwise be designed so that it does not require the use of these die components.



Figure 2.20 Automated Die Casting Cell
The advanced equipment shown here has been used to create an automated die casting manufacturing cell. The sizable capital investment for this equipment is one of the processing costs associated with die castings.

3. Tooling Costs

Tooling costs for high-precision die casting are among the highest of any high-volume production process. The cost is justified when production rates are relatively high and the tooling cost is spread over many castings. It can also be justified at lower volumes where complex machining or assembly operations can be eliminated through die casting. Die cost per die casting produced is equal to the initial price of tools prorated over the expected production life, plus the cost of maintenance.

Die casting dies are subjected to very severe operating conditions in normal service. Although dies are made from high-quality, engineered tool steel, the injection of molten metal and the subsequent rapid cooling induce thermal shock and cyclic thermal stresses which cause deterioration and ultimately failure of the die steel. The rate of deterioration is a function of the quality of the die steel, the total amount of heat transferred from the molten metal to the die and the associated temperature increase. Deterioration is also affected by the tendency of the molten metal to attack the die steel.

The high-speed flow of molten metal through the die also causes die steel erosion, called die wash or washout. The amount of erosion on one shot is infinitesimal, but the accumulation over many shots must be recognized. The most severe erosion occurs at locations of high metal flow velocity, sudden change in the direction of metal flow, and at irregular die features and die sections, where these locations cannot be provided with sufficient cooling. Often, these factors can be mitigated in the design of the product through early die caster consultation.

The most obvious visual effects of die degeneration on the casting are loss of sharp definition of the more intricate details, deterioration of surface quality, and thickening of some sections. As the die degenerates, it must be removed from production periodically and repaired; ultimately, the die cavities may need to be replaced and eventually the entire die. Die deterioration occurs most rapidly when aluminum alloys are cast, due to the relatively high casting temperature and the tendency for aluminum to attack steel. Magnesium alloys are cast at approximately the same temperatures as aluminum, but they do not exhibit the same tendency to attack the die steel. Die life is therefore longer and die maintenance costs lower than for aluminum alloys. Zinc alloys are cast at lower temperatures than aluminum and magnesium, and do not attack the die steel at casting temperatures. Therefore die life is greatest and maintenance costs lowest for zinc alloys.

Tooling costs can be minimized to some extent in the design of the product.

- Die components such as core slides, mentioned above, add to the cost of manufacturing and maintaining dies. While their benefits in producing near-net or net-shape castings can be great, they should be avoided when not justified.
- Where possible, the die casting should be designed with the parting line in one plane to simplify trim die design.

Tooling costs also include trim dies, which can be estimated at an additional 15 to 20% of the die casting die cost.



*Figure 2.21 Engine Cylinder Head
This die cast cylinder head required careful development and complex tooling to produce the configuration shown. Tooling and development costs were justified by the design improvements, high production rates, reduction of weight and reduced machining requirements provided by the die casting process.*

4. Post-processing Costs

Four types of operations may be performed on die castings after casting.

- Trimming
- Machining
- Impregnating
- Surface Finishing

Trimming

Die castings are ejected from the dies with their gates, runners, overflows, and metal extension (flash) attached, and must be separated from these incidental features, which may be remelted and recast. Separation is normally accomplished in trim dies, which shear off the unwanted “scrap” features. In some cases, particularly with small and mini-size castings, degating dies are employed, which remove the casting from the scrap during ejection.

As in other metal-shearing operations, the rough casting must incorporate features that will provide support in the trim die. The castings must also have sufficient strength and rigidity so that the finished casting will not be deformed by the forces generated in trimming. The runners and overflows are utilized for support as much as possible, but the casting design must reflect the requirements imposed by the trimming operations. It is usually advantageous to consult with the die caster early in the design process to ensure that proper allowance has been made for trimming. Metal extension occurs at the die parting; thus, trim die cost can be reduced if the parting surface can be kept in a single plane. Further economies in trim cost can be realized by eliminating or avoiding irregular features on the parting line. The cost of more complex, multi-stage trim dies can be justified when costly secondary operations can be eliminated, lowering final piece-part costs.

Machining

Die castings typically require few, if any, finish machining operations to achieve specifications. Powdered metal products and precision stampings are similar in this respect; other alternative processes usually require more. Machining after die casting is employed when extremely close tolerances are specified, or to generate features that cannot be formed by the die casting process.

Where machining operations are required, the machining characteristics of aluminum, magnesium, zinc and ZA die casting alloys are equivalent to similar foundry alloys, and superior to ferrous alloys. Copper alloys are superior in machinability to some die casting alloys, and inferior to others, particularly the magnesium group.

Impregnation

Impregnation is a process in which an organic material is forced into the surface pores of a casting. It is specified when high pressure-tightness standards are required in a die cast component. The level of pressure tightness of a casting depends on the casting process and the alloy. The relative pressure tightness of die casting alloys, cast by the hot and cold-chamber methods, is addressed in the later section on die casting alloys.

The cost of impregnating die castings can be minimized by pressure testing all castings and impregnating only those that do not meet specifications. This minimizes impregnation cost and ensures 100% compliance. Squeeze and semi-solid metal casting can be used to yield very low levels to no porosity.

Surface Finishing

A variety of surface finishes can be applied to die castings to provide decorative effects, corrosion protection, or increased hardness and wear resistance. Costs are equivalent to those for alternative materials and processes. Die castings often perform without surface finishes in environments where ferrous alloys require corrosion protection. Conversely, die castings may require corrosion protection in applications where copper and stainless steel alloys do not. Surface finishing will be covered in finer detail in Chapter 3 Section 3.4 Surface Finishing.

2.4 Die Casting Versus Other Processes

Powdered metal

Die casting and powdered metal processes are highly competitive with respect to dimensional precision and machining requirements. The advantage may depend on the orientation of features and desired wall thicknesses. The choice between die casting and powdered metal frequently depends on product size, weight or performance requirements rather than economics. Light-weight die castings can be made in sizes that exceed the capabilities of powdered metal. Powdered metal can be the choice when metals such as ferrous, stainless steel, and copper alloys are required to achieve strength, wear resistance, or high operating temperatures.

Stamping

Stamping from sheet steel offers economy that is difficult to equal when a component can be made from one relatively simple stamping. When a highly complex stamping or several stampings are required, die casting can be a cost-effective alternative. In the case of multiple stampings, the costs of fixturing and welding, added to the costs of fabricating and assembly of the additional parts, can make die casting very competitive. Steel stamping dies that perform a single operation are less costly than die casting dies. The relative costs for tooling and processing depend on the number and types of dies and presses required. Material costs for stamping may be substantially higher than indicated by published per pound costs due to high scrap rates. Stampings invariably consume more material than is contained in the end product, sometimes substantially more. The raw material, rolled sheet material, is uniform in width and thickness, and does not always conform to the required blank configuration. The process also requires peripheral material for clamping the sheet metal in the dies. Therefore, significant amounts of metal are removed from the perimeter, as well as from interior openings. The material that is trimmed becomes scrap and returns only a small fraction of the original purchase price. Die casting, as noted previously, is very material efficient.

Foundry casting

Foundry casting is the choice when requirements for strength, wear resistance, or high operating temperatures require metals such as ferrous, stainless steel, and some non-ferrous alloys. When equivalent alloys are compared, materials purchase price is equivalent. Foundry castings usually incur lower tooling and sometimes lower material costs, but higher production costs.

Die casting offers great precision, eliminating most or all finish machining operations required for foundry castings. The economic advantage for die casting increases when production quantities are high and the tooling cost can be spread over a large number of components. The break even point is lowered when the precision forming capability of die castings eliminates finish machining operations.

Investment casting

Investment casting is a high-precision process that employs alloys with properties similar to foundry alloys. Tooling cost is substantially lower, but production costs are higher. Investment casting is competitive with die casting only at very low production volumes.

*Figure 2.22 Professional Digital Camera Enclosure
The die casting enclosure assembly pictured here was produced in relatively low quantities. The intricate configuration and precision requirements made die casting the most economical manufacturing process.*



Extrusions

Extrusions made from aluminum, magnesium, and zinc alloys exhibit strength and rigidity similar to die castings; however, their ductility is generally higher. Tooling and production costs are comparatively low, making the process very competitive. The extrusion process produces continuous shapes with constant cross section. Components that require changes in cross section, or features such as holes and slots that can often be die cast, require machining operations when made from extrusions. In most cases the choice is economic, and governed by the number of machining operations. The choice is occasionally governed by minor differences in material properties, such as strength or surface treatment characteristics.

Forgings

Die castings can be produced to more complex shapes than can forgings; they can be designed with thinner sections; can be held to closed dimensions and have cored holes and features not feasible in forgings. Forgings, however, have the properties of wrought alloys, with more density and strength than traditional die castings, and can be produced in ferrous and other metals and in larger sizes not suitable for die castings. Development of the new high-density squeeze and semi-solid metal casting processes now offers reduced costs over forgings for many applications.

Automatic screw machining

Automatic screw machining entails the lowest tooling cost of any production method. Highly automated screw machines are not labor intensive. The process, however, which uses bar stock as raw material, offers very poor material utilization, sometimes less than 50%. The choice versus die casting may depend on production quantities, with the die casting advantage increasing as production rates increase. Miniature die casting production can offer substantial savings over screw machining of very small parts. The die casting advantage is less for brass than for ferrous screw machined components. Cutting rates for brass are substantially higher, tool maintenance is lower, and brass chips bring a relatively high scrap price.

The choice may be governed by material requirements and component configuration rather than economics. Ferrous and copper base alloys, which exhibit high temperature and mechanical properties that cannot be achieved by die cast alloys, can be formed on screw machines. Screw machining operations are most advantageous when the component configuration is symmetrical about a central axis, such as cylindrical features. Die casting offers a wider latitude of component configurations.

Injection-Molded Plastics

Developments in plastics technology over the past two decades have made injection-molded plastics competitive with die castings in many applications, particularly decorative ones. The optimum choice between plastics and die castings requires careful analysis of all product requirements.

Aluminum, magnesium, zinc and ZA die castings are often preferred over plastics in electronic components where strength, stiffness and minimum packaging space are required. They often eliminate the need for inserts to receive threaded fasteners. Their thermal conductivity often eliminates the need for cooling fans, which is essential in many electronic equipment designs. Die castings are also preferred over plastics where strength and rigidity are required and for medium to large size decorative components operating at elevated temperatures.

EMI and RFI (electromagnetic interference and radio frequency interference) shielding, which requires special measures for plastic products, is inherent in die castings. Plastic shielding alternatives (painting, coating, resin fillers, metallic barriers, multi-layered electroless nickel plating) have performance problems and/or heavy cost penalties. Surface treatments for EMI/RFI on decorative plastic housings will also require a final paint finish.

Aluminum die castings are frequently chosen over plastics in computer cover panels, board assemblies and chassis; valve bodies that are subject to continuous pressure, particularly at elevated temperatures; and hand tools such as utility knives and drills that require minimum weight, rigidity and good surface quality.

Magnesium die castings are frequently chosen in applications that require minimum weight combined with strength, stiffness, and minimum packaging space. Components for high-speed devices, which require rigidity at minimum weight; cases requiring mounting features, high quality surface, and impact resistance; and decorative trim for luggage are frequently produced by magnesium die casting.

When decorative components require a durable electroplated finish plus strength or rigidity, zinc die castings are usually selected. This category includes architectural, computer and automotive hardware such as handles, window cracks, coat hooks and mirror brackets.

Decorative plastic components that are subjected to continuous loads, such as automotive headlight bezels, often require support from steel stampings to develop stiffness and creep resistance. Zinc alloys offer improved stiffness and higher creep resistance. Where creep resistance greater than that afforded by zinc alloys is required, ZA-8 offers equal stiffness, improved creep resistance and equivalent plating characteristics at slightly lower weight.

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3

PRODUCT DESIGN

This section presents a systematic approach for configuring a product design to maximize performance, economy, and ease of manufacturing by die casting. It assumes that an evaluation of production economies, discussed earlier, has pointed to the die casting process as a superior or equal manufacturing alternative.

The objective of good product design is to develop the optimum configuration consistent with the product function, material, and manufacturing processing. With the increasing emphasis on achieving the benefits of designing for manufacturability, the second and third elements of this objective have taken on added importance. Three tasks are essential to reach the desired goal through die casting:

- Defining the product function independent of existing or traditional forms.
- Developing a configuration that can be readily produced by die casting and meet product objectives in the selected alloys.
- Utilizing design features that are consistent with the die casting process and capitalizing on its unique characteristics.

Define Product Function

Creative design should begin with a clear statement that precisely defines the product functions to be performed, independent of the traditional form. The traditional form of a product is usually governed more by the constraints of the existing material and manufacturing process than by the functions it performs. A clear statement of product functions will overcome the tendency to link functions with the forms traditionally employed and eliminated a common barrier to creative design.

This point is illustrated by the development of the wheel. Old-style wooden wheels employed heavy spokes to transmit loads from the rim to the hub. Steel wheels use a stamped, developed disk for heavy-duty applications and thin, prestressed spokes for light duty. The wheel shown in Figure 3.1, designed to be made by die casting for light duty applications, utilized a structure compatible with the die casting process. Heavy spokes are impractical for die casting, a thin disc of sufficient strength is not materials efficient, and wire-like spokes are impossible to die cast.

Radial and lateral loads in the die cast design are transmitted from the outer rim to the hub by six broad, thin spokes oriented axially to transmit lateral loads from the outer rim to the hub. The outer rim is reinforced against both radial and lateral loads by six shorter intermediate spokes supported by an intermediate rim. The intermediate rim also distributes lateral loads to adjacent spokes. This design can be readily die cast using aluminum or magnesium alloys for applications such as wheelchairs and bicycles. It can also be used as an inertia wheel for stationary exercise bicycles by converting the outer rim to a more massive, solid section and selecting a zinc alloy.

The wheel shown in the figure was designed for a wheelchair. Additionally, it incorporates four bosses with tapped holes located near the outer rim to support the tubular rim used for hand propulsion by the occupant. The broad spokes and open design are easy to clean, an important benefit in clinical applications. In this case a clear understanding of function enabled the product designer and die caster to get together and “reinvent the wheel.”



*Figure 3.1
This wheel design was developed for die casting as a cost-effective alternative to the conventional steel rim and wire spoke design.*

3.1 Geometry Optimization

After product function has been defined, a configuration compatible with the die casting process and the selected alloy must be developed. Alloy selection is based primarily on the required mechanical, physical and chemical properties. When more than one die casting alloy is feasible, relative economics generally prevails. Alloy properties are discussed and relative merits compared in the later section on die casting alloys.

A product configuration optimized for die casting will:

- Fill completely with metal.
- Solidify quickly and without defects.
- Eject readily from the die.

These results can best be achieved by applying five principles when designing component walls and sections and establishing tolerances.

A. Keep Uniform Wall Thickness

Uniform wall thicknesses are preferred. There are no hard and fast rules governing maximum and minimum limits for wall thicknesses. They should be as consistent as possible throughout the component and, where variations are required, transitions should be provided to avoid abrupt changes. Die casters who use high-technology equipment and techniques routinely produce castings with maximum and minimum wall thicknesses and with variations that were impossible a few years ago. This capability should be utilized only as necessary to achieve performance or economic advantages.

B. Add Fillets and Blending

Sharp corners should be broken with fillets, radii or chamfers to reduce die maintenance. In special situations, sharp exterior corners can be specified on appearance surfaces when crisp styling features are desired. Intersections of features, such as walls, ribs and gussets, should blend with transition sections and generous radii. This practice promotes metal flow and structural integrity and rarely creates a conflict between casting requirements and product integrity.

C. Draft

In most cases, standard draft, per the NADCA Product Standards Manual, should be specified to facilitate ejection from the die and reduce die maintenance. Draft angles may be minimized where metal content is critical, such as this sections oriented parallel to die draw. Casting to zero draft may be specified in some cases to eliminate finish machining operations. These capabilities may be utilized as necessary to gain an economic advantage or to reduce weight.

D. Undercuts

Undercuts should be avoided whenever possible, because they require machining operations or additional die members, such as retractable core slides. When core slides are used, the design should allow them to be located in the die parting plane.

E. Keep Critical Dimensions on One Die Member

Dimensions with critical tolerances should relate to only one die member, where possible. The updated NADCA Product Specification Standards for Die Castings, should be consulted regarding dimensioning and tolerancing guidelines. This volume is available at www.diecastingdesign.org, presents coordinate dimensioning specifications for current production practices under two manufacturing levels, “Standard” and “Precision” tolerances. Placing dimensions with critical tolerances between die members that move independently of each other are susceptible to greater dimensional variation.

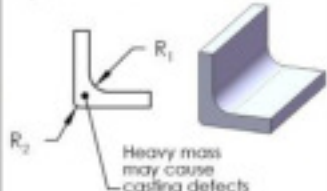

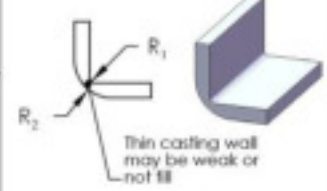
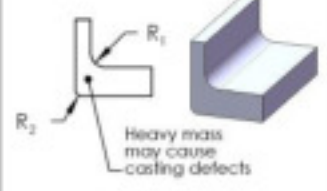

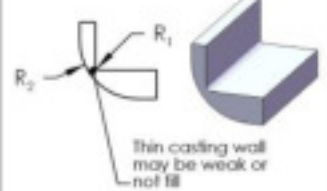
Utilizing Features to Capitalize on the Die Casting Process

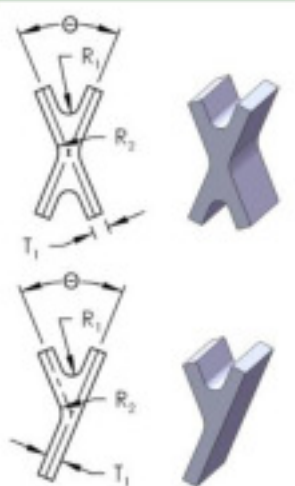
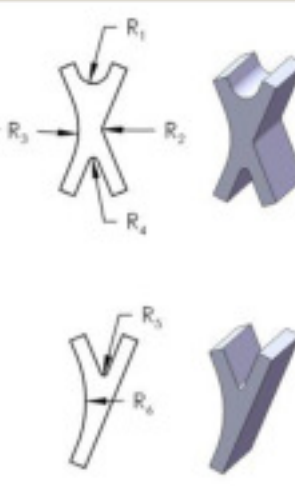
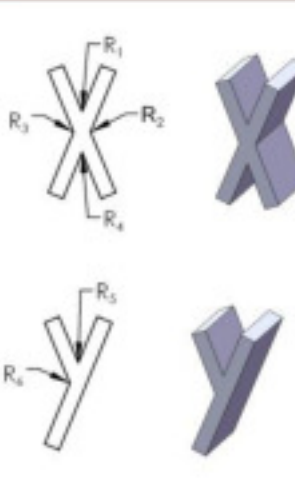
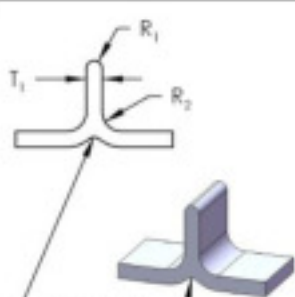
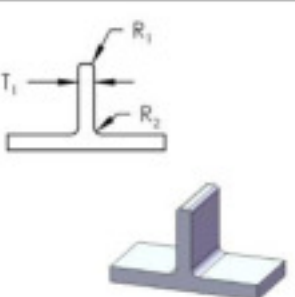
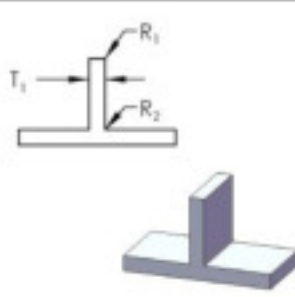
Many features can be readily die cast when proper detail dimensions are specified. The configurations and dimensions recommended in this section tend to: fill consistently; reduce the tendency for defects such as sink marks and porosity; minimize die wear; and eject easily. Information in the later section on the die casting process clarifies questions on compatibility between the features of a die casting product design and the die casting production process.

Fillets

Fillets, which connect interior surfaces of a component, are molded at the juncture of external die surfaces. Properly sized radii enhance structural integrity by reducing stress concentration, and promote good metal flow with reduced erosion in the die. Corners, generated by the junction of exterior surfaces of a component are molded at the juncture of internal die surfaces. Properly sized radii relieve stress concentrations in the die and ensure that molten metal fills corners properly. Figure 3.2 illustrates sound principles for fillet and corner design for die castings.

Figure 3.2
Optimal, Less Desirable & Not Recommended Dimensions for fillets.

FILLETS			
	OPTIMAL	LESS DESIRABLE	NOT RECOMMENDED
BETWEEN UNIFORM WALL JUNCTIONS	Where $T_1 = T_2$	R_1 Too large R_2 Too small  Heavy mass may cause casting defects R_2 Will shorten die life	$R_1 = 0$ $R_2 = 0$ (not parting line)  Will cause weak part & die casting die
	$R_1 \geq T_1$ $R_2 = R_1 + T_1$ or If $R_2 = 0$ (parting line) Then $R_1 = T_1$ to $1.25 \cdot T_1$ General Tip: The larger the radius the longer the die life, as long as uniform walls are maintained.	R_1 Too small R_2 Too large  Thin casting wall may be weak or not fill R_1 Will shorten die life	General Tip: Sharp corners cause high stress concentrations in the part and die. High stress concentration areas may lead to early failure of the part, and will be the starting point of cracks in the die, typically called "heat checking".
BETWEEN NON-UNIFORM WALL JUNCTIONS	Where $T_1 < T_2$	R_1 Too large R_2 Too small  Heavy mass may cause casting defects R_2 Will shorten die life	$R_1 = 0$ $R_2 = 0$ (not parting line)  Will cause weak part & die casting die
	$R_1 \geq 2/3 (T_1 + T_2)$ $R_2 = R_1 + T_2$	R_1 Too small R_2 Too large  Thin casting wall may be weak or not fill R_1 Will shorten die life	

FILLETS			
	OPTIMAL	LESS DESIRABLE	NOT RECOMMENDED
AT X & Y WALL JUNCTIONS	 <p> $\Theta = 90^\circ: R_1 \text{ \& } R_2 = T_1$ $\Theta = 45^\circ: R_1 = 0.7 T_1$ $R_2 = 1.5 T_1$ $\Theta = 30^\circ: R_1 = 0.5 T_1$ $R_2 = 2.5 T_1$ </p>	 <p> R_1, R_3, R_4 will cause heavy mass R_2, R_4, R_5 will shorten die life </p>	 <p> R_2 Will cause weak part & die casting die </p>
	OR VARIATION	<p> $R_1 = \sin \Theta T_1$ $R_2 = (1/\sin \Theta) T_1$ </p>	
ON RIB TOPS & TEE JUNCTIONS	 <p> Depression promotes uniform wall thickness $R_1 = 0.5 T_1$ $R_2 = T_1 \text{ to } 1.25 T_1$ </p>	 <p> $R_1 < 0.5 T_1 \text{ to } 0.25 T_1$ $R_2 < T_1 \text{ to } 0.5 T_1$ </p>	 <p> $R_1 < 0.25 T_1 \text{ or } = 0$ $R_2 < 0.5 T_1 \text{ or } = 0$ Will cause weak part & die casting die </p>

Ribs

Ribs are employed for reinforcement more than any other feature. Die casting technology currently allows deeper, thinner ribs than were previously feasible. Figure 3.3 illustrates principles for configuring ribs and interfacing them with other features.

Figure 3.3 Recommended configurations for ribs.

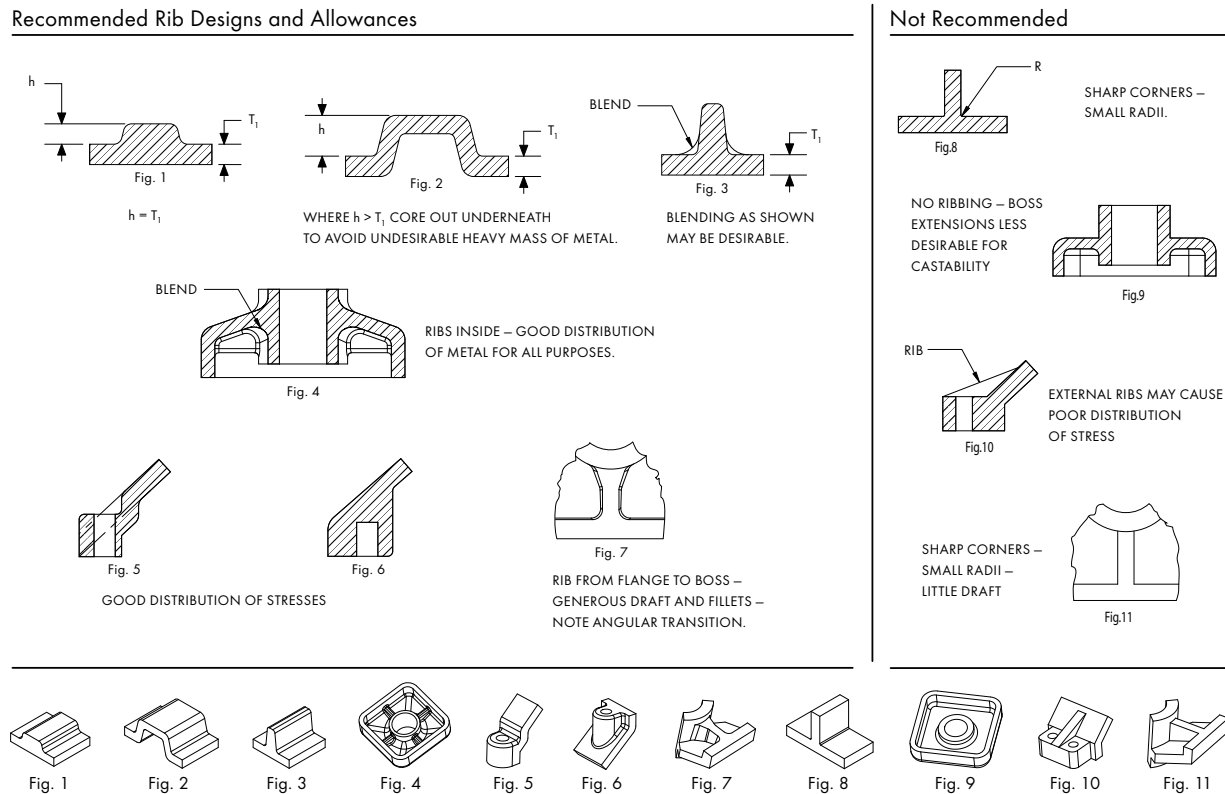
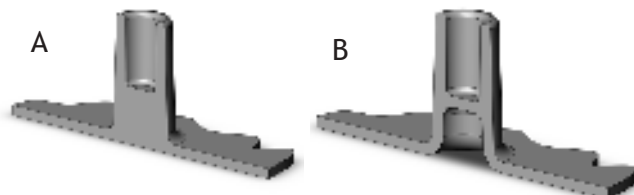


Figure 3.4 Reducing a heavy mass under a boss. The heavy mass of metal trapped in the design of the boss at A may be reduced by using a metal-saver core as shown at B.



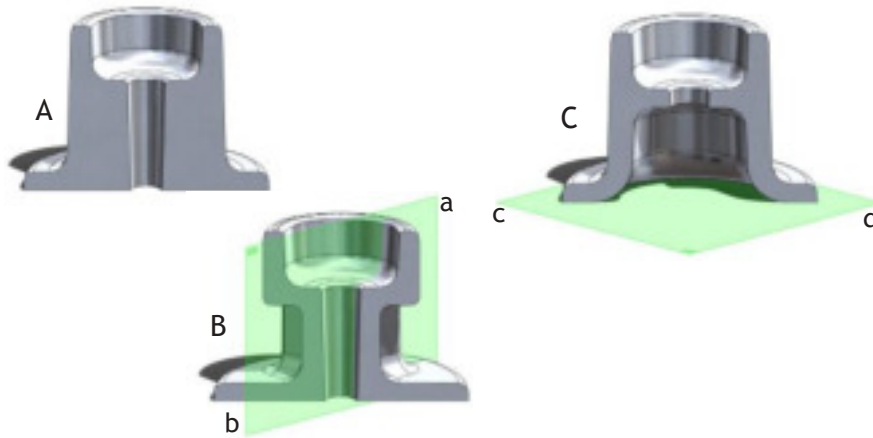


Figure 3.5
Three boss alternatives. Boss A is undesirable because of the heavy mass of metal in the walls. Boss B is cast with the parting plane at a-b, and the exterior is formed with movable core slides. Thin walls and rib reinforcements replace the heavy mass in A. Boss C, formed with the parting plane at c-d, achieves thin walls and requires no movable core slides.

Reducing heavy masses

Heavy masses are usually redesigned with thinner walls and rib reinforcements. Sometimes extensive redesign is possible, to preserve essential features and revise non-essential features. Figures 3.4 and 3.5 illustrate conditions where heavy masses were redesigned and features modified.

Die simplification

Some features, such as undercuts, bosses and holes, require core slides because their features are not oriented in the direction of die draw. Slides increase the costs of fabricating and maintaining the die and increase the casting cycle time. They also tend to cause flash on exterior surfaces. When removal is necessary, additional costs are incurred. Figure 3.6 illustrates die simplification through component redesign to eliminate core slides.

Figure 3.6
Eliminating core slides.
Design A requires movable core slides.
Design B allows the component to be die cast without movable core slides.

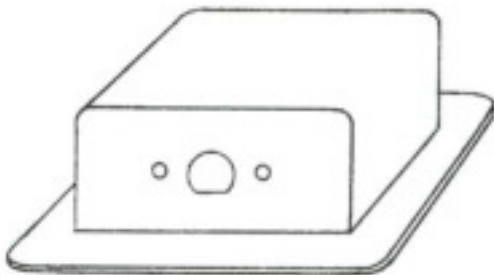
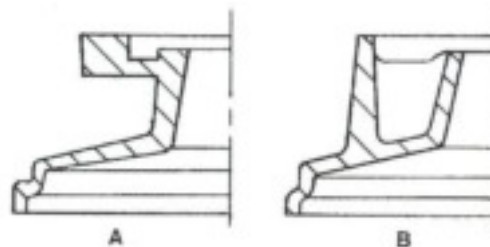


Figure 3.7
The holes in the side walls of this thin-wall die cast box can often be punched after die casting more economically than forming with a core slide.

Punched holes

In thin wall castings it is sometimes advantageous to punch holes in features to eliminate the need for core slides that would otherwise increase die cost and wear. Punching can also save additional cleaning operations. Figure 3.7 shows a thin-wall box with holes oriented in a way that would require core slides. Punching is often a cost effective option in this type of application.

Eliminating undercuts beneath bosses

Undercuts beneath bosses from features that lock the casting onto the die and prohibit ejection. Where the features cannot be eliminated, machining operations or core slides are required as noted above. In some cases the location of undercuts prohibits die casting. Figure 3.8 shows four design alternatives that eliminate an undercut formed by an interior boss without requiring core slides.

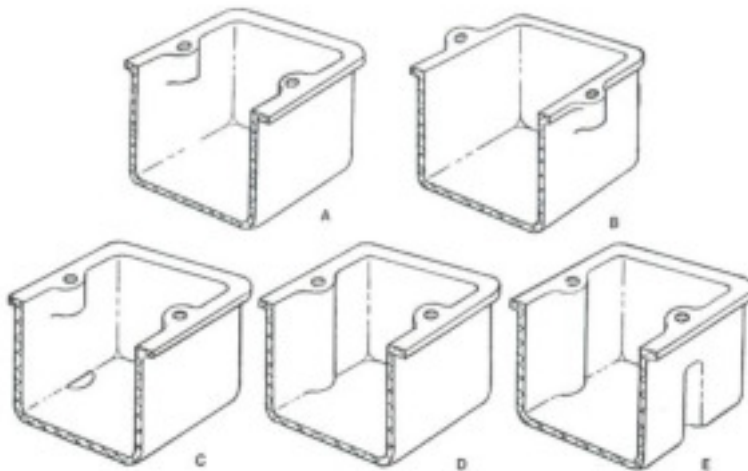


Figure 3.8
Four alternatives for eliminating undercuts at bosses.
The housing is shown as desired at A, but the bosses create undercuts. Four options are illustrated for eliminating the undercuts, starting with least desirable options and ending with the most desirable.
B. The boss is relocated outside the housing.
C. The boss is cored by breaking through the bottom wall of the housing.
D. The boss is extended to the bottom of the housing.
E. The exterior wall of the housing is cored.

Die parting

The die parting plane location may be important to the casting because of the line left on the casting where the die halves meet. The casting must be trimmed along this line, and the trim die must be configured to it and maintained. Simplification of the parting configuration will reduce the cost of manufacturing and maintaining the trim die. In some cases, a simplified parting line may negate the need for clean-up operations on exterior surfaces. Figures 3.9 and 3.10 show minor design modifications that simply trimming operations and eliminate the need for clean-up.

Figure 3.9
Terminating scallops to simplify parting line. Terminating the scallops slightly above the base of the knob, as shown at B, eliminated irregularities from the parting line, leaving a simple circle which is easy to fabricate, maintain and trim.

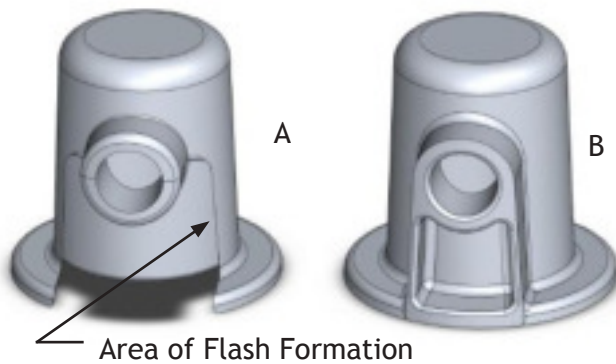
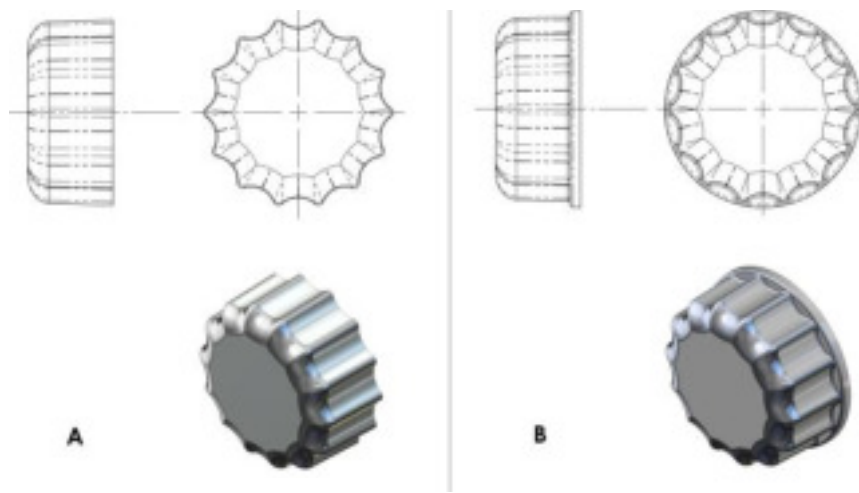


Figure 3.10
Redesigning to eliminate flash lines on appearance surfaces. The irregular parting line of design A can leave traces of flash on the casting, which may be difficult to eliminate. The slight modification shown B facilitates the trimming operation.

Draft requirements

Draft is highly desirable on surfaces parallel to the direction of die drawing because it facilitates ejection by allowing the casting to release easily from the die surfaces. Draft may be minimized or eliminated on a limited basis to gain economic advantages; otherwise, NADCA Product Standards⁴ recommendations for minimum draft should be specified. The recommended draft can be approximated by the formula:

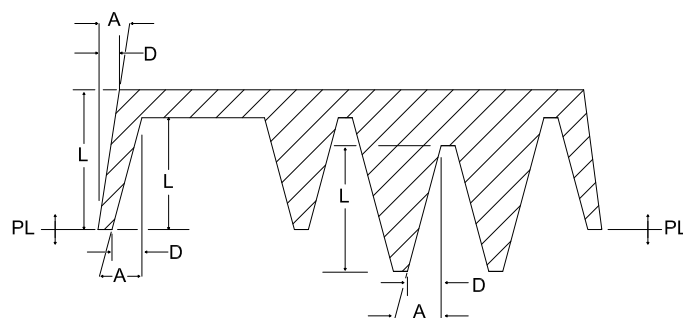
Calculation for Draft Distance

$$D = \frac{\sqrt{L}}{C}$$

Calculation for Draft Angle

$$A = \frac{\left(\frac{D}{L}\right)}{0.01746} \quad \text{or} \quad \frac{57.2738}{C \sqrt{L}}$$

Figure 3.11
Draft dimensions defined for interior and exterior surfaces (draft is exaggerated for illustration).



The values of C for the features shown in Figure 3.11 are:

Alloy Group	Inside Surface	Outside Surface	Hole, Total
Zinc and ZA	50	100	34
Magnesium	35	70	24
Aluminum	30	60	20
Copper	25	50	17

Note that twice as much draft is recommended for inside surfaces as for outside surfaces. This provision is made 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).

The formula indicates that draft, expressed as an angle, decreases as the depth of the feature increases. For example, consider an aluminum alloy inside surface, for which $C = 30$.

Depth, in.(mm)	Draft, in.(mm)	Draft, Degrees
0.1 (2.5)	0.010 (0.25)	6.0
1.0 (25)	0.033 (0.84)	1.9
5.0 (127)	0.075 (1.89)	0.85

It is not common practice to compute the draft for each feature. Draft is usually specified by a general note with exceptions called out for individual features. The formula is useful for establishing general draft requirements and identifying exceptions. For example, the table above indicates that an aluminum die casting with most features at least 1.0 inch deep can be covered with a general note indicating 2° minimum draft on inside surfaces and a 1° minimum on outside (based on outside surfaces requiring half as much). To achieve lesser draft than normal production allows, Precision Tolerances maybe specified, see *NADCA Product Specification Standards for Die Castings*⁴ for more details.

High-Precision Casting

Many die casters can employ high-precision casting techniques to reduce tolerances of size and location, improve flatness, and reduce or eliminate draft on selected features. These techniques require very close control of many casting parameters, which implies world class machinery and control systems. The investment, and consequently the machine operating rates, increase with the level of control.

Very high-precision casting requires that additional time and effort be expended to “fine-tune” the die and process before and during production, imposing additional cost. In order to maintain very high casting precision and high quality cosmetic surfaces, the die caster may have to remove the dies from service periodically and perform maintenance, prolonging the useful life of the dies, but adding to the cost of production. A set of backup dies may be required to sustain production during maintenance intervals.

These added costs should be balanced against the benefits which can be achieved when high-precision casting eliminates finishing operations and combines parts that would otherwise have to be separately fabricated and assembled. Both product improvement and cost reduction can result. The designer must, however, refrain from “overtolerancing,” which incurs additional cost with little or no benefit.

3.2 Assemblies

Bearing Applications

The die casting process is rarely used to produce individual bearings or bearing inserts. However, the designer can often incorporate bearing surfaces into a die cast component, thus eliminating the cost of separately fabricated and assembled bearings.

There are two distinct classes of bearings, depending on lubrication conditions: full film and partial film. Each has its own distinct design parameters and alloy selection criteria.

1. Full Film Lubrication

Bearings with full film lubrication are classified as hydrodynamic or hydrostatic. Hydrodynamic applications are much more common and are frequently used in mass-produced products such as crankshaft and camshaft bearings of internal combustion engines. Hydrostatic bearings are usually employed in special purpose, few-of-a-kind applications that are not die cast.

In a hydrodynamic application the shaft runs at very close radial clearance within the bearing, usually at a relatively high speed. Lubricating oil is supplied in abundance to the bearing under pressure, where the rotating shaft draws some of it into the narrow clearance between the shaft and bearing. This action develops an oil film which separates the shaft from the bearings. Relative motion between the rotating shaft and stationary bearing shears the thin lubricant film, generating heat. Expulsion of the used oil and through flow of the excess supply remove most of the heat; the remainder is conducted away through the bearings into the casting and dissipated.

The presence of the lubricating film minimizes the need for the anti-galling and abrasion resistant properties that are important with partial film lubrication. Galling and abrasion tend to occur only briefly during start-up, while the film is being established. Properties that are desirable or essential for the die casting alloy are:

- Chemical compatibility with the lubricant to avoid corrosion.
- Good thermal conductivity to dissipate the heat transmitted from the lubricant to the bearings.
- Strength and creep resistance at the expected operating temperatures to maintain structural integrity of the bearings.

Successful experience with aluminum and magnesium alloys in the camshaft bearings of internal combustion engines indicates that alloys in these groups have the properties required in high speed, heavy load applications at elevated temperatures.

Since there is no contact between the shaft and bearings surfaces under hydrodynamic conditions, bearing performance is independent of material composition. Critical bearing factors such as minimum journal-to-bearing clearance, lubricant film strength, friction, and heat generation are determined by applying conventional design technology for hydrodynamic bearings.

2. Partial Film Lubrication

Bearings operating at partial film lubrication experience some metal-to-metal contact between the shaft and bearing during normal operation. They generally run with greater clearances and at lower speeds than hydrodynamic bearings. Alloy selection criteria for the die cast bearing include the three enumerated for hydrodynamic applications plus:

- Anti-galling to inhibit transfer of metal from the die cast bearing surface to the shaft, which is generally steel.
- Wear resistance to reduce the tendency to remove metal from the die cast bearing surface.

Several die casting alloys exhibit characteristics that adapt them in partial film bearing applications with steel shafts. Aluminum alloy 390 exhibits high resistance to abrasion, due to its high silicon content and free silicon constituent. The alloy has been used in automotive engine blocks without requiring iron cylinder liners. Special surface preparation techniques applied to the cylinder surfaces and plating of the aluminum pistons allow the pistons to run directly against the die cast cylinder surfaces. Alloy 390 also finds applications in hydraulic valve bodies.

Magnesium alloys have little tendency to gall when running against steel. The following guidelines are recommended for magnesium die castings running with steel shafts.

- Shaft hardness of 350-600 BHN.
- Maximum surface speed of 1000 ft/min (5 m/s).
- Maximum bearings pressure 2000 psi (14 MPa).
- Maximum operating temperature 220°F (105°C).

The ZA alloys exhibit low coefficients of friction when running against steel. In all cases, it is essential that surfaces of shafts and bearings be smooth, and that the lubrication supply be ample. Research on ZA alloys has focused on primarily sand cast bearings and bearings machined from continuous cast stock. The data indicates some variations in bearings characteristics between the two alloy forms, probably due to differences in the rates at which the metals solidify. The data cannot be directly applied to the design of bearing surfaces in die castings, but can provide a beginning point subject to verification by test. The research recommends two guidelines for steel shafts running in ZA bearings:

- Maximum roughness of 16 micrometers.
- At least 80 BHN harder than the bearing.

Figure 3.12

The ZA-8 die cast bracket on the left incorporates the bronze bushings, which were formerly fabricated separately and pressed into the steel bracket. Coin shown: United States Mint image.

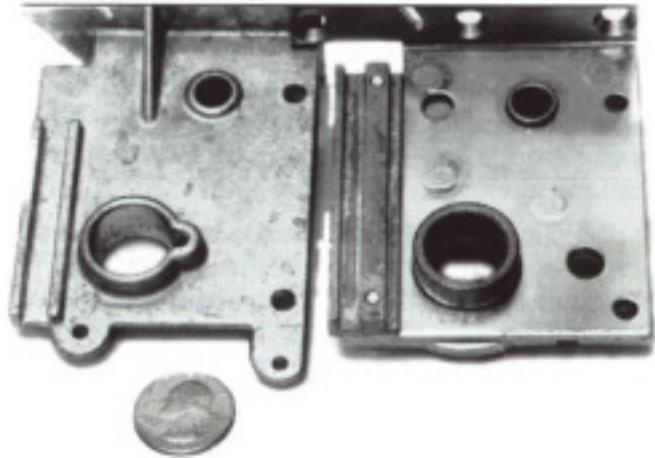


Figure 3.13

The bearing areas of this ZA-27 die cast connecting rod for a high-pressure pump run against an 8620 steel crankshaft and a mild steel wrist pin.

Die castings made from ZA alloys are being used for their bearing properties in die castings, such as the ZA-8 bracket shown in Figure 3.12 and the ZA-27 connecting rod shown in Figure 3.13.

Fastening and Joining

This section discusses recommended approaches for fastening and joining aluminum, magnesium, zinc and ZA die castings with other die castings and components made from other materials. It covers the following topics:

- Threaded Fasteners
- Inserts
 - Types Of Inserts
 - Insert Configuration
 - Insert Materials: Galvanic Considerations
 - Controlling Stresses Induced By Inserts
- Self Cutting/Forming Fasteners
- Die Cast External Threads
- Interference Fits
- Attachment Systems With Limited Application
 - Crimping, Staking And Swaging
 - Adhesive Bonding And Soldering
 - Welding
- Characteristics Of Die Castings Requiring Special Design Measures
 - Galvanic Potential
 - Response To Continuous Long-Term Loading

Die castings are fastened to other die castings, wrought and gravity cast alloys, ceramics, plastics and wood with a satisfactory record of performance in many operating environments. Theoretically, almost any fastening method used for any metal may be used for die castings in all alloys.

Joints employing through bolts or rivets are predictable and easy to design because they impose only compressive and bearing loads on the casting. Methods employing threads tapped into the casting, inserts, self-cutting or self-forming fasteners, push-on and stand-off fasteners are often used. Adhesive bonding is becoming more common. Welding, brazing, and methods requiring plastic deformation of the die casting are limited to die castings made from alloys with certain requisite properties. Soldering is of limited value for die castings.

1. Threaded Fasteners

Steel bolts and studs are commonly used to join aluminum. Magnesium, zinc and ZA die castings; aluminum bolts are sometimes recommended with magnesium die castings when there is potential for galvanic corrosion. When attachment is required at this walls, bolts pass through clearance holes in the casting and are secured with nuts. Where conditions permit, bosses may be designed into the casting to receive studs or bolts threaded into tapped holes. Both coarse and fine threads are tapped; coarser threads are generally preferred.

The interaction between bolts or studs and tapped holes in die cast alloys involves a number of factors such as seizing or erratic friction, dilation of the hole, thread shearing, thread bending, thread stiffness, and the effect of tolerances on load distribution. These factors have not yet been fully quantified. The following guidelines are helpful in developing a first design approximation.

- Coated steel bolts and studs, such as by phosphated or plated, have less tendency to seize than uncoated steel and aluminum fasteners. Therefore the relationship between torque and clamping force is more consistent.
- A margin of safety should be provided to prevent over torquing of the fastener caused by variations in the torque applied by production tools.
- The joint should be designed so that the bolt fails rather than the casting. Since bolt threads are usually stronger than die casting threads, bolt failure will be by tensile failure rather than thread stripping.
- The shear strength and modulus of elasticity of die casting alloys is much lower than that of cast iron and steel, making the die cast joint more prone to dilation than a ferrous casting. (Dilation is expansion of the boss caused by the wedging action of the threads which weakens the joint by reducing the contact between mating threads.) Therefore, the boss diameter should be at least twice the bolt diameter.
- Tapped holes should be cored to minimize porosity in the thread area. If core draft required, particularly on deep holes, the draft will increase the minor diameter of the threads at the large end of the hole and reduce the thread height. Coarse threads have greater thread strength required, the holes should be cored slightly under size and finished to the required tap drill diameter.

When coring for tapped blind holes, it is essential to provide sufficient hole depth to ensure tool clearance beyond the last full thread. If tool clearance is not adequate and the tap bottoms, it can strip the threads, or worse, severely weaken the threads in a manner that will not likely be detected.

- If operating conditions indicate a potential for thread relaxation, it will be necessary to verify that the joint can maintain the required clamping for by test. (See “Response to Long Term Loading” in part 7 of this section.)
- It is possible to cast internal threads in die castings by employing spin-out cores or by unscrewing the casting from the core. However, practical considerations such as the increase in cycle time and required draft (which weakens the threads) usually make it feasible to tap the threads in a separate operation.

2. Inserts

Some design parameters impose conditions that exceed the capabilities of the selected die casting alloy. These conditions include:

- Excessive wear on tapped threads caused by frequent removal and reinstallation of fasteners.
- Concentrated loads requiring external or internal threads with very high strength.
- Abrasion or wear, typically at bearing points.
- Continuous long term-loading (see part 7 of this section) or cyclic loads that make it necessary to limit casting stresses to relatively low levels.

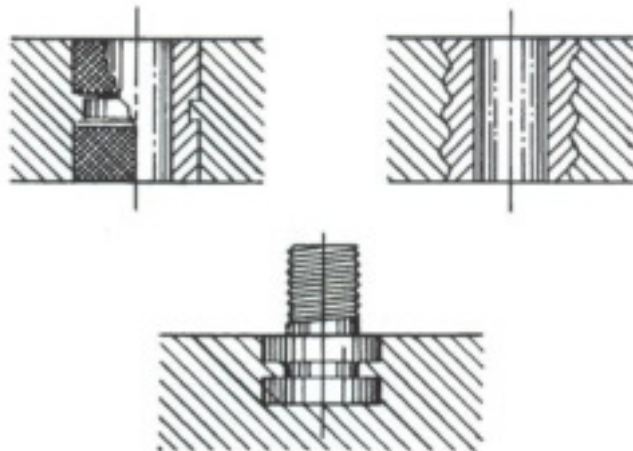
Inserts made from a material with properties superior to those of the die casting are commonly used under these conditions.

Types of Inserts

Inserts may be cast in place or post-installed; the choice is governed first by function, then by economics. Cast-in-place inserts allow a wide latitude in the method of securing, such as undercuts that develop a mechanical lock, because the alloy is cast around the insert (Figure 3.14). This type of insert cannot be post-installed because that undercuts prevent installation. Design parameters may therefore impose conditions requiring cast-in-place inserts.

Die-casting-cycle economics determine the choice where either option is available. In general, cast-in-place inserts must be dimensionally accurate as the die into which they are placed, whereas post-installed inserts are made to less stringent tolerances. More important, cast-in-place inserts must be loaded into the die, increasing machine cycle time and cost. Where small parts are produced on highly automated machines with fast cycles, the extra time required to load even one insert usually makes it more economical to post-install them on a less expensive, high-speed machine. Die casting cycle times increase with the size of the casting, so that the time required to load inserts becomes a proportionately smaller part of the total cycle time for larger castings. With very large castings, casting-in-place may be more economical. Economics are always best determined by consulting with the die caster.

Figure 3.14
Typical cast-in-place inserts.



Insert configuration

Inserts may be knurled, grooved, splined or eccentrically shaped to develop the necessary anchorage for the anticipated loading. They should be configured to avoid sharp corners, projections surrounded by thin sections of die casting alloy, other factors that lead to stress concentrations in the casting. Figures 3.14 through 3.16 show various types of inserts. The design shown in Figure 3.16 reduces long-term stress in the casting by insulating it from bolt tightening loads. This feature may be important when designing to stress corrosion cracking of creep criteria.

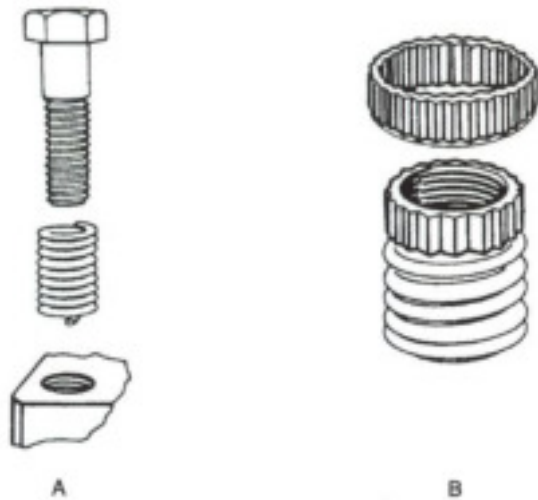
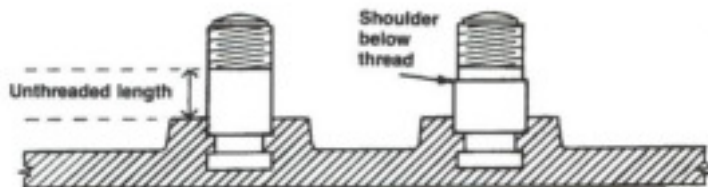


Figure 3.15
Two types of common screwed-in inserts.
A. Screw thread bushing of helically coiled wire.
B. Screwed in bushing with locking ring.

Figure 3.16
Inserts with and without shoulders.
The shoulder on the insert prevents the transfer of bolt tightening loads to the casting. The threads should be kept clear of the casting to prevent flash from entering them.



Insert materials: galvanic considerations

Steel, brass, and bronze inserts are commonly used with all die casting alloys; zinc alloy inserts are sometimes used with magnesium castings. Although ferrous and copper alloys are not galvanically compatible with die casting alloys, most of the contact surface is within the casting, where water is effectively sealed out. If galvanic corrosion is a potential problem at the external interface, the dissimilar metals may be surface treated, plated, or insulated as shown in Figure 3.17.

Controlling stresses induced by inserts

Inserts, whether cast-in-place or post-installed, induce residual stresses in the casting. Residual stresses must be analyzed to determine whether there will be problems in long-term retention. Part 7 of this section includes a discussion of stress corrosion cracking in inserts and recommends appropriate design measures.

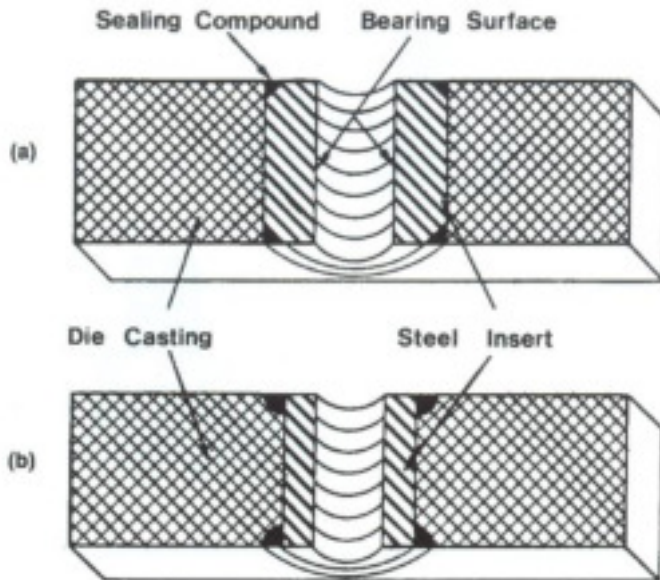


Figure 3.17
Methods of preventing galvanic corrosion between die castings and dissimilar metal inserts

3. Self-Cutting/Forming Fasteners

This fastener category includes self-tapping screws, thread forming screws, spring clips and stamped nuts that anchor in the die casting by cutting into or forming it as they are installed. Die casting alloys are relatively soft, compared with the hard steel commonly used, and readily accept these fasteners. The use of steel fasteners alerts the designer to determine whether galvanic precautions are required, especially for magnesium-to-steel contact.

Published literature from fasteners manufacturers gives retention capabilities, installation forces, and recommended dimensions for the die cast features that will receive the fasteners. Spring clips and stamped nuts that attach to integral cast studs or posts provide very low cost fastening they also develop a relatively low retention force. They are usually made of high-strength steel with hard cutting edges and are installed by pushing or spinning on.

Standard self-tapping screws with cutting action, and thread-forming screws that deform metal without removing it, are effective in die castings. The cost is higher than for spring clips and stamped nuts, but retention capability is greater. The cost is less than for tapped threads because the tapping operation is eliminated. But retention is lower. They are less suitable if repeated removal and reinstallation is anticipated.

In many cases, holes can be cast to the required size. Self-tapping screws with cutting action form chips, which may not be tolerable in electronic equipment. In those cases, thread-forming fasteners are preferred.

4. Die Cast External Threads

Under certain conditions, external threads can be die cast on cylindrical features. The threads can be formed across the parting line of the dies, with slides, or with solid die components. When threads are formed across the parting line or with slides, some flash is usually left in the threads, and this is difficult to remove. If the flash is not severe, and if conditions of assembly and use permit, the first installation of the nut can serve as a flash removal operation.

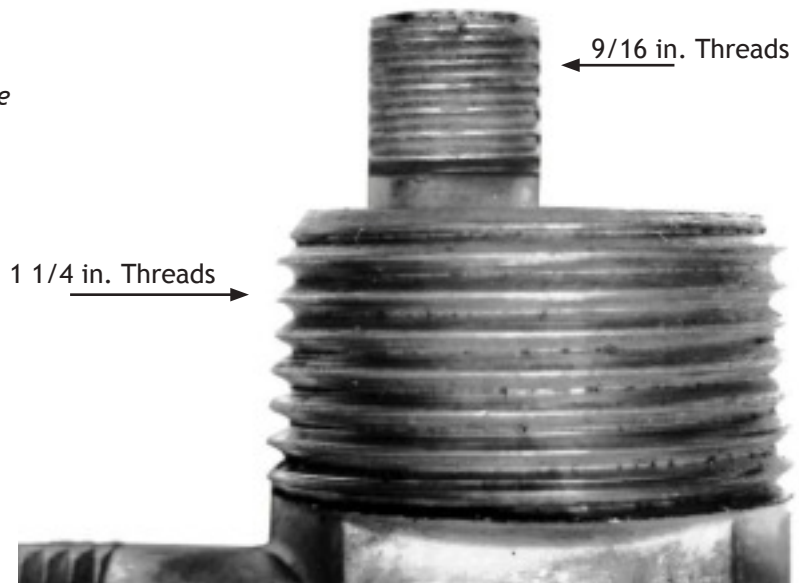
It is also possible, if some thread strength can be sacrificed, to cast flats on the parting line at the root of the threads. The flash is formed on the flats where it is easily trimmed off. Advances in flash-free die casting technology are making die cast external threads more practical.

5. Interference Fits

Components such as bearings and dowel inserts can be retained in die castings by interference fits. Where interference is light, typically 0.001 in./in (0.001 mm/mm) or less, installation is usually performed with both members at room temperature. Heavy interferences usually require that the external member be heated, the internal member be cooled, or both.

Figure 3.18

The 1 1/4 in. threads are cast across the die parting line without flats; the 9/16 in. threads are flatted. Neither requires a thread cutting operation.



The amount of retention is a fraction of residual stress levels, which can be calculated using classical right cylinder analysis. Heavy interferences may cause metal removal, reducing retention. The tendency for either member to remove metal from the other depends on the relative hardness of the metals, the amount of interference, use of lubricant, and the leading edge profiles of the members. It is usually advisable to check the effectiveness of interference fits by testing production samples to determine the force required to disassemble the members, or the torque required to cause rotation.

Where the die cast alloy has sufficient ductility, crush ribs can be used to develop interference between the internal and external member. A typical rib profile used to retain a 5/8 in. O.D. metal bushing in a zinc die cast housing is shown in Figure 3.19. The design includes a slight radial relief at the root of the rib to receive metal displaced from the rib, and a lead chamfer to facilitate installation for the internal member (not shown). Crush ribs do not require the very close dimensional tolerances required by conventional diametral interference fits. Design parameters, such as require ductility of the die cast alloy, optimum number of ribs, allowable diametral tolerances, and retention capability have not been quantified. The design must be verified by testing production samples

The design and test program must evaluate long term-effects, such as that of creep and of stress corrosion cracking (AZ91 magnesium alloys only) if either condition is possible. (See part 7 of this section.)

6. Attachment Systems for Selected Applications

Attachments that require plastic deformation of the die casting, such as crimping, staking, and swaging, are generally limited to alloys with relatively high ductility, such as the zinc alloy group. The operations are sometimes used on alloys with lower ductility when minor plastic deformation is required. Ductility can be increased by applying heat locally, either with a heated tool or by spinning the tool against the metal.

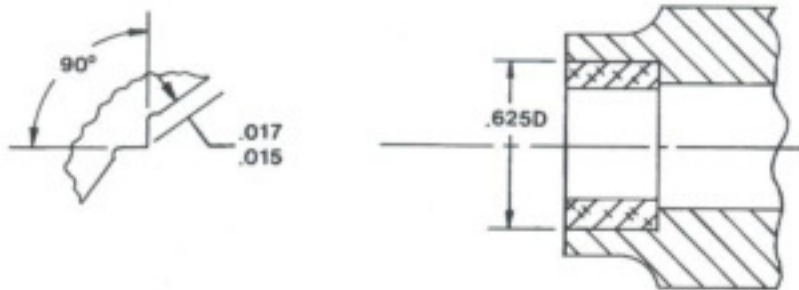


Figure 3.19
Crush rib configuration for a
.625 in. diameter bore in a zinc
die cast housing.

Adhesive bonding of metals has become more common in recent years, primarily due to the bonding of sheet steel member in automobile bodies. New developments include improvements in adhesive bonding strength, application technology and reductions in the time and fixtures required to make a bonded joint.

Adhesives offer several advantages over alternative methods of fastening and joining. They are well suited for joining non-uniform materials, stresses are transmitted uniformly over the entire bonded area, and exposed surfaces are not disturbed. The plastic properties of adhesives allow them to perform additional functions as sealants, insulators and corrosion barriers. The sealant capability is advantageous in environments where moisture might penetrate the joint and cause corrosion. The ability to insulate makes adhesives advantageous when joining dissimilar metals in environments where there is potential for galvanic corrosion. A flexible adhesive of proper thickness can also accommodate differential thermal expansion between dissimilar materials. Bonded joints should be designed to specifications provided by the adhesive supplier.

Stand-off fasteners developed for sheet metal can be adapted to die castings to mount electronic circuit boards and similar applications.

When gas porosity is present, arc and torch welding of die castings is difficult. Heat transferred to the die casting by the welding operation increases the gas pressure within the pores and weakens the casting walls, often causing protrusions or surface blisters. Advances in die casting technology allow die casters to sharply reduce or eliminate gas porosity. Appropriate procedures for control of porosity can be resolved by consulting with the die caster. Electronic beam and laser welding, which concentrate heat to the immediate area of the weld, are being used to some extent.

AZ91D magnesium alloys are subject to stress corrosion cracking, as noted in section 7, below. Die castings made from these alloys must be heat treated to relieve stresses induced by welding and prevent stress corrosion cracking. A stress relief cycle of two hours at 350°F (177°C) is advisable.

Soldering is not used for structural attachments of die castings since soldered joints are low in strength and sometimes brittle. Soldering can be used to attach light-weight components such as wires, electronic chips and circuit boards, particularly when an electrical contact is required.

7. Characteristics of Die Castings Requiring Special Design Measures

Two characteristics of die casting alloys require special design measures: galvanic potential and the response to long-term loading.

Galvanic potential

Die castings in contact with dissimilar metals create a potential for galvanic corrosion that can be controlled by appropriate design measures. All combinations of dissimilar metals are subject to galvanic corrosion. The tendency and severity are a function of their relative positions in the electromotive series, which is shown below in Table 3.20.

Table 3.20 Electromotive Series		
	Element	Electrode Potential at 25 C (77 F) (volts)
Anodic		
	Magnesium	-2.34
	Beryllium	-1.70
	Aluminum	-1.66
	Manganese	-1.05
	Zinc	-0.76
	Chromium	-0.71
	Iron	-0.44
	Cadium	-0.40
	Nickel	-0.25
	Tin	-0.14
	Lead	-0.13
Zero		
	Hydrogen	0.00
Cathodic		
	Copper	+0.34
	Mercury	+0.79
	Silver	+0.80
	Palladium	+0.83
	Platinum	+1.20
	Gold	+1.42

Two principles help quantify the potential galvanic problem.

- Anodic metals are deteriorated by galvanic corrosion
- The wider the spread, the greater the galvanic potential

The electromotive series indicates that die casting alloys are highly anodic and that the potential for galvanic deterioration is high when in contact with alloys containing iron and copper.

The galvanic corrosion rate for a combination of metals is usually determined by laboratory tests that expose the alloys to abnormally severe conditions, typically salt-spray tests. Actual service conditions are usually much less severe, so that minimal or no protective measures maybe required in some applications where laboratory tests indicate galvanic potential. For example, salt-spray tests indicate that the copper content in aluminum alloy 380 makes it incompatible with any magnesium alloy. In practice, a 380 aluminum transmission housing bolted directly to an AZ91D magnesium clutch housing and subjected to road testing that included salt splash required no galvanic insulation between the members. However, the magnesium housing required galvanic insulation from the steel bolts. The product engineer must use judgment based on experience, usually confirmed by a test program, to determine the need and extent of galvanic protection required for each application. Case studies assist by documenting real world experiences.

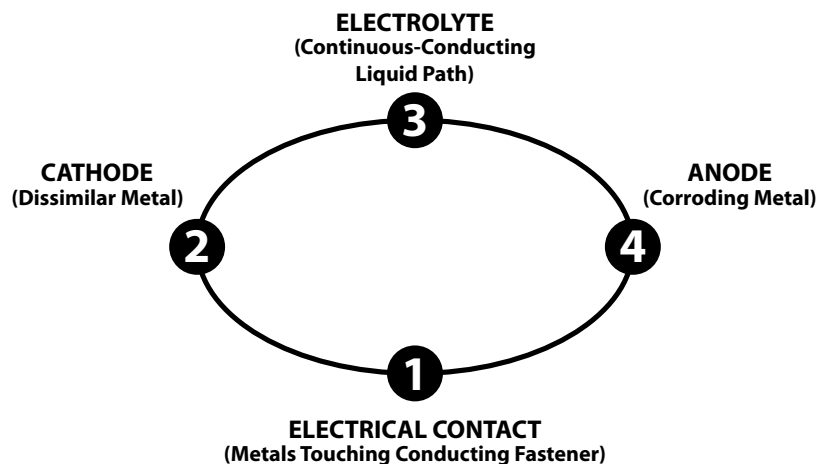
Four conditions must exist for galvanic corrosion to occur:

- An anode, or corroding metal
- A cathode, which is a dissimilar metal that is less anodic or more cathodic
- An electrical contact, typically metals directly touching
- An electrolyte, or continuous conducting liquid path

These conditions and their interrelationship are shown schematically in Figure 3.21. Since all four conditions must coexist, eliminating any one breaks the galvanic circle and prevents galvanic corrosion. The galvanic circle can be broken in the design process by applying the following steps alone or in combination:

1. Exclude or minimize the accumulation of electrolyte, usually water, at critical contact surfaces.
2. Choose metals with maximum compatibility.
3. Insulate against electrical contact.

Figure 3.21
The galvanic corrosion circle.



Choose alloys with maximum compatibility

Galvanic compatibility between alloys varies with their chemical compositions. For example, among die casting alloys, aluminum, zinc, and ZA are mutually compatible as are magnesium, zinc and ZA. Copper levels of 1.25 to 2.50% (maximum values) in zinc 5 and ZA alloys, which might otherwise render them incompatible with magnesium, are believed to be passivated by the of zinc. Aluminum die casting alloys 360, 392, 413, 443 and 518 with restricted copper levels are compatible with magnesium alloys. Alloys 380, 383, 384 and 390 have higher controlled levels of copper, are not compatible, and may require galvanic protection under severe conditions. Aluminum wrought alloys 2024, 3003 and 7075 are not compatible with magnesium die casting alloys, whereas wrought alloys in the 5000 and 6000 series are used as galvanic insulators between magnesium alloys and iron.

The position of magnesium at the top of the galvanic series indicated that galvanic corrosion is more of a problem in magnesium alloys than in aluminum, zinc or ZA. Detailed guidelines for developing the optimum system of galvanic protection for magnesium die castings have been documented and published.

Insulate against electrical contact

Dissimilar metals with galvanic potential should be insulated from each other in environments where electrolytes such as water may be present. The following methods, alone or in combination, are employed:

- Sealing components such as paints
- Non-absorbent tapes
- Fabricated insulators

Painting, correctly performed, is convenient means of insulation. Instinct may suggest that the die casting should be painted, because it is the member to be protected. In practice, the paint will usually experience one or more local failures, typically a pinhole or scratch. When only the die casting is painted, a small area of it transfers metal to a large area of the cathodic member through a break in the paint, and severe pitting occurs in the die casting. When the cathodic member is painted, a very large area of the die casting transfers metal to very small area of it. The corrosion on the die casting is superficial and not serious. Both conditions are shown in Figure 3.22. Therefore it is better to paint the cathode than the die casting; better still to paint both members.

Nonabsorbent tapes, such as vinyl and rubber, as thin as 0.003 in. (0.075mm) are suitable. Cloth supported tapes are not recommended; they may be counter-productive because the cloth can act as a wick. Where practical, tapes, sealing compounds, and paint coatings should extend .12 to .25 in. (3.2 to 6.4 mm) beyond the die casting as shown in Figure 3.23.

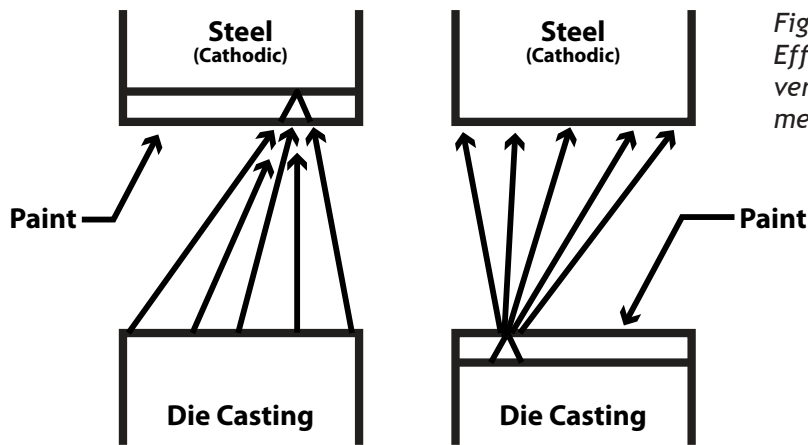


Figure 3.22
Effect of painting the die casting versus painting the cathodic member.

Figure 3.23
Protective measures for bolted construction.

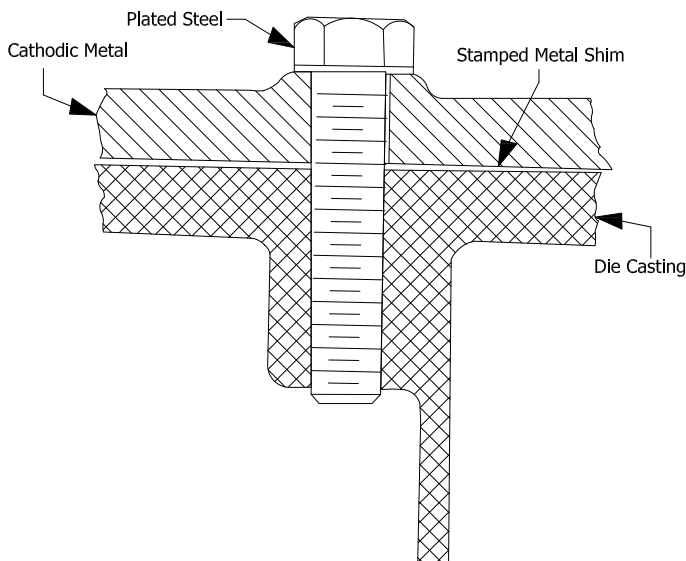
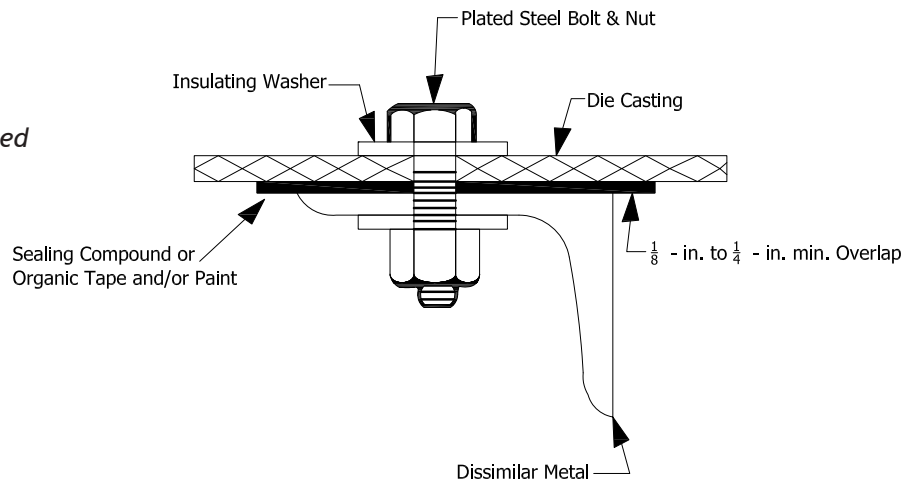
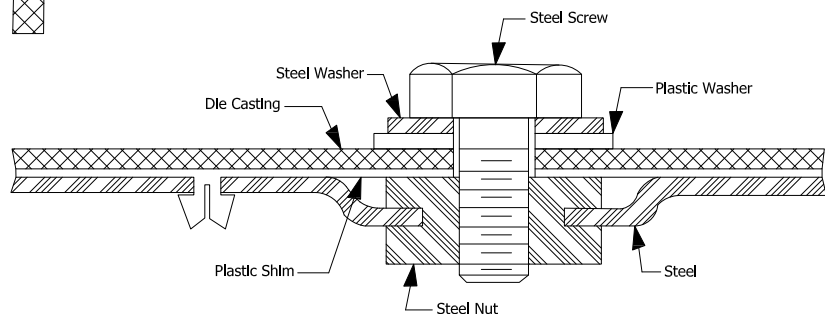


Figure 3.24
Joint with metal insulators.

Figure 3.25
Joints with plastic insulators.



Fabricated insulators may be inserted between the die casting and its fasteners or between the die casting and cathodic components. Washers, spacers, bushings, grommets made from or coated with compatible metals or plastic are most common. The material choice depends primarily on operating temperature and load. For example, metal shims and washers are used under bolt heads where heavy retention loads are applied, whereas plastic shims and washers are used with sheet metal screws. Where very light retention is required, such as a push-on steel spring clip, closed cell sponge washers are adequate. Open cell sponge is unacceptable because it serves as a wick, retaining water between the surfaces. Joints employing metal and plastic insulators are shown in Figures 3.24 and 3.25.

Wherever possible, it is good practice to combine the insulating function with other functions to reduce the number of parts required. For example, a push-on nylon washer that retains attaching screws during assembly can often be used or modified to serve also as an insulator.

Response to continuous long-term loading

Two responses requiring special design measures can occur under conditions of continuous long-term loading; creep and relaxation, and stress corrosion cracking. Creep and relaxation, different manifestations of the same phenomenon, can occur in any metal, depending on temperature and conditions of loading. They must be considered in zinc and ZA die castings at all temperatures. Stress corrosion cracking is a potential problem only with AZ91 magnesium alloys.

Creep and relaxation

Creep and relaxation are discussed in Chapter 2, Section 2.3 “Structural Criteria.” The term relaxation indicates the loss in retention that occurs in attachments that must withstand long-term sustained loads. Relaxation can occur under conditions of sustained loading when metal temperatures are elevated sufficiently; it can occur at room temperature in zinc alloys and, to a lesser degree, in ZA alloys. Creep characteristics for zinc and ZA alloys have been documented and published. (Representative creep data for each of the three die cast metal families are shown in chapter 2 section 2.3)

The potential loss of retention at attaching points is rarely prohibitive. The attachment usually meets functional requirements when proper design procedures are followed. Die castings are widely used in applications such as internal combustion engines, are compressors and electric motors where operating temperatures indicated potential relaxation.

The following guidelines, subject to verification by testing, are a beginning point in designing to counteract the effects of possible relaxation:

- Reduce thread stresses in the die casting substantially by increasing thread diameter, increasing the length of thread engagement beyond that required to prevent stripping, and increasing the number of fasteners.
- Reduce stresses where staking or swaging is used by increasing the number of staking operations and increasing the area that is swaged.
- Where possible, use through bolts and nuts rather than inserting studs or bolts in tapped holes so that compression stresses only are induced in the die casting alloy. Confine shear, bending and tensile stresses to the bolt and nut.
- Use inserts, where possible, to distribute the loads into the die casting and reduce stress concentrations.
- Where inserts are used, design the joint so that long-term continuous loads are not transmitted to the die casting.
- Combine fastening methods, such as bonding or staking inserts in addition to interference fit.

Stress corrosion cracking (AZ91 magnesium alloys only)

Magnesium-aluminum-zinc alloys containing more than 1.5% aluminum may be subject to stress corrosion cracking. This category includes only the AZ series of the common die casting alloys. As the name implies, cracks may be initiated in areas where prolonged stresses of at least 30% tensile yield (7 ksi or 48 MPa for AZ91B and D) occur in the presence of a corrosive atmosphere. Design and assembly practices that can induce continuous stresses above the limits include:

- Forcing parts into alignment for riveting or bolting
- Failure to relieve stresses after welding
- Inadequate design for press fit assemblies or cast-in-place inserts

Alignment problems occur when the interfacing components are rigid and tolerance control is poor, such as in structural assemblies made from stamping. They can also occur when castings distort. Flexibility must be provided in the attaching system to avoid inducing stresses in the magnesium die casting. Light-gauge sheet metal and plastic components are normally quite flexible; they usually pull into alignment without inducing significant stresses in the relatively rigid die casting. Machined cast iron, powdered metal, and die cast components which maintain close tolerances present no alignment problems.

Inserts, whether cast-in-place or post-installed, including residual stresses in the casting. To avoid stress corrosion cracking when AZ91 magnesium alloys are used, residual stresses must be limited. Inserts cast in place absorb heat from the molten magnesium and contract with the casting on cooling, relieving stresses in the casting to some extent. Insert wall thicknesses 0.050 in. (1.25 mm) or less will heat and subsequently contract, and limit residual stresses to safe levels. Inserts with thicker walls must be preheated. Bearings and dowel inserts retained by interference fits may be subject to stress corrosion unless residual stress levels are limited. Safe design data for cast-in-place steel inserts, and data specific to post-installed steel, brass, and Babbitt inserts, have been published.

3.3 Machining

Die casting is a net or near-net shape process which minimizes or totally eliminates the need for finish machining operations. Machining operations, when required, are performed economically at high production rates.

There are no precise rules for determining when a machining operation is required for a die casting. The need is largely determined by factors such as:

1. The precision casting capability of the die caster. Die casters are continuously improving their capability to maintain closer casting tolerances and lower draft angles than others. However NADCA Product Specification Standard for Die Castings may be used to determine the general limits of die casting.
2. The alloy selected. Some alloys can be cast to closer tolerances and lower draft angles than others.
3. The context of the component feature in question. The shape of a feature and its location with respect to other features may affect casting parameters and consequently minimum achievable tolerances and draft angles.
4. Production economies. Product volumes may determine whether it is more economical to machine a feature or utilize additional die members, such as core slides, to cast it.

These factors emphasize the need for interaction between the design engineer and die caster in a simultaneous engineering program, beginning at the earliest design stages.

1. Specifying Machining Operations

Two tasks must be addressed when machining operations are being considered:

- Determine, with the die caster, which features should be machined and which should be produced as-cast.
- When machining is necessary, make adequate provisions.

Two real-world experiences illustrate the advantages of consulting with a die caster to determine which features must be machined. In one case, the OEM designed a die casting to industry standards for tolerances and draft, then purchased special-purpose machines to perform finish machining operations in-house. It was subsequently discovered that the selected die caster could have precision cast the component, eliminating nearly all of the machining operations.

In the other case, the die caster was involved in the development of the product, and eliminated the two required machining operations by precision casting holes to press-fit tolerance.

Machining operations can often be eliminated on components with complex features—like undercuts, or bosses and holes with the axis not parallel to the direction of the die opening—by utilizing additional die members, usually core slides. Although the additional members increase tooling cost, somewhat increase machine cycle time, and can cause the formation of flash which usually has to be removed, this additional expense can be more than offset by the savings on machining costs. The die caster can provide an accurate assessment of the cost benefits such trade-offs present.

When machining operations are specified, the part design may require modifications. The following factors can be resolved through consultation with the source responsible for machining:

- Features to be machined must be arranged to permit access by the machine tools.
- Casting features that receive and transmit machining loads must have adequate strength and rigidity. Strength of a feature may be controlled by machining rather than functional criteria.
- Features may be required for locating and clamping the casting. When these features are identified early in the design of the part, they may be combined with functional features at little or no cost penalty.
- Wherever possible, clamp locating pads should be on areas formed by the same half of the die as the surface to be machined. This will eliminate the additional tolerances that accumulate across the die parting line.
- Surfaces to be machined must be carefully selected when pressure tightness is required to avoid interrupting the dense die cast “skin,” which is normally pressure tight.

Die castings rarely distort or warp by cold working during machining. When they do, the problem can usually be traced to poor machining practices such as dull tools, slow feeds, tool dwell, and operations that induce excessive heat in the casting. Since rough cuts induce more heat generation by limiting the maximum depth of cut, even at the expense of an additional rough or finish machining operation.

2. Machining & Porosity

It is important to address the porosity in the design of the die cast part when secondary machining operations are to be performed, since zero porosity throughout the part is virtually impossible to achieve. Porosity can be minimized and localized through die design and processing technology. The specifier should always clearly indicate on part prints the precise areas, extent and depth of secondary machining - before any die construction begins. It is always desirable to keep material removal by machining to a minimum. For economic production the user should always be willing to accept a specified amount of porosity in areas of the casting where it can be tolerated without compromising strength.

3. Machining Characteristics of Die Casting Alloys

Die casting alloys exhibit very good to excellent machinability in terms of high cutting speeds, low energy requirements, and long tool life. Machinability is rarely a dominant factor in selecting among the four families of die casting alloys, but may be a factor in selecting among alloys within a family, particularly aluminum. The following overview of machining characteristics will be helpful when machining operations are specified.

Aluminum alloys

Machining characteristics vary somewhat among the eight commercially available die casting alloys, but the entire group is superior to iron, steel, and titanium. The rapid solidification rate associated with the die casting process makes die casting alloys somewhat superior to wrought and cast alloys of similar chemical composition.

Alloy 518, with magnesium the major alloying element, exhibits the best machinability. Alloy 390, with the highest silicon content and free silicon constituent, exhibits the lowest. Alloy 380, the most widely used, is better than average. (See Table 4.3, Chapter 4.)

In most cases, two cuts are required: a rough cut to remove the aluminum oxide surface coating, and a finish cut to achieve the required tolerances and surface finish. Cutting fluids are used for nearly all machining operations to lubricate the tool, cool both the tool and work piece, and flush chips away from the work piece. Chip removal is especially important in automated machining operations.

Magnesium alloys

Magnesium alloys exhibit the best machinability of any group commercially used metal alloys. Machining operations are performed at extremely high surface speeds, usually at the maximum obtainable on modern machine tools. Heavy cuts and high rates of feed and speed are usually employed. Energy consumption per cubic inch of metal removed is lower than for any other metal, and tool life is usually several times as great.

The free-cutting characteristics procedures well-broken chips with no tendency for the metal to tear or drag. Machining operations requiring rough and finish cuts on other alloys can usually be done in one operation. It is also common practice to drill 15 to 20 diameters deep without withdrawing the drill for chip removal.

Fine magnesium particles produced during certain machining operations can present a fire hazard. However, potential hazards in storing, machining, and grinding magnesium are eliminated by careful attention to guidelines for machining operations and the application of a few basic, virtually cost-free procedures. Coolants can be employed, but it is desirable and economical to machine dry whenever possible. Recommended practices for machining, and guidelines for safe handling of magnesium alloys are available.

Zinc and ZA alloys

The machining characteristics of Zinc and ZA alloys are very good. For example, tool wear tests on drilling operations with high-speed twist drills indicated lower wear with ZA-12 than SAE-40 brass casting alloy.

The use of cutting fluids, though not always necessary, is strongly recommended because the heat generated tends to soften the alloys and contribute to galling and burr formation. Cutting fluids promote good chip formation and surface finish.

Moderate to high feed rates and cutting speeds are employed. Dwells in feed rate should be avoided because they generate heat rapidly and lead to galling, burr formation and surface finish deterioration. High-quality surface finishes and good productivity are achieved when available guidelines for machining zinc are followed.

3.4 Surface Finishing

Surface treatments systems are applied to die castings for one or more of the following purposes:

- Provide a decorative finish
- Form a protective barrier against environment exposure
- Fill and seal small surface pits and interconnected subsurface porosity
- Improve resistance to wear
- Insulate from a dissimilar metal when there is potential for galvanic corrosion

Galvanic insulation is covered in detail in section 3.2 on assemblies; this section addresses the other purposes of surface treatment. Systems that offer the highest performance levels and are specified most frequently are summarized in Table 3.29.

Even when a die casting requires no further surface treatment for decoration, protection, or improved performance, a deburring operation is nearly always recommended. This step removes any flash, burrs, sharp or ragged edges that might remain after trimming, to facilitate handling and any further finishing treatments. Mechanical, chemical, and thermal deburring techniques are available, with vibratory deburring the most common.

1. As-Cast Surface Finish

In many cases the as-cast surface finish of a die casting may meet product requirements without the addition of surface finishes. A very thin and transparent oxide layer forms on all die castings shortly after being removed from the die casting die. This oxide layer may be adequate to protect the die casting in many applications. If a surface finish is required, the as-cast surface finish may play a role in the application, performance and appearance of subsequent surface finishes applied to the die casting. Table 3.26 lists the as-cast surface roughness that can be expected in a new die and over the life of a die for various die casting alloys. Additional as-cast surface finish guidelines can be obtained from the *NADCA Product Specifications Standards for Die Castings* publication #402.

Table 3.26 Typical As-Cast Surface Roughness Guide

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

2. Cast-In Decorative Surface Textures

Textures such as stipples and grain can be cast into the surface provided that the textured surface is generally oriented perpendicular to the direction of die draw. Using photoengraving techniques in the making of the die casting die, virtually any desired pattern, depth and graining can be integrally die cast into the surface of a part (selected sample show below, greatly enlarged). Acrylic-type finishes are used as the final finishing step. Product enhancement through the use of detailed cast-in patterns should be weighed against reduced die life and required added die maintenance.

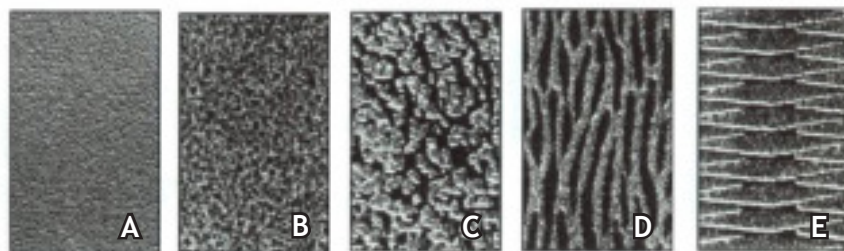


Figure 3.27
 Cast-in Decorative Surface
 Textures
 A. Fine Sand
 B. Sand
 C. Spanish Stucco
 D. Bark
 E. Lattice

3. Decorative Finishes

Three types of decorative surface treatments are used on die casting: painting, plating, and bright finishing other than by plating. Decorative finish quality largely depends on casting surface quality. Bright chrome and paint systems that produce high luster or gloss require a high-quality surface. Systems that produce a textured finish are much less sensitive to surface quality. Therefore the die caster must know the surface quality and finish requirements to apply appropriate process controls, perform required die maintenance, and schedule secondary operations.

Bright finishes, such as chrome-plated hardware, usually require a buffing operation to develop a mirror-like surface to receive the plating, and intermediate buffing during successive plating operations. Matte finishes, typically used for furniture and luggage, are achieved by sand blasting, grit lasting or scratch brushing followed by a clear lacquer. Scratch brushing develops smooth line textures or a satin finish.

Die castings that are to be electroplated must be designed to accommodate the electrical current density patterns that characterize the process. The complexity of the casting and the shape of features can affect current distribution and hence plate thickness. Good uniformity is achieved on gently curving convex surfaces. Corners, edges, fins, ribs and similar protruding features concentrate current flow and receive more than the average deposition of plated metal. Recessed features, such as grooves, serrations, holes, concavities and deep recesses, receive less than average, see Figure 3.28.

Electroplating requires successive steps of immersion in plating solutions and rinsing. All casting features, particularly deep recesses, must be designed so that plating solutions will readily drain. The castings must also be designed so that they can be buffed and racked economically.

Process controls, such as shields, cathode robbers and auxiliary cathodes, help to equalize plate thickness. However, the most effective means of achieving good distribution at minimum cost is to follow recommended design procedures for configurations and orientation of features. Table 2.28 shows general principles for designing die casting for electroplating. Indicated plate thicknesses and improved design configurations have been exaggerated to emphasize the principles. Recommended dimensions and proportions have been determined and published.

Die castings can be painted, like ferrous and nonferrous wrought and sheet products. However, when exacting standards for a color-match with adjacent dissimilar materials must be met, the paint may have to be specially formulated to achieve the desired result. Color match, surface preparations and priming vary depending on the alloy and application.

Further information regarding decorative finishes specific to each alloy group is presented in parts 7-9 of this section.

4. Atmospheric Corrosion

Die casting alloys are relatively active metal with a high potential to react chemically with substances in the atmosphere, primarily water and airborne pollutants. The reaction forms a tight surface coating on die castings that seals the surface and retards further corrosion. The coating builds up at a progressively diminishing rate, developing an effective barrier that frequently requires no additional corrosion protection, even in moderately severe environments.

Factors that affect atmospheric corrosion can be managed through quality control and design specification when designer and die caster interact in a simultaneous engineering program. Metal purity is especially important to the corrosion resistance of magnesium die casting alloys. Zinc and ZA die casting alloys must adhere to equally stringent purity levels to prevent inter granular rather than atmospheric corrosion. The specifications that control aluminum alloys allow higher levels of nonessential constituents with no adverse effects on atmospheric corrosion resistance. The United States die casting industry follows strict procedures for achieving and maintaining required levels of metal purity (refer to the section on die casting alloys in this manual). Where additional corrosion protection is required, the designer can opt from a variety of systems that are described later in this section and in the end notes.

Table 3.28 Design Features that Influence the Electroplating Characteristics of Die Castings

Original Design Feature

Platability Factors

Improved Design Features



Convex Surfaces

Ideal shape. Easy to plate uniformly, especially where edges are rounded.

Flat Surfaces

Not as desirable as crowned surfaces. Use a 0.015 inch/inch crown to hide undulations caused by uneven buffing

Sharply Angled Edges

Undesirable. Reduces thickness at center areas and requires increased plating time for depositing a minimum thickness of durable electroplate. All edges should be rounded. (Edges that will contact painted surfaces should have a minimum radius of 0.03 in. or 0.8mm).

Flanges

Large flanges with sharp inside angles should be avoided to minimize plating costs. Use a generous radius on inside angles and taper the abutment when an unsupported, narrow flange is necessary.

Slots

Narrow, closely spaced slots and holes reduce electroplatability and cannot be properly plated with corrosion-protective nickel and chromium unless corners are rounded.

Blind Holes

Blind holes must usually be exempted from minimum thickness requirements

Sharply Angled Indentations

Sharp angles increase plating time and costs for a specified minimum thickness and reduce durability of the plated part.



Original Design Feature



Platability Factors

Flat-Bottom Grooves

Inside and outside angles should be rounded generously to minimize plating costs. Plating thickness distribution will tend to restore the crisp design concept that is usually desired for styling grooves.

V-shaped Grooves

Deep, V-shaped grooves cannot be satisfactorily plated with corrosion-protective nickel and chromium and should be avoided. Shallow, rounded grooves are preferred.

Fins

Fins increase plating time and costs for a specified minimum thickness and reduce the durability of the plated part.

Ribs

Narrow ribs with sharp angles usually reduce electroplatability; wide ribs with rounded edges impose no problem. Taper each rib from its center to both sides and round off edges. Increase spacing if possible.

Concave Recesses

Electroplatability is dependent upon dimensions.

Deep Scoops

Scoops increase plating time and costs for a specified minimum thickness.

Spearlike Juts

Build-up on jut will rob corners from their share of electroplate. Crown the base and round off all corners.

Rings

Electroplatability is dependent upon dimensions. Round off corners and crown from the center line, sloping toward both sides.

Improved Design Features



Table 3.29 Coatings for Castings				
	Coating	Applicable Material	Advantages	Price
Pretreatments	Alodine 5200	Al, Mg	1, 2, 3	Medium
	Chromate (Class 1A & 3)	Al	1, 2, 3, 4	Medium
	Iron Phosphate	Al, Mg	1, 3	Low
	NH 35	Mg	1, 2, 3	Medium
Primers	Urethane	Al, Mg, Zn	1, 3, 5	Medium
	Epoxy	Al, Mg, Zn	1, 2, 3, 6	Medium
	Zinc Rich	Al, Mg, Zn	1, 2, 3, 6	High
	Zinc Chromate	Al, Mg, Zn	1, 2, 3, 5, 6	Medium
	Vinyl Acid Wash	Al	1, 2, 3, 6	Low
	E-Coat	Al, Mg, Zn	1, 2, 3, 6	Low
Liquid Topcoats	Urethane	Al, Mg, Zn	1, 3, 5, 6, 7	Medium
	Epoxy	Al, Mg, Zn	1, 2, 3, 6	Medium
	Acrylic	Al, Mg, Zn	1, 3, 5, 6, 7	Medium
	Waterbase	Al, Mg, Zn	1, 2, 3, 5, 6, 7	Medium
	Fluropons/Architect	Al, Mg, Zn	1, 2, 3, 5, 6, 7	High
Powder Coats	Polyester	Al, Mg, Zn	3, 5, 6	Medium
	TGIC	Al, Mg, Zn	1, 2, 3, 5, 6, 7	Medium
	Urethane	Al, Mg, Zn	3, 5, 7	Medium
	Epoxy	Al, Mg, Zn	1, 2, 3, 6	Medium
	Hybrid	Al, Mg, Zn	1, 2, 3, 6	Medium
Anodic Films	Annodize	Al, Mg	1, 2, 3, 5, 6, 7	Low
	Hardcoat - Hard Annodizing	Al, Mg	1, 2, 3, 6, 7	Medium
Electroplating	Copper	Al, Mg, Zn	1, 2, 4, 6, 8	High
	Copper/Nickel	Al, Mg, Zn	1, 2, 4, 6, 8	High
	CU/Ni/Chrome	Al, Mg, Zn	1, 2, 4, 6, 8	High
	Brass	Al, Zn	1, 2, 4, 6, 8	High
	Bronze	Al, Zn	1, 2, 4, 6, 8	High
	Zinc	Al, Zn	1, 2, 4, 6, 8	High
	Silver	Al, Zn	1, 2, 4, 6, 8	Very High
	Gold	Al, Zn	1, 2, 4, 6, 8	Very High
Electroless Plating	Electroless Nickel	Al, Mg, Zn	1, 2, 3, 4, 5, 6, 7, 8	High
	Electroless Copper	Al, Mg, Zn	1, 2, 3, 4, 5, 6, 7, 8	High

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

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

Chromating is one system of surface treatment that is often applied to aluminum, magnesium, zinc and ZA die castings as a corrosion protection system or a base for paint or dyes. The film presents a physical barrier, and the hexavalent chromium content inhibits corrosion. When the film is disrupted, the hexavalent chromium in contact with water slowly leaches and effectively self-heals. The degree of protection increases with film thickness, progressing from the thin clear films, to the intermediate light iridescent films, to the heavy olive drab and brown coatings. Applications range from humidity protection during storage to marine atmosphere exposure.

Chromate coatings are normally soft and easily damaged while wet, and become reasonable hard when dried. They will accept dyes when soft, providing an economical means of color coding. When hard, they will withstand considerable handling, but not continued abrasion or scratching. Mechanical fastening usually causes local damage; the corrosion protection will then depend on the self-healing capability of the film. Prolonged exposure to temperatures in excess of 150°F (66°C) can substantially decrease the protective value of conversion coatings on aluminum and zinc. However, normal paint-curing cycles do not appear to affect chromate coatings.

Phosphate conversion coatings are applied to aluminum, magnesium, zinc and ZA die castings to improve corrosion resistance and increase paint adhesion. There are three basic types, in terms of metal ions present: iron, zinc and heavy (manganese). The three types and the weights associated with each are:

Coating Weight	Iron	Zinc	Heavy (Manganese)
Mg/ft ²	15 to 75	130 to 370	130 to 370
Gm/m ²	0.16 to 0.80	1.4 to 4.0	1.4 to 4.0
Primary Application	Paint Base, Low corrosion	Paint Base, high corrosion	Unpainted service

The crystalline nature of the zinc and manganese phosphates enables them to physically hold oils, waxes and paints, greatly increasing the corrosion resistance.

The following checklist will assist in evaluating the effects of corrosion and determining the level of protection required:

- Determine the type and severity of corrosive agents expected in the operating environment.
- Define the condition that must be maintained. It is not always necessary or desirable to require no corrosion at all. For example, a component remains serviceable as long as its function is not impaired by corrosion.; therefore, discoloration and dullness are tolerable when the product is purely functional or when in a non visible location.
- If anticipated corrosion is objectionable, reduce it to tolerable levels with a suitable surface finishing system.

5. Impregnation, Porosity and Pressure Tightness

Impregnation is sometimes used to develop pressure tightness and smooth surfaces in die castings. The preferred method, where possible, is to prevent the formation of porosity which causes the condition. The second method is to avoid removing surface metal, exposing porosity in critical areas. Simultaneous engineering, beginning at the outset of product development, is effective in preventing and controlling porosity by resolving factors such as the locations of gates and overflows, the locations of ejector pins, and the configurations of hard-to-cast features. These factors can usually be resolved through timely interaction in a manner compatible with product requirements and good die casting practice.

Impregnation is more common with aluminum die castings manufactured by the cold-chamber process than with zinc, ZA-8 and some magnesium die castings manufactured by the hot-chamber process. Porosity can be minimized in both processes by careful control of die casting parameters; it may be virtually eliminated by employing one of several available proprietary systems. Gas porosity, when present, is buried in the core of a die cast section beneath the dense, pressure-tight skin. When machining operations remove 0.020 in. (0.8 mm) or more of metal, subsurface pores may be exposed, leaving the surface pitted. Where possible, machining operations should be avoided in areas that require a smooth or pressure-tight surface. Minimum-draft, zero-draft and close tolerance casting techniques are often employed to eliminate machining operations on critical surfaces.

Systems employing anaerobics and methacrylates are currently employed when impregnation is specified. These systems produce sealed castings ready for pressure testing in 40 minutes at a yield of 90%, assuming average porosity. Typical turn-around time is three days when impregnation is out-sourced, and one day when performed in-house.

6. Wear Resistance

An abrasion-resistant surface can be applied to die castings in applications subject to severe abrasion and wear. Protection is often applied locally when only a localized area is subject to abrasion. Aluminum and magnesium alloys are hard-coat anodized; magnesium, zinc and ZA-8 and -12 alloys may be hard-chrome-plated. Further information on wear resistance specific to each alloy group is presented in parts 7-9 of this section.

7. Surface Treatment Systems for Aluminum Alloy Die Castings

Aluminum die castings exhibit good to excellent corrosion resistance, depending on alloy copper content. Alloys with restricted copper content exhibit improved corrosion resistance in atmospheric exposure. When corrosion protection is required beyond that afforded by the protective surface film, aluminum die castings can be chromated, painted or anodized.

As previously stated, a high-quality decorative surface requires a high-quality cast surface. Advances in die casting technology, particularly in vacuum die casting and die temperature control, have increased the durability of die casting die surfaces. This translates into improved die casting surface quality. These advances have opened opportunities for aluminum die castings in applications requiring decorative surfaces. Aluminum die castings are frequently painted; electroplating is performed on a limited basis.

Painting

Available paint formulations for aluminum die castings penetrate the normally thin oxide coat and develop adhesion. When aluminum die castings have been stored for an extended period prior to painting, particularly in conditions of high humidity, the oxide layer accumulates, making it necessary to remove it by vibrating the casting in an abrasive medium or surface blasting it. In conditions where the component is subject to impacts, such as stone damage that can chip paint, or when very corrosive atmospheres are anticipated, paint adhesion can be improved by applying a conversion coating such as chromating or phosphating as a paint base.

Painting systems for aluminum die castings encounter few production problems. When they do occur, they are generally traced to processing factors which are readily corrected. When exacting standards for color match with adjacent sheet steel must be met, paint formulation is adjusted to achieve the desired color match.

Anodizing

Anodizing is used to improve the natural corrosion resistance of aluminum die castings. Aluminum anodizing is an electrochemical process that converts aluminum into aluminum oxide at the surface of the casting. The process is accomplished by suspending the casting in an electrolytic cell and making it the anode (the member that receives the build-up). The oxide coat is porous, making it necessary, in most cases, to seal the surface. The casting is immersed in hot water, which hydrates the oxide and causes it to swell, sealing the pores.

The thickness of the anodized surface can be increased to develop a wear-resisting hard coat. As silicon content increases, aluminum alloys become more difficult to anodize.

Anodizing is not generally used as a decorative coating on aluminum die castings (except for alloys 443 and 518, which have 4.5% to 6.0% and 0.35% maximum silicon content respectively) for two reasons:

1. The chemical composition of aluminum die casting alloys, particularly, imparts a color that prohibits dyeing.
2. Anodizing amplifies visual surface defects that do not affect structural integrity, such as flow marks.

Electroplating

Aluminum die castings are commercially electroplated on a limited basis to produce a decorative surface, as noted above. Design guidelines to facilitate plating are similar to those for zinc die castings, which are discussed in part 7 of this section.

8. Surface Treatment Systems for Magnesium Die Castings

During prolonged environmental exposure of a product, the natural pattern of corrosion on magnesium is formation of a surface film of hydroxide on exposure to water, and formation of a surface coating of hydroxide-carbonate on exposure to the atmosphere. The coating thus formed on the casting offers some protection against further corrosion, and is partially self-healing. The atmospheric corrosion resistance of a magnesium die casting is vastly superior to unmodified mild steel, somewhat superior to copper-modified mild steel, better than die cast 380 aluminum, and inferior to zinc and ZA alloys.

A wide variety of surface treatment systems has been developed for magnesium die castings to provide short-term protection, long-term protection, decorative surface finish, and resistance to abrasion and wear. An overview of available systems is presented here. A comprehensive discussion and guide for specification has been compiled and published.

Short-term protection

Short-term protection is often applied to magnesium die castings to retain a bright metallic showroom appearance, or to protect the surface until subsequent surface treatment systems are applied. There are two classes of short-term protection: oils and waxes and chemical treatments. A thin film of oil or wax is often applied to bare magnesium surfaces to provide protection during storage in dry environments and in shipping. The films are low in cost and applied by brush, spray, or dip. Oil coatings can be readily removed prior to machining or painting by vapor degreasing, alkaline cleaning, or solvent dipping followed by a final rinse in clean, unused solvent.

A number of chemical treatments (conversion coatings), both chemical and electrochemical, are used for short-term surface protection. The coatings replace the naturally alkaline hydroxide-carbonate film with a surface which is more corrosion inhibiting and less alkaline to slightly acid.

Painting

Paint Systems that perform well on zinc or aluminum are generally satisfactory on magnesium die castings. They have been effectively applied to magnesium alloys by conventional solvent spray, electrostatic powder, and electrophoretic deposition from aqueous emulsion. Proper surface preparation and choice of priming materials are important, particularly under severe conditions, to ensure good contact between the primer and the metal surface. Surface preparation is often accomplished by applying one of several available chemical treatments that prevent oxidation in storage and shipment, form a good paint base, and retard the natural alkali which forms at any point of damage on a painted magnesium alloy surface. Chemical or electrochemical treatments improve adhesion and durability, but are not necessary in less severe applications.

Bright finishes

Polishing and buffing produce a bright metallic luster on magnesium die castings. Mechanical finishes acquire a gray film on atmospheric exposure; the luster must therefore be protected with a clear baked lacquer. This treatment is used for furniture and luggage. A ferric nitrate bright pickle chemical treatment is used to develop a semi-bright to bright silvery surface on magnesium die castings suitable for interior and mild exterior service. Typical uses include business machines, furniture, luggage trim, and tools. A more durable bright finish is obtained by a mild etch followed with a clear anodize.

As mentioned in part 1 of this section, magnesium die castings can also be bright chrome-plated to produce a high-luster, durable surface. Plated castings can be processed to withstand temperatures as high as 550°F (290°C). Corrosion tests in salt spray, high humidity, and interior and exterior exposures generally indicated good performance from plated magnesium. However, no qualitative data are available which correlate plating cycles with expected service life. Therefore, service testing is recommended to determine the proper plating cycle for the conditions anticipated.

Where increased wear resistance is required, heavy chrome plates may be applied. In the absence of quantitative design data, the required plating thicknesses must be determined by test.

Design guidelines to facilitate plating are similar to those for zinc die castings, which are addressed in part 9 of this section.

Anodizing

Anodizing of magnesium alloys essentially follows the same procedure used on other metals: surface cleaning, deoxidation, and anodize. Both alkaline and acid anodizes are available. However, anodic coatings on magnesium alloys do not lend themselves to dyeing. Color effects are achieved by bright pickles in combination with tinted or dip-dyed clear lacquers. Alkaline anodize must be post-treated for paint adhesion, but is harder and more wear- and abrasion-resistant than acid anodizes. Acid anodizes are more flexible, less subject to spalling or chipping, and make excellent paint bases even under most severe conditions.

Other available processes include hard anodize, for improved resistance to wear, and an impregnation anodize process, which is applied where impregnation plus a protective or paint-base coating is required.

9. Surface Treatment Systems for Zinc and ZA Alloy Die Castings

Electroplating

The plating characteristics of the zinc (Zamak) alloys have made them the prevailing choice for hardware applications, particularly where moderate to high strength is required. Zinc alloys readily accept a decorative bright chrome finish or a wear-resistant hard chrome finish. Chrome plating also improves corrosion resistance. Some zinc die casters develop and maintain high-quality polished surfaces on their die cavities that impact surfaces which do not require buffing prior to bright chrome plating.

ZA-8 can be plated using the processes as the zinc alloys. ZA-8 is being used as an alternative to zinc in applications where bright chrome plating combined with higher strength or improved creep resistance is required. ZA-12, with higher aluminum content, required some process modifications. ZA-27 is not chrome plated.

Painting

The zinc alloys are readily and economically painted with essentially no processing problems. Color-match with sheet steel is excellent. Zinc die castings painted in the same operation as contiguous sheet steel members meet the exacting standards for adhesion and color match of the automotive and home appliance industries. Bases such as primers and chromates are specified to improve adhesion and durability in severe conditions.

ZA alloys are also readily painted. There is, however, less experience with these alloys, particularly color-match with steel.

Chromate treatments

Chromate treatments are applied to the zinc alloys to develop a decorative finish, a base for paint, and corrosion protection. Chromate treatments combined with chemical polishing solutions have replaced more expensive finishing operations for zinc die castings. The corrosion protection afforded to zinc alloy die castings by various chromate treatments has been quantified and published. See Table 3.30.

ZA-8 and ZA-12 readily accept chromate finishes. Chromating ZA-27 requires some process modification. Zinc plating prior to chromating produces a highly decorative, inexpensive finish.

Table 3.30 Corrosion Protection for Zinc from Chromate Conversion Coatings²	
Process	Corrosion Protection (Hours)
Two-step clear	24-96
Yellow	100-200
Olive Drab	200-400
Chemical polish clear	48-200
Chemical polish yellow	100-300

Anodizing

Aside from the name, zinc anodizing bears no resemblance to aluminum and magnesium anodizing. Zinc alloys, ZA-8 and ZA-12 can be anodized using one basic process; the aluminum content of ZA-27 requires some process modification. The process has been proven in severe operating environments. However, the cost is high relative to other processes, and it is not currently in wide use.

Zinc anodizing deposits a semi-fused composite build-up of zinc oxides, phosphates and chromates via an anodic spark discharge at high voltage. The basic process produces a moss-green finish typically 0.00125 in. (0.031 mm) thick. Approximately one-fifth of the thickness is surface conversion and four-fifths is build-up. The build-up is friable in contrast to the hard surface and tight adhesion which characterize aluminum and magnesium anodize. The process has excellent throwing power, which ensures a consistent coating thickness on irregular surfaces and deep recesses including tapped holes. Zinc anodizing offers improved abrasion resistance, but is not recommended for castings that will be severely deformed.

Zinc anodizing provides an excellent barrier for galvanic corrosion. It also provides excellent resistance to surface corrosion, even when scratched to the base metal. Tests have demonstrated excellent protection against exposure to water, industrial and rural atmospheres, oils, road salts, most organic solvents, moderately strong bases, and weak acids. Corrosion and abrasion properties for zinc anodize systems have been quantified and published.

Because of its excellent allowance throwing power, the process requires no design provisions except allowance for 0.001 in. (0.025 mm) surface build-up and provision from drainage of plating solutions.

3.5 Prototyping

This section describes prototyping processes being used today in the development of die cast products. The following material is covered:

- Effects Of Alloy And Process
- Die Cast Prototyping Processes
 - Single-Cavity Prototype Die
 - Gravity Casting
 - Machining From Similar Die Castings
 - Machining From Wrought And Sheet Stock
 - Rapid Prototyping (Rp)
- Selecting The Optimum Prototyping Process
 - Aluminum Die Castings
 - Magnesium Die Castings
 - Zinc And Zn Die Castings

Prototyping is an essential stage in most product development programs. The die casting process itself is used for prototyping with single-cavity prototype dies. When other processes are used for prototyping eventual die castings, die casting alloys are not generally satisfactory. Approximate raw materials must be employed with these alternate processes.

In most cases a prototyping strategy for eventual die casting can be developed that will meet cost and time constraints and generate data that will be useful in validating the component design. In order to select the optimum prototyping process, the designer must first understand the effects of alloy and process on material properties and know the available processes.

1. Effects of Alloy and Process

Rapid solidification and cooling, high liquid metal pressures, and turbulent metal flow associated with die casting develop characteristics in the castings that cannot be duplicated by other methods. The most important variations are:

- **Skin effect.** The exteriors of a die cast section, to a depth of approximately 0.020 in. (0.5 mm), is dense and free of porosity, with somewhat superior mechanical properties. See Figure 2.6 in Chapter 2.
- **Internal porosity.** The center (core) of a die cast section may contain porosity due to air that is mixed with the molten metal when it is being injected.
- **Mechanical properties.** Die casting imparts a unique combination of mechanical properties. One or several properties may be approximated by other methods, but some properties of the prototype will differ, some significantly.
- **Chemical composition.** Alloys used for die casting are not usually suitable for the gravity casting or wrought and sheet alloys often used in prototyping. The chemical compositions are different, causing some variations in properties.

Some properties are independent of process, or nearly so. Modulus of elasticity is nearly uniform for all alloys of a metal whether die cast, gravity cast or wrought. The density of die castings is slightly lower than that for other processes, due to entrained porosity, but the difference is usually insignificant. Other properties vary with process, some significantly, due to differences in solidification rate and subsequent forming operations.

2. Die Cast Prototyping Processes

The only certain way to fabricate a prototype with all of the properties of a die casting is by actual die casting in the designated alloy. This is often feasible when a change to a different die casting alloy is contemplated. Prototypes may be cast in existing dies if the die casting processes are compatible and the die will properly fill with the new alloy.

The majority of product design programs for die casting involve either a totally new design or redesign from another process. New dies are then required, which involve a new tooling investment and lead times that may be incompatible with prototyping budgets and schedules.

Single-Cavity Prototype Die

The best approach to die cast prototyping for comprehensive testing is creation of a single-cavity die casting die. Surface finish and all other characteristics can be precisely evaluated. The cavity insert of this die can then be used as one of several inserts in a multiple-cavity die for final volume production.

While the time for initial prototyping is increased, production time for construction of the final dies and secondary trim tools will be shortened. Secondary tools are normally built until production castings are available. With this approach it is practical to make a limited range of alternations in the original die design after prototype parts are produced.

Where important design questions must first be resolved or lead times are not available, alternate means must be used that conserve money and time and produce prototypes with essential characteristics approximating those of the die cast end product. Die casting alloys are not generally suited for use with other processes and carefully selected alternate raw materials must be substituted.

Three of the most commonly employed prototyping alternatives are gravity casting, machining from die castings with similar shape, and machining from wrought or sheet stock.

Figure 3.31

The prototype sprocket on the left was cast in ZA-27 in a plaster mold using the original iron sprocket, modified with wax, as a pattern. The teeth were machined. When tests verified the durability of the teeth, the sprocket on the right, optimized for die casting, was die cast to tolerance in ZA-27 and retested.



Gravity casting

Gravity casting is the alternative method most often used to fabricate die cast prototypes. The process is economical for small quantities and lead times are relatively short. Sand or plaster molds are used with an alloy (and sometimes subsequent processing) that develops the desired properties. The castings are sometimes heat treated to bring properties such as ductility or yield strength closer to that of the die casting.

The zinc die casting alloy group (Zamak 3, 5 and 7), containing 4% aluminum, is very sensitive to solidification rate; strength and hardness of gravity castings are substantially lower than die castings. These Zamak alloys are therefore inappropriate for prototyping by gravity casting, except for decorative components where mechanical properties are not important particularly tensile strength, decrease for ZA-8, ZA-12 and ZA-27 with increasing aluminum content (8, 11 and 27% respectively). The strength and hardness of ZA-27 are essentially the same whether die cast or gravity cast, so that ZA-27 gravity castings are used as prototypes of ZA-27 die castings.

Foundries experienced in gravity casting aluminum or zinc alloys can adapt to ZA alloys. However, ZA-12 and 27 require some distinctly different techniques. ZA alloy suppliers can provide technical prototyping support to foundries in metal handling and mold design techniques for ZA-12 and 27.

Magnesium sand castings are being routinely produced for magnesium die casting prototypes (see Section 3, Magnesium).

The major limitations of gravity casting processes are dimensional precision, minimum wall thicknesses and fatigue strength. Gravity castings require extra stock and finish machining on features when very close dimensional precision, achievable by die casting, is required. Gravity casting can achieve most of the wall thicknesses by machining, their effects must be factored into the analysis of test results. Gravity castings generally exhibit high fatigue strength than die castings, due to lower porosity.

Experimentation with the new prototyping process of stereo lithography, combined with metal-spray mold making technology, is producing rapid, economical investment cast prototypes. This technique should make possible more timely and accurate evaluation prior to construction of a complex die casting die.

In stereo lithography, which uses direct input for CAD or solid modeling databases, a laser cures and hardens successive layers of a liquid photo polymer. A solid plastic model is thus created in a matter of hours. Atomized arc spraying of the plastic model with a specialized molten metal results in a molded pattern which is ready for use in producing an investment cast prototype.

Plaster molding

Plaster molds provide a surface finish similar to that produced by die casting, with thinner walls than possible with sand casting. They are often used for prototyping with aluminum and zinc alloys, and many plaster mold foundries have adapted to ZA alloys with the support of their alloy suppliers. Magnesium is cast in plaster molds by a small but growing number of foundries. Magnesium can react with plaster molds; therefore special techniques have been developed to make the process safe and reliable. When several stages of prototyping with successive changes are anticipated, it may be advisable to make the first stages from an aluminum alloy and cast, only the final design in magnesium alloy.

The plaster mold process begins with a pattern from which intermediate rubber tool is produced. Plaster molds are poured from the tool, which tolerates a variety of pattern materials. Wood patterns are usually employed, but other materials are used when stringent development schedules require minimum tooling time. For example, a pattern can be quickly made by modifying an existing plastic or metal component with wax.

Machining from similar die castings

Prototypes may be made by machining from die castings of similar size and shape. Prototypes of small components can sometimes be machined from heavier sections of large die castings. There are two limitations to this process.

- The size and shape of the prototype is limited by the size and shape of existing die castings.
- Machining removes the dense surface skin which uniquely characterizes a die casting.

The process is useful, in spite of these limitations, particularly when many prototypes are required and automatic machining processes are available to fabricate them. It is well suited to prototyping small gears and screw machined products for die casting.

Machining from wrought and sheet stock

Prototypes may be machined from a number of sheet and extruded aluminum and magnesium alloys. However, wrought and sheet materials exhibit relatively high ductility compared with die castings and sometimes very low compressive yield strength. Properties may also be directional, according to the direction that the sheet or extrusion was formed. Direct transfer of CAD product designs into CNC machining programs has made machined prototypes an attractive option, particularly when multiple prototypes are needed and the properties of the stock to be used approximate final die cast part requirements.

Continuous cast (Con Cast) Zinc 3, ZA-8, ZA-12 and ZA-27 are also available in 3/4 to 9 inch diameter bars and 5/8 to 4 1/2 inch thick flat stock for machining. The properties of the zinc bar stock closely approximate the properties in the zinc die cast condition.

3. Selecting the Optimum Prototyping Process

The optimum prototyping process depends on the alloy to be die cast and the properties to be evaluated. Working knowledge of the properties of die casting alloys and the available prototyping alloys is essential to selecting the optimum process. The following sections outline appropriate strategies from prototyping aluminum, magnesium, zinc and ZA die castings.

Aluminum

Aluminum die castings are readily prototyped, usually by gravity casting in sand or plaster molds. Aluminum gravity casting alloys use an alpha-numeric designation system similar to die casting alloys. The system consists of a three-digit root with a letter prefix, a one-digit suffix, or both (e.g. A332, 355.1 and A390.1). The three-digit root indicated the major alloying elements; the prefix and suffix designate minor variations in levels of impurities and minor alloy constituents that adapt the alloys for die casting or gravity casting. The discussion will refer to the various alloys by the three-digit root only.

356 is the most frequently selected gravity casting alloy because its casting properties allow close approximation of thin walls and intricate features that often characterize die castings. Mechanical properties can be altered by heat treating to T51, T6, T7 or T71. Although the tensile and yield strengths are generally lower than die cast alloys, 356 with heat treating options meets the requirements of most prototyping programs.

When die casting alloy 380 is selected, and resistance to corrosion is important, the prototypes can be made from gravity cast 319. The alloys have the same copper content, and the 319 prototypes will have essentially the same corrosion performance as the 380 die castings.

When die casting alloy 390 is selected for resistance to abrasion and wear, prototypes can be made from 390 gravity casting alloy.

Table 3.32 lists the ultimate strength, yield strength and elongation for the prototyping alloys listed above. These properties may be compared with the properties of die casting alloys, tabulated in the later section on material properties, to clarify the interpretation of prototyping testing.

Table 3.32 Properties of Aluminum Prototyping Alloys

Gravity Cast		Tensile Strength		Yield Strength		Elongation
Alloy	Temper	ksi	(Mpa)	ksi	(MPa)	%
356	T51	25	(175)	20	(140)	2.0
	T6	33	(230)	24	(165)	3.5
	T7	34	(235)	30	(210)	2.0
	T71	28	(195)	21	(1450)	3.5
319	F	27	(185)	18	(125)	2.0
	T6	36	(250)	24	(165)	2.0
390	F, T5	26	(180)	26	(180)	<1.0
	T6	40	(280)	40	(280)	<1.0
	T7	36	(250)	36	(250)	<1.0

Magnesium

Die castings made from AZ91B and D can be prototyped using gravity casting alloys AZ91C and E and AZ92. Properties of the gravity cast prototypes can be modified by heat treating to T4, T5 or T6 designations. Table 3.33 indicates the properties of the die casting that are attainable by gravity casting. Published values of materials properties should be used to quantify the comparisons.

The introduction of high-purity gravity casting AZ91D die castings in the gravity cast prototype. When the high purity of AZ91E is required, the designer must be concerned with the chemistry of the castings as well as the chemistry of the ingot received in the foundry. The high purity of the ingot must be conveyed to the casting through proper metal handling practices and good housekeeping in the foundry. It is especially important that the foundry use protective gas shielding rather than fluxes to prevent oxidation of the molten magnesium. Fluxes can become mixed with the metal and promote corrosion in the casting. Castings that are cleaned by particle blasting may pick up iron particles from the blasting media. Only clean, nonmetallic blasting media should be used.

One magnesium supplier recommends the following principles when AZ91E is specified and corrosion resistance is important:

1. Specify high purity AZ91E per ASTM B93
2. Specify ASTM B117 corrosion performance
3. Enforce the specifications

Die castings made from AM60A and B can be prototyped using gravity casting alloys. When the higher ductility of AM60 is important, AM100 may be used from prototyping. However, there is currently no high-purity grade of AM100, so the prototype will not display the corrosion resistance of AM60B. Alloys AZ91C, AZ91E and AZ92, which are used to prototype AZ91B and D, can also be used to prototype AM60A and B. Selection depends on the properties that are to be matched.

Table 3.33 Properties Matchup-Gravity vs Die Casting

Property	AZ91D vs AZ91E Matchup
Yield Strength	Attainable
Modulus of Elasticity	Attainable
Ductility	Attainable
Corrosion Resistance	Attainable
Wear Resistance	Attainable
Sound Dampening	Attainable
Machinability	Attainable
Finishing	Attainable
Tensile Strength	Difficult to match
Fatigue Strength	Difficult to match
Porosity/Soundness	Difficult to match
Impact Strength	Attainable

Zinc and ZA

The optimum gravity cast prototyping alloy for the zinc alloys, and for ZA-8 and ZA-12, must be carefully selected from material properties to simulate selected properties of the die casting. For example, gravity cast ZA-8 exhibits approximately the same tensile strength as fully aged Zinc 3. Gravity cast ZA-27 can be heat treated to reduce strength and increase ductility, making these properties closely approach those of die cast Zinc 5 and ZA-8.

ZA-27, as noted earlier, develops similar properties by gravity casting and die casting. Therefore, ZA-27 die castings can be prototyped by gravity casting in ZA-27.

Table 3.35 summarizes prototyping options for zinc and ZA alloys. Matchups are approximate and provide guidelines. Published values of materials properties should be used to quantify comparisons.

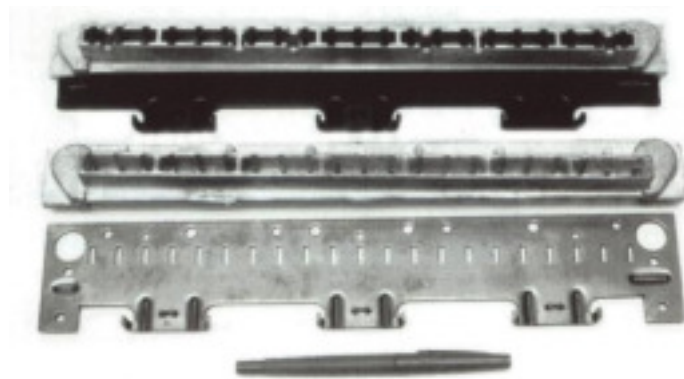


Figure 3.34

The zinc die casting, shown assembled to a steel stamping, was prototyped in ZA-12 using the plaster mold process. The prototype casting is shown in the center, and the unpainted stamping on the bottom.

Table 3.35 Prototyping Properties Matchup for Zinc ZA Alloys

	Tensile Strength	Ductility	Chrome Plate	Min Wall	Wear	Creep Strength	Fatigue Strength	Impact Strength
Zinc 3, 5& 7								
Gravity cast in same alloy								
	-	*	=	-	*	*	*	*
Machine from Con Cast bar stock in alloy 3 or 5								
	=	-	=	=	**	**	**	*
Machine from existing die casting in the same alloy								
	=	=	=	=	*	=	=	=
Gravity Cast in ZA-12								
	=	-	-	-	+	+	=	=
Gravity cast in ZA-27 and heat treat								
	=	=	n/a	=	+	+	*	-
ZA-8								
Machine from ZA-8 Con Cast bar stock								
	=	-	=	=	**	**	**	*
ZA-12								
Gravity cast in ZA-12								
	=	-	=	-	=	=	*	*
Machine from ZA-12 Con Cast bar Stock								
	=	=	=	=	**	**	**	*
ZA-27								
Gravity in ZA-27								
	=	=	n/a	=	=	**	*	*
Machine from ZA-27 Con Cast bar and flat stock								
	=	=	n/a	=	=	**	*	*

= The prototype can reasonably approximate the property of the die casting

+ The prototype will perform better than the die casting

- The prototype can not approximate the property of the die casting

* The properties have not been evaluated for both the prototype and die cast conditions

** The properties have not been evaluated for both the prototype and die cast conditions, but should be nearly equal

n/a The property is not applicable to the alloy

References:

1. Paul Frederick, Prototyping Magnesium Alloy Castings, SAE Paper #880511, Society of Automotive Engineers, p 2, 3, 7
2. Gene Cowie, Designing in Zinc, International Lead Zinc Research Organization, New York, 1988, p 43
3. American Society for Metals. (1962). Design of die castings. In Casting design handbook (pp. 113-138). Metals Park, Ohio.
4. North American Die Casting Association, NADCA Product Specification Standards for Die Castings. Wheeling, Illinois PDF, print and CD format available at: www.diecastingdesign.org



The Conventional Die Casting Process

This section presents an overview of the conventional die casting process as an aid to product designers who will interact with die casters in the development of their products. Understanding the fundamentals will aid in making design decisions early in the product development process that can have the maximum effect on cost reduction and performance improvement.

The following material is covered in this section:

- Understanding the Die Casting Cycle
 - Hot-chamber and cold-chamber processing
 - Miniature Die Casting
 - Die characteristics
 - Die Filling
- Characteristics of Die Castings
- Preventing Casting Defects
- Alloys and Properties
- Aluminum Die Castings
 - Effect of Alloy Constituents
 - Aluminum Die Casting Properties - As-Cast
 - Aluminum Die Casting Properties - T6 Heat Treated
 - Aluminum Die Casting Properties - T5 Heat Treated
- Magnesium Alloys
- Zinc Alloys
- ZA Alloys
- Early Designer-Die Caster Interaction
- Alloy Selection

Conventional die casting is a process in which molten metal is injected at controlled high velocity and pressure into the cavity of a mold (die) made of high quality steel. Rapid fill and high metal pressures, typically 2,000 to 10,000 psi (14 to 69 MPa), give the process distinct characteristics. Rapid fill allows the temperature of the die to be maintained at a level 300-500°F (150-260°C) below the solidification temperature (solidus point) of the incoming metal in order to freeze (solidify) the casting as quickly as possible. Fill times may be as brief as a few milliseconds for the smallest components and as long as half a second for the largest. The high pressure imposed on the metal ensures complete cavity filling and faithful reproduction of intricate details. Die castings also exhibit excellent surface quality and close dimensional tolerances, necessitating few if any machining operations. These characteristics make die casting particularly well suited for components requiring high production volumes, intricate details, and/or close tolerances.

4.1 Understanding the Die Casting Cycle

Die casting technology has been advancing rapidly during the last twenty years or so, and particularly in the last decade. Some die casters are adopting the newest technology, while others are not. There is, therefore, a wide diversity of die casting practices. Some of the advances in die casting (such as heat treating) will be considered later in this chapter, while modified die casting processes such as high vacuum, squeeze and semi-solid casting, will be described in a later chapter of this book.

Hot-chamber and cold-chamber processing

There are two basic die casting processes: hot-chamber and cold-chamber. The hot-chamber process is used for zinc alloys, ZA-8, and select magnesium alloys. The cold-chamber process is used for aluminum alloys, ZA-12 and ZA-27 alloys, and magnesium alloys.

The basic components of a hot-chamber die casting machine and die are illustrated in Figures 4.1 and 4.2. In the process, the plunger and cylinder are submerged in the molten metal in the holding furnace. The energy to pump the metal into the die cavity is provided by a hydraulic-electrical or pneumatic system. Force is applied at a rate that will bring the pressure and flow to the desired operating level each time a shot is made.

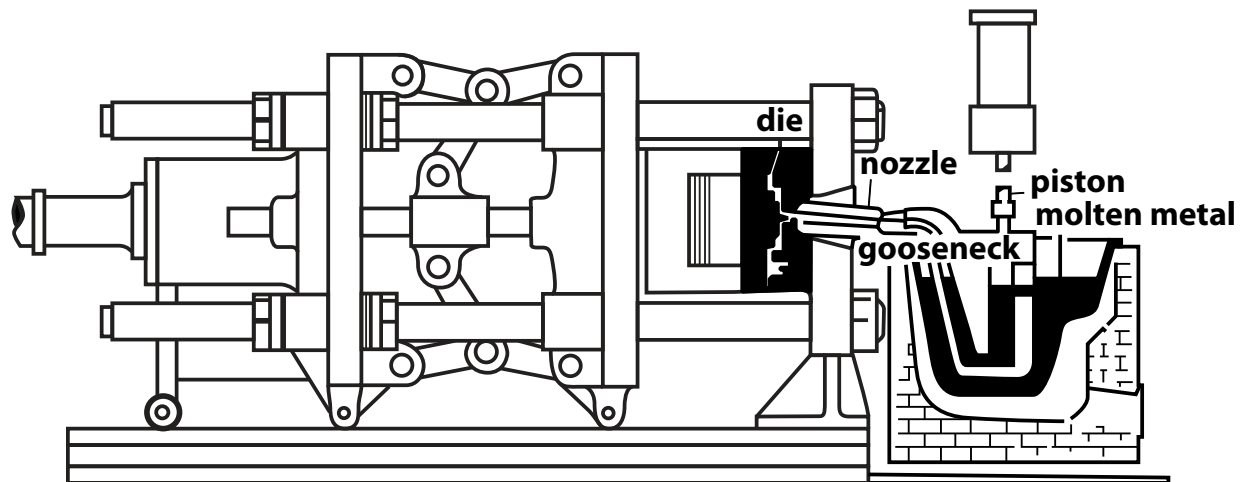


Figure 4.1 Cross section of a hot chamber die casting machine

Figure 4.2 A typical hot-chamber die.

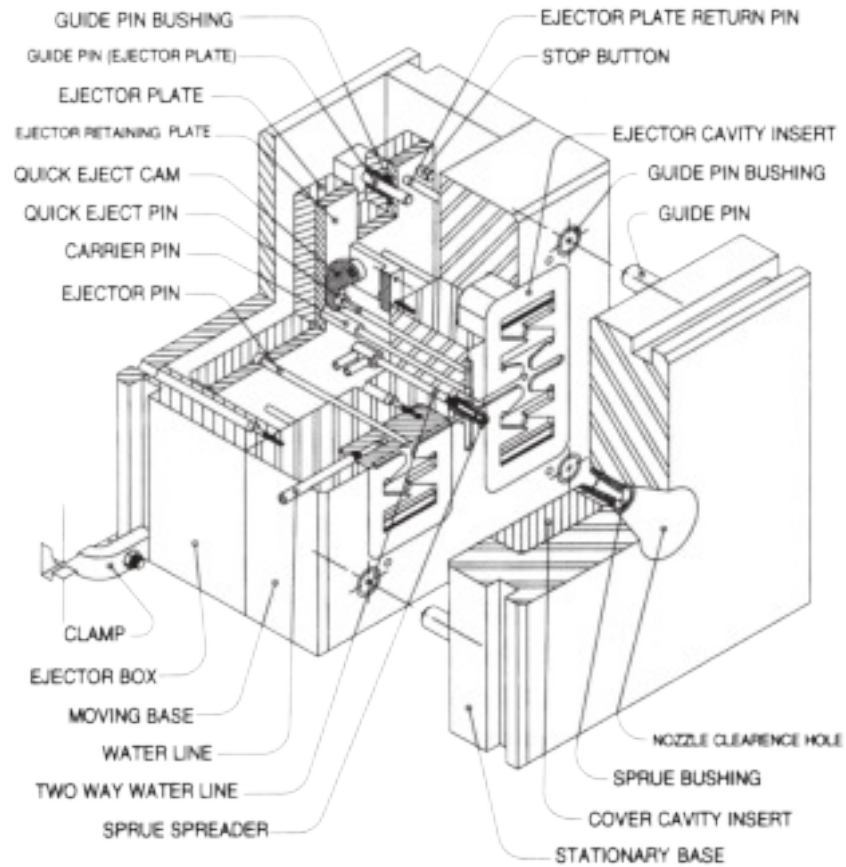
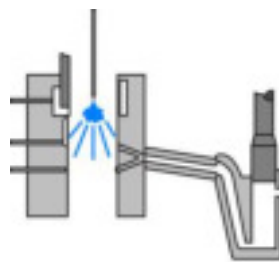
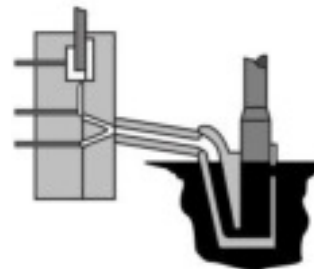


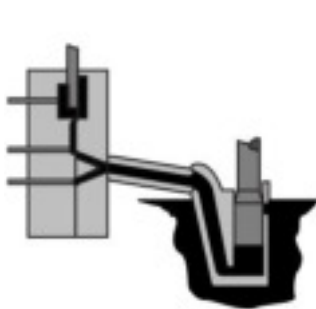
Figure 4.3 Operating sequence of the hot chamber die casting process.



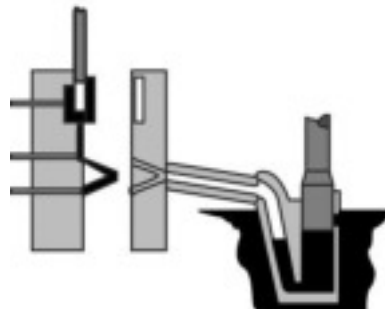
1. Die is coated with release agent (spray)



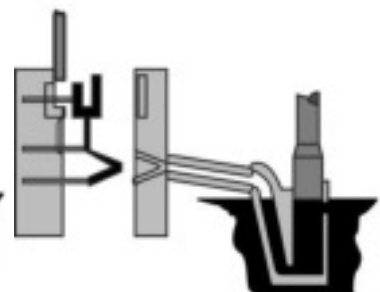
2. The die is closed and the hot chamber (gooseneck) is filled with molten metal



3. The plunger pushes molten metal through the gooseneck and nozzle into the die cavity where it is held under pressure until it solidifies.



4. The die opens and cores, if any, retract. The casting remains in the ejector die. The plunger returns, allowing molten metal to flow back through the nozzle and gooseneck.

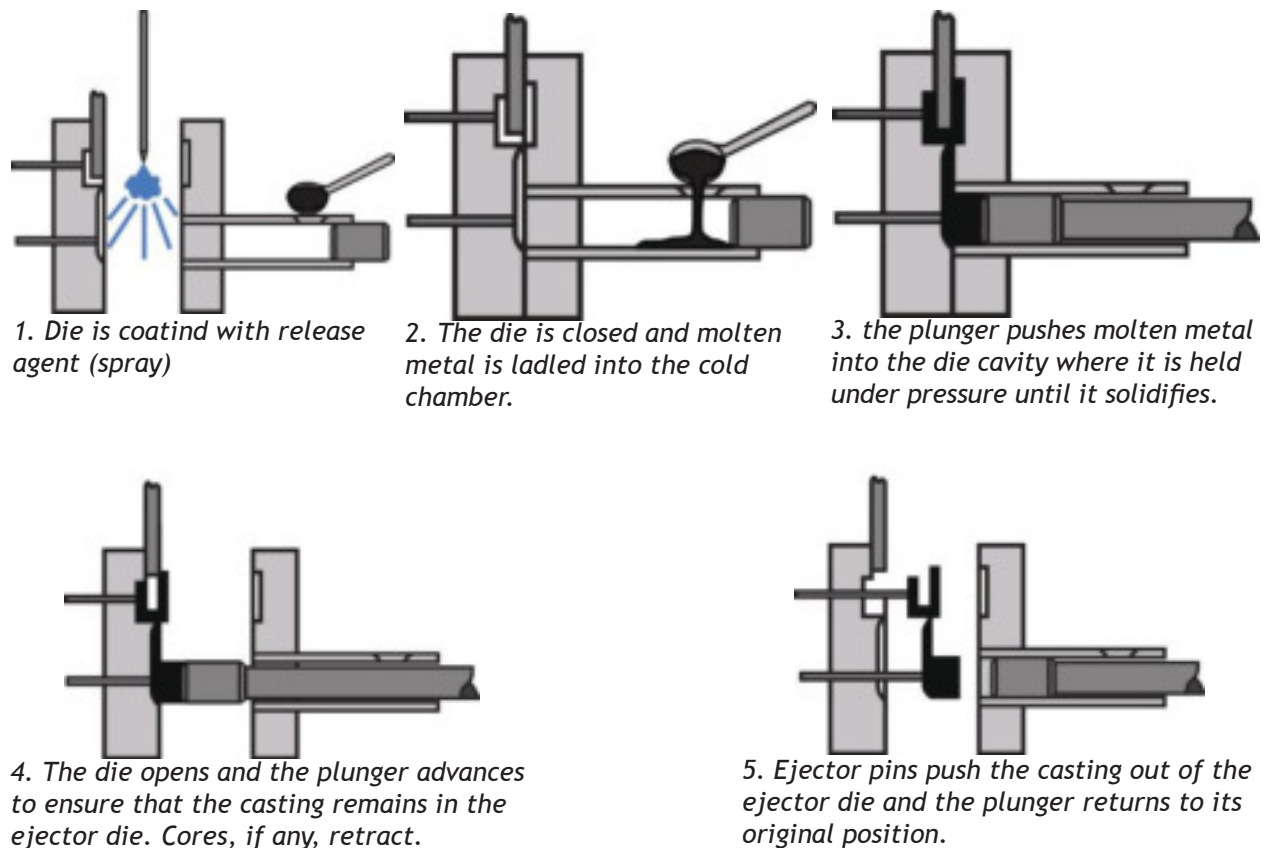


5. Ejector pins push the casting out of the ejector die. As the plunger uncovers the filling hole, molten metal flows through the inlet to refill the gooseneck.

The operating sequence for the hot-chamber cycle is illustrated in Figure 4.3. A die lubricant, or mold-release compound, is sprayed onto the die to facilitate release of the casting. When a shot is made, the plunger is driven downward, forcing molten metal through the gooseneck and nozzle into the die cavity. After the cavity is filled, the metal is allowed to solidify, the casting is ejected, and the cycle repeated. The system refills automatically when the plunger is withdrawn because the gooseneck and plunger are submerged in the molten metal.

The operating sequence for the cold-chamber process is illustrated in Figure 4.4. The operating sequence is essentially the same as for hot-chamber, except for the manner in which the molten metal is fed into the shot system prior to injection into the die. In the cold-chamber process, a die lubricant, or mold-release compound, is sprayed onto the die, molten metal is ladled, either by hand or machine, or pumped into a horizontal shot cylinder. A hydraulically actuated plunger then advances to force the metal into the die.

Figure 4.4
Operating sequence of the cold-chamber die casting process.



There are four significant characteristics common to both cycles which should be noted:

- The casting, as normally ejected from the die, is attached to extraneous metal (biscuit, runner and overflows, often called offal). The entire shot is typically cooled and transferred to a trim die, which separates the casting from the offal. The metal that is removed is subsequently recycled.
- The metal injection portion of the cycle normally terminates with a spike in metal pressure, arising from the rapid deceleration of injection system. Intensification is then developed by increasing the hydraulic pressure on the plunger to pack metal in the die cavity and feed shrinkage during solidification. It is beneficial to the extent that it promotes complete filling of the die cavity and uniformly sound metal density. Excessive intensification is undesirable, because it forces molten metal between die members, forming flash.
- The peak pressure multiplied by the projected area of the entire shot generates the force imposed on the machine structure. Die casting machines must be sized according to this force, and they are rated in terms of number of tons of locking force they are capable of developing in long-term, continuous operation.
- Peak pressure often dictates the size of the machine required to make a casting, which can affect the cost of the product.

Miniature Die Casting

In the production of extremely small parts, miniature die casting technology has developed as one of the most cost-effective manufacturing alternatives. Cycling up to 100 times per minute, automated hot-chamber, direct-injection die casting machines are producing miniature components flash-free, ready for tumble degating and shipment, with no further secondary operations. It is often possible to combine multiple-assembled components into a single piece, as cast, for significant total cost reductions. Because of part size and the specialized machines used, miniature die castings can be produced to closer dimensional tolerances than larger castings. Tolerances on hole locations and other details that are influenced by shrinkage are more readily held on small parts.

Miniature die casting production should always be investigated when small components are being considered for plastic injection molding, stamping, powder metal, screw machining or cold heating. An outline of the miniature die casting process, typical design and tolerance data, recommended alloy considerations in designing miniature die castings, and available finishes appears in the NADCA Product and Specifications Standards for Die Castings Manual.

Die Characteristics

A typical hot-chamber die, illustrated in Figure 4.2, consists of two sections: the cover half and the ejector half, which meet at the parting surface. The orientation of this surface and the direction that the die moves relative to the casting must be recognized in the product design. The cover half is secured to the front or stationary platen of the machine. The sprue, which directs the molten metal towards the die cavity is in this half of the die, and it is aligned with the nozzle of the casting machine. The ejector half of the die contains the ejector mechanism and, in most cases, the runners.

The cold-chamber die, which is illustrated in Figure 4.4, is arranged in essentially the same manner. The die cavity, which forms the component to be cast, is machined into both halves of the die block or into inserts that are installed in the die blocks. The die and the casting are so designed that the casting remains in the ejector side when the die opens. The casting is then pushed out of the cavity by the ejector pins that come through holes in the die and are actuated by the ejector plate, which, in turn, is powered by the machine. Guide bars or leaders pins, extending from one die half, enter holes in the other half as the die closes to ensure alignment of the halves.

Dies may contain fixed and/or movable cores in either half to produce complex shapes. Fixed cores are anchored in the die, and so the casting must be designed to permit their movement parallel to the direction of the die opening. Moveable cores, which are locked in place when the die closes, are actuated by the cam pins or hydraulic cylinders. They may be incorporated into either half, but the best location from the die caster's viewpoint is in the die parting. Movable cores add to die fabrication and maintenance costs, and may increase cycle time. However, they can be employed to advantage when they allow features to be cast, eliminating the need for subsequent machining operations.

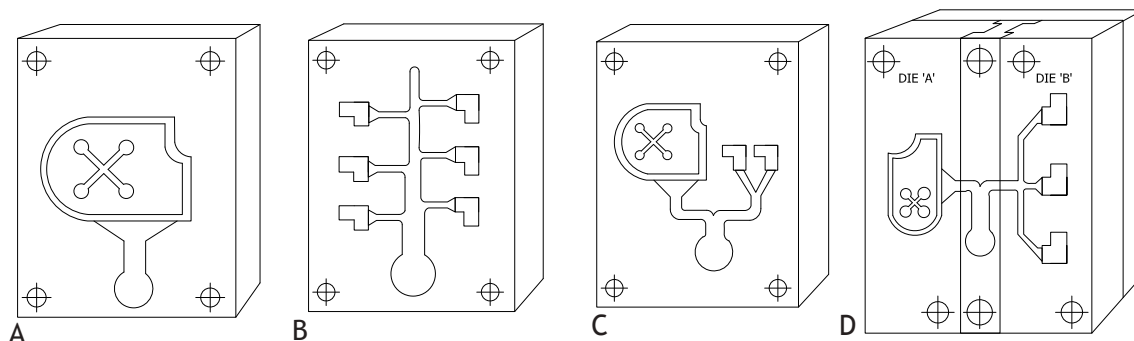
Whenever there is relative motion between die members, there must be clearance, and all such clearances tend to increase due to wear. Molten metal may be forced into these clearances, leaving flash on the casting, which often must be removed. The designer should visualize the die relationship to the casting, so that potential flash can be predicted, and provision made for removal where necessary.

Multiple-Cavity Dies

Whenever possible, particularly when production volumes are high, dies may contain more than one cavity so that several castings are made on each shot. A die with identical cavities is usually referred to as a multiple cavity die (Figure 4.5b). A die with cavities of different shapes is referred to as a combination die or family die (Figure 4.5c). Combination dies are frequently used to make sets of components for an assembly.

Figure 4.5

- A. Single Cavity Die (one large part)
- B. Multiple Cavity die (six small parts)
- C. Combination Die (one large part, two small parts)
- D. Unit Die (one large part, three small parts)



Unit Dies

A class of dies widely used for high volume production is the unit die (Figure 4.5d), which consists of a die holder into which a number of standard size blocks are fitted. Each die holder contains one or more cavities. Unit dies provide for quick changeover and high degree of flexibility. However, they are additional pieces to be fitted, and thus constitute an additional tolerance in the die alignment (ejector side to cover side) stackup.

Die Filling

Much of the recent research and development work designed to improve die casting technology has focused on proper filling of the die with molten metal. In the ideal case, the molten metal should move in a solid wave front through the metal delivery system, through the gates (orifices that connect the runner to the cavity), and into the cavity. The air in the system should be pushed out of the cavity ahead of the molten metal. In the actual case, the solid wave front does not fully develop. The metal flow is somewhat turbulent, so that air is entrained, possibly forming porosity in the casting. The metal solidification process tends to drive this porosity away from the surface into the core of the section.

Die castings normally exhibit smooth surfaces with no visible defects, but metal removal operations that cut deep enough to penetrate this skin may expose the porosity which could lie beneath. Where product applications require a smooth surface, or where the porosity is interconnected and pressure tightness is required, the presence of such porosity would call for impregnation of the die casting.

The last area of the die cavity to fill tends to exhibit the poorest quality. This area generally has the coolest metal and potentially the highest porosity. It is therefore common practice to locate overflow cavities at the die parting plane in these areas. The overflows receive the poor quality metal, raising the quality of adjacent metal in the die cavity. Overflows are carefully sized, because they constitute additional extraneous metal, or scrap, which must be recycled.

4.2 Characteristics of Die Castings

The rapid solidification achieved in the die casting process imparts distinct characteristics to the metal. Grain structure is much finer and porosity distribution is different from gravity castings, which cool much more slowly. Metal in the die casting die solidifies and cools by transferring heat through the surface of the die cavity into the die where it is removed by cooling oil or water.

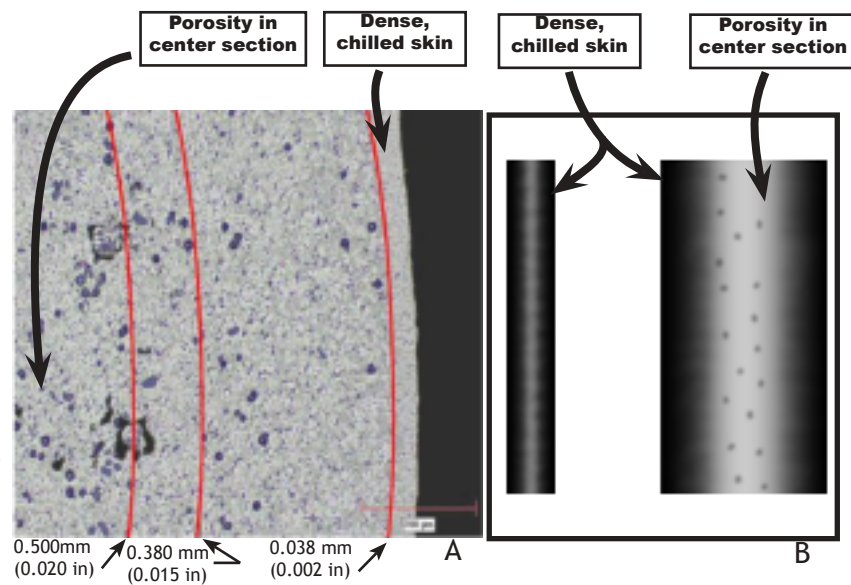
Solidification begins at the surface of the casting and progresses to the center, generating two distinct zones in each wall section, as shown in Figure 4.6. The skin, which has finer grain structure, begins at each surface and extends inward to a typical thickness of 0.015 to 0.020 in. (0.38 to 0.50 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 of the casting. 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 0.020 in. (0.50mm) by secondary processes such as machining, increases the chance of exposing porosity in the core. These important points are not widely recognized by designers.

Parting lines usually appear on die castings as small ridges of flash wherever two die members meet. In the case of decorative components, these lines are usually removed to enhance appearance. Flash height and thickness depend upon the condition of the die and the control of process variables. In certain applications, advanced casting processing can greatly minimize or eliminate flash.

The most pronounced parting line is formed at the interface of the ejector and the cover dies, where die surfaces are separated by the hydraulic shock loading (pressure intensification) associated with the injection of molten metal. This parting line is particularly significant in product design because in-gates and out gates (the orifices which conduct metal into and out of the die cavity) are usually located in the parting plane and appear as thick areas of the parting line. Gate location may affect the mechanical properties and/or appearance of the casting. Consequently, the product designer should work with the die caster to determine mutually satisfactory gate locations.

When the gates are trimmed from the casting, the surface exposed by trimming is not skin; it is interior or core metal, which may have some degree of porosity that may act as stress risers, leading to premature failure of the casting.

Figure 4.6 Skin Effect
 Due to rapid solidification in the die, a die casting's outer skin has a dense, fine grained structure with a higher strength than underlying metal. According to Borland and Tsumagari (2006), 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 shown in micrograph A, and as portrayed in pictorial image B.⁶



4.3 Preventing Casting Defects

Casting defects are undesirable in critical structural areas and on decorative surfaces, particularly those that are bright finished or painted. Minor defects that would not be particularly noticeable can become quite obvious after surface treatment. Elimination of defects is generally accomplished through control of the casting process, and is the responsibility of the die caster. However, the product designer should also be conversant with the various types of defects, particularly those that can be reduced by appropriate design practice.

Cracks

Under certain casting conditions, cracks may occur in die cast magnesium and, to a lesser extent, in other alloys. In most cases, die casting cycle parameters, such as die temperature, direction of metal flow, and lubrication techniques, are adjusted to eliminate the problem. However, some types of cracks are caused, at least in part, by the design of the die casting. In these cases, the die caster may request some minor product changes to remedy the problem.

Shrinkage-restrained cracks may occur when a long expanse of cast metal is terminated by a restraining rib. In such cases, the metal contracts to the point where the hot strength is exceeded and a crack forms at the junction of the restraining rib. This type of defect can often be eliminated by the addition of more ribs to distribute the shrinkage forces or by decreasing the holding time to eject the casting before shrinkage has reached its normal value.

Castings designed with thick-walled frame members that intersect at right angles may be susceptible to corner cracks, resulting from restraint and relatively slow freezing characteristics. In such cases, adequate radii in the component design are important. It may also be necessary to increase the metal injection pressure considerably to eliminate the defect.

Visible cracks may appear at the junction of a very hot stream of metal and a returning cold stream. This kind of trouble would be corrected only by a redirection of the filling pattern.

Non-Fill Areas

Incompletely filled areas sometimes exhibit a rough surface described as woody because of its texture. Die casting parameters are usually adjusted to improve metal flow to the affected area such as increasing the metal pressure or adjusting the gate and runner system. Die temperature control, venting, and lubrication may also be adjusted to eliminate trapped gas and improve metal flow. Cast walls, which are too thin by design or by accident, may result in a poorly filled woody area. Wall thicknesses should be carefully evaluated during design. Such areas can usually be reworked as required after the die has been fabricated.

Shrinks

Ragged, irregular porosity in the form of shrinks often results from local overheating of the die. The spot can be locally cooled or the casting cycle time increased. In cases where the cycle time cannot be increased, it may be necessary to enlarge the gate and/or runners to feed the troublesome spot. In other cases, it has been found necessary to add flat or vertical ribs to the cast wall to improve the feeding characteristics.

Unusually thick sections add to the likelihood of shrinkage defects and the best remedy is to redesign the component with metal saving cores. Shrinkage defects may also be encountered in adequately designed castings when the casting pressure is too low. Here the solution will be to increase the pressure on the metal. Squeeze pins can often be used to reduce shrinkage porosity in localized areas.

Misruns, Cold Shuts, and Swirls

These defects develop when two streams of molten metal containing some partially solidified metal join. When an area does not fill, it is termed a misrun; when the metal joins but does not fuse, it is termed a cold shut; when a surface defect with a swirl pattern forms it is termed a swirl. These types of defects can be caused by cold dies; in this case the immediate solution will be to run at a faster rate and reduce the cooling until good castings are produced. Misruns and cold shuts may also occur if the time required to fill the die cavity is too great. The filling conditions should be reviewed and the shot speed increased.

Gas porosity

Smooth internal porosity in the form of bubbles indicates that gas is being trapped. When close to the casting surface or skin, these pores can cause blisters if the die casting is subsequently reheated. The die caster will explore changes in venting, gating, or lubrication to reduce porosity problems. Many die casters now employ proprietary vacuum systems for reducing or totally eliminating gas porosity.

Shrinkage Porosity

Shrinkage pores are large and irregular in size compared with gas pores. They tend to occur in heavy sections. Shrinkage pores may affect the integrity of the die casting, especially when they are in the vicinity of certain machining operations, such as thread tapping. They do not contain gas, and are not a source of blisters.

Shrinkage pores are usually controlled by varying die casting parameters. In some cases it is necessary to eliminate the thick walls by redesigning the section. Holes for tapped threads should be cored, so that the threads are formed in metal that is free from shrinkage pores.

Segregation

Surface segregation of the constituents in magnesium AZ91 alloys appears to increase in components with relatively thick sections. It is helpful if the component can be redesigned with thinner walls. An excessive injection pressure on the metal seems to increase the amount of segregation; thus, reduced pressures are used to lessen the effect.

Segregation of the alloy constituents in ZA may occur when they are being melted. The problem is easily eliminated through application of proper metal handling techniques.

Soldering and Oxidizing

When the velocity of an aluminum or magnesium alloy in the gate stream or in a connection to an overflow is excessive, the metal in that area may stick to the surface of the die. The remedy is to increase the cross section at the trouble point and to reduce the gate velocity, if possible. Fog lubrication of the die face and a slower cycle, which tends to reduce the temperature of the die, are steps that are also used here.

Soldering and oxide deposits may occur on the die in conjunction with thick sections in the casting. Again, designing thinner sections will avoid such problems. Where a die has already been fabricated, cooling will be used to remedy these effects.

Surface Blisters

Surface blisters occur when gas porosity is severe. Blisters are raised on the surface of the casting following ejection or on the subsequent reheating of the casting. One remedy will be to increase the time that the casting is held in the die, allowing the walls to cool and thereby increase in strength. A more satisfactory remedy is to reduce or eliminate porosity as discussed earlier.

Galling or Drag

Drag is usually caused by undercuts in the die, which can be polished out as required. In some cases, the draft is inadequate and the die cavity must be reworked. In other cases, if the ejector plate advances unevenly, cocking the casting and causing drags, repair of the ejector plate will then be required.

Warped Castings

When one portion of a casting sticks in the die due to a local undercut or insufficient draft, the casting will often be warped in the process of ejection. Draft requirements should be reviewed with the die caster while the component is being designed. Later, the remedy will be to polish out the undercut, or rework the die cavity to provide the required draft. Warping may also be caused by an overheated die, in which case local cooling will be added or cycle time increased.

Unusual features of the casting sometimes shrink unequally, causing warpage. A solution will be to add ribs to distribute the shrinkage or to compensate by locally cooling the die.

Raised Fins (Heat Checking)

A pattern of raised fins on the surface of the casting near the gate indicates that the die surface is failing by a process known as thermal fatigue. The life of the die can be prolonged by polishing the area at the first sign of failure. The appearance of raised fins will be delayed by proper preheating of the dies, operation at proper temperatures, and fog lubrication of the die faces at frequent intervals.

4.4 Alloys and Properties

This section presents an introduction to die casting alloys used for the production of conventional die castings, produced at a level for product designers that does not require a metallurgical background. It enables the design engineer to better evaluate the available die casting alloys and select the optimum for a product application.

Typically most die castings are used in the as-cast condition and are not heat treated. Historically this occurred as die castings tend to form surface blisters when exposed to the high temperatures associated with heat treatment. However, recently new technologies have been developed that allow die castings to be heat treated while avoiding blistering, and so heat treating of die castings is becoming a little more common, at least for aluminum die castings.

Range of Properties

Four major alloy groups account for most of the functional and decorative die castings produced in North America: aluminum, magnesium, zinc and ZA (zinc-aluminum). These four groups offer the designer a wide range of material properties. For example:

- Material densities range from 0.066 lb/in³ (1.81 gm/cc³) for magnesium alloys to 0.24 lb/in³ (6.65 gm/cc³) for zinc alloys, a ratio of near four to one.
- Ultimate tensile strengths range from 31 ksi (210 MPa) for magnesium alloy AS41A to 60 ksi (414 MPa) for ZA-27, a ratio of approximately two to one.
- Modulus of elasticity varies from 6.5×10^6 psi (45GPa) for magnesium alloys to 11.9×10^6 psi (71 GPa) for aluminum alloy 390, a ratio of almost two to one. (The modulus of elasticity of zinc alloys varies with stress level and is not usually represented by one number.)

Die casting alloys have several characteristics in common:

- They do not exhibit the sharp yield point characteristic of carbon steels; instead they yield gradually when stressed. Therefore, the term yield strength is used, and is defined as the stress at which the stress-strain curve deviates 0.2% from the modulus line (0.2% offset).
- They have low melting points relative to copper and ferrous alloys and may exhibit a tendency to creep under conditions of long-term continuously applied loads. Creep occurs particularly at elevated temperatures, where it does not occur with copper and ferrous alloys. The tendency varies with the alloy. A moderate amount of creep does not prohibit the use of a material, but does require special design measures.

4.5 Aluminum Die Castings

The element aluminum (Al) has a specific gravity of 2.7, placing it among the light-weight structural metals. It is used as a base to die casting alloys along with three other primary constituents: silicon, copper and magnesium. Eight available aluminum die casting alloys give the designer the widest choice among the four primary alloy groups, and they account for the majority of die castings in terms of tons of components produced.

Seven of the eight alloys are based on the aluminum-silicon system. The eutectic (system) composition, 12.6% silicon, is a convenient reference point for grouping them. The seven alloys are further grouped as either copper containing or having a restricted copper content. Other major alloying elements in the aluminum-silicon system are magnesium and iron. Some constituents are considered impurities, and maximum limits, expressed as a single number, are imposed.

The eighth alloy, 518, has a very low silicon content, is based on the aluminum-magnesium system. All eight aluminum alloys are grouped according to silicon and copper contents in Table 4.7.

Table 4.7 Aluminum Alloys by Silicon and Copper Content

Silicon	Copper Containing	Copper Restricted
Al-Si system Less than 12.6%	380, 383, 384	360, 443
Nominal 12.6% (eutectic)		413
More than 12.6% (hypereutectic)	390	
Al-Mg system 0.35% max. silicon		518

Product Applications

Alloy 380 is the workhorse of the aluminum alloys. It is most often specified because it offers the best combination of cost, casting behavior and product properties. It is used for the widest variety of products such as lawn mower housings, chassis for electronic equipment, engine brackets, cases for automotive drive lines, home appliances, furniture, hand tools and power tools.

Alloys 383 and 384 are alternatives to 380 that are specified when very intricate components that require improved die filling characteristics and improved resistance to hot cracking. Alloy 360 offers high corrosion resistance and superior strength at elevated temperatures as compared to 380. Other properties are essentially equivalent. Alloy 443 offers the highest ductility of the aluminum die casting alloys. Alloy 413 offers excellent pressure tightness, making it the choice for products such as hydraulic cylinders and pressure vessels. Its casting characteristics make it useful for very intricate components.

Alloy 390 was developed for automotive engine blocks. Resistance to wear is excellent, but ductility is the lowest of the die casting alloys, with elongations less than 1%. Surface treatment systems allow engine pistons to run directly on the alloy, negating the need for iron liners. It is also used for valve bodies and bearing surfaces subject to abrasion and wear. Two other aluminum alloys, 361 & 369, are being utilized in limited applications where vibration and wear are of concern.

Alloy 518 is used in escalator components, conveyer components, and marine and aircraft hardware fittings. It offers good ductility and very good corrosion resistance. It can be polished and anodized for a decorative finish.

The comparative die casting and product characteristics of the eight aluminum alloys are shown in Table 4.8. The designation 1 indicates best or most desirable; 5 indicates worst or least desirable.

Table 4.8 Comparative Characteristics of Aluminum Die Casting Alloys

	Aluminum Die Casting Alloys										
Commercial: ANSI/AA	360 360.0	A360 A360.0	380 380.0	A380 A380.0	383 383.0	384 384.0	390* B390.0	13 413.0	A13 A413.0	43 C443.0	218 518.0
Resistance to Hot Cracking (A)	1	2	2	2	1	2	4	1	1	3	5
Pressure Tightness	2	2	2	2	2	2	4	1	1	3	5
Die-Filling Capacity (B)	3	3	2	2	1	1	1	1	1	4	5
Anti-Soldering to the Die (C)	2	2	1	1	2	2	2	1	1	4	5
Corrosion Resistance (D)	2	2	4	4	3	5	3	2	2	2	1
Machining Ease & Quality (E)	3	3	3	3	2	3	5	4	4	5	3
Polishing Ease & Quality (F)	3	3	3	3	3	3	5	5	5	4	1
Electroplating Ease & Quality (G)	2	2	1	1	1	2	3	3	3	2	5
Anodizing (Appearance) (H)	3	3	3	3	3	4	5	5	5	2	1
Chemical Oxide Protective Coating (I)	3	3	4	4	4	5	5	3	3	2	1
Strength at Elevated Temp. (J)	1	1	3	3	2	2	3	3	3	5	4

(A) Ability of alloy to withstand stresses from contraction while cooling through hot-short or brittle temperature ranges. (B) Ability of molten alloy to flow readily in die and fill thin sections. (C) Ability of molten alloy to flow without sticking to the die surfaces. Ratings given for anti-soldering are based on nominal iron compositions of approximately 1%. (D) Based on resistance of alloy in standard type salt spray test. (E) Composite rating based on ease of cutting, chip characteristics, quality of finish, and tool life. (F) Composite rating based on ease and speed of polishing and quality of finish provided by typical polishing procedure. (G) Ability of the die casting to take and hold an electroplate applied by present standard methods. (H) Rated on lightness of color, brightness, and uniformity of clear anodized coating applied in sulphuric acid electrolyte. (I) Rated on combined resistance of coating and prolonged heating at testing temperature. Sources: ASTM B85-92a; ASM; SAE

* Two other aluminum alloys, 361 & 369, are being utilized in limited applications where vibration and wear are of concern. There are also other heat treatable specialty alloys available for structural applications, such as the Silafonts and AA365, and high ductility, high strength alloys such as Mercalloy and K-Alloy. Contact your alloy producer for more information.

Note: Die castings are not usually solution heat treated. Low-temperature aging treatments may be used for stress relief or dimensional stability. A T2 or T5 temper may be given to improve properties. Because of the severe chill rate and ultra-fine grain size in die castings, their "as-cast" structure approaches that of the solution heat-treated condition. T4 and T5 temper results in properties quite similar to those which might be obtained if given a full T6 temper. Die castings are not generally gas or arc welded or brazed.

Welding

As welding involves heating the die castings to high temperatures, surface blistering is a problem. Therefore conventional die castings are typically not welded. However, the lower amounts of entrapped gases in high integrity die castings (high vacuum, squeeze and semi-solid solid casting, which are covered in the next chapter) does allow them to be welded.

Effect of Alloy Constituents

The following discussion of alloy constituents gives additional background to guide the design engineer in evaluating aluminum die casting alloys, and comparing them with aluminum wrought and gravity cast alloys.

Silicon

As the silicon content in aluminum alloys approaches 12.6%:

- Fluidity of the liquid metal increases
- Solidification shrinkage decreases
- Pressure tightness improves
- Hot shortness (tendency to crack or tear during solidification) is reduced
- Modulus of elasticity increases
- Specific gravity decreases (silicon is less dense than aluminum)
- Thermal expansion decreases
- Corrosion resistance improves

As the silicon content is increased above 12.6% to approximately 17% (the nominal composition for alloy 390) fluidity and wear resistance increase significantly due to the presence of primary silicon in the alloy.

Silicon contributes to fluidity largely due to its high heat of solidification. When silicon solidifies, it releases a large amount of heat, reheating the remaining liquid aluminum, delaying solidification and allowing the mass to continue flowing. Fluidity contributes to castability, but does not translate directly, as other die casting process parameters, such as liquid alloy temperature and micro-cleanliness, die temperature, and die surface conditions are also important.

Copper

Copper content is controlled to improve desirable characteristics (such as strength), and restricted to reduce others, particularly atmospheric corrosion. Copper content, in the range of 2.0% to 3.0%, increases tensile strength and hardness and improves mechanical properties at elevated temperatures. In these concentrations it marginally influences alloy density. (Copper is more than three times as dense as aluminum.)

Copper, however, can be very beneficial for T6 heat treated die casting alloys, as it can provide significant strengthening during artificial aging.

The principal disadvantage of copper in Al-Si-Cu alloys, as noted above, is the marked effect of corrosion resistance. Corrosion resistance decreases with an increase in copper content. To maximize corrosion resistance, alloys are commercially available with low maximum copper contents of 0.40%, 0.30%, and 0.20%. These alloys, however, typically carry a cost premium.

Magnesium

Magnesium is controlled to relatively low levels in most aluminum-silicon alloys, generally to 0.10% or 0.30%. Higher concentrations, particularly well above 0.30%, tend to reduce ductility, and in extreme cases, embrittlement may occur. Precise control of magnesium content within the specified range, however, can enhance chip formation and removal in machining operations.

Magnesium is a controlled addition (0.45% to 0.60%) in alloy 360. It contributes to strength and hardness, which are otherwise lost by the restricted copper content (0.60%, max). It is also added to alloys 390 and 392 to increase hardness.

Magnesium also provides strengthening during heat treating. During T5 heat treatments, the amount of strengthening is directly proportional to the magnesium concentration. Magnesium also provides strengthening during T6 heat treatments.

Alloy 518 differs from the aluminum-silicon alloys in that its composition is based on the aluminum-magnesium system. Alloy 518 and its derivatives offer relatively high ductility and excellent finishing characteristics. These alloys are not widely available, however, as special handling is required to control the oxidation of the magnesium when in the liquid condition.

Iron

Historically iron has been necessary in aluminum die casting alloys because iron-free liquid aluminum alloy aggressively attacks ferrous metals, including die steels, causing severe erosion. Iron-free alloys also tend to stick, or solder, onto die surfaces. Iron in aluminum die casting alloys, in the range of 0.60% to 1.20%, tends to prevent these conditions and helps to inhibit hot-shortness.

However, iron is essentially insoluble in solid aluminum and is generally limited in specified alloy composition to a restricted maximum amount. In aluminum alloy microstructures, iron exists as an intermetallic compound that forms as needles or platelets. The particles tend to affect ductility adversely and often act as fracture initiation sites. The iron-aluminum intermetallic phase can be altered to a more benign state when manganese and chrome are present.

Consequently, there have been some die castings alloys developed over the past 10-20 years with lower-iron concentrations that limit the number of detrimental platelet-shaped particles. These alloys, therefore, tend to have higher elongation values. To minimize soldering to the ferrous die casting dies, the iron is replaced with either higher levels of manganese or strontium.

Manganese

Manganese has limited solid solubility in aluminum. Its primary purpose is to modify the iron-aluminum intermetallic phase described above.

Zinc

Zinc is limited to restricted maximum amounts in commercial aluminum die casting alloys; generally to 1.0% or 3.0%. Zinc provides some solution-strengthening effects, and concentrations within specified ranges have positive influence on machinability. However, excessive amounts of zinc induce cracking tendencies. Because zinc has a wide solid solubility range in aluminum, it can be introduced without difficulty. Excessive amounts of zinc often result from cross-contamination of the liquid aluminum alloy melt by the inadvertent introduction of zinc ingot, scrap castings, or turnings. Proper housekeeping procedures are essential to avoid cross-contamination.

Aluminum Die Casting Properties - As-Cast

Table 4.9 shows typical properties in the as-cast condition of the aluminum alloys commonly produced by conventional die casting. Note that ASTM Specification B557 provides a shape for an as-cast tensile bar for die castings, and that properties listed in Table 4.9 are for separately die cast tensile bars, not for specimens cut from production die castings. Due to the internal structure of die castings shown in Figure 4.6, tensile samples cut from production castings normally do not contain the dense as-cast skin, and so their mechanical properties will be different than those measured following the procedures outlined in ASTM B557.

Table 4.9 Aluminum Die Casting Alloys Material Properties – As Cast

Aluminum Die Casting Alloys

Commercial:	360	A360	380	A380 (E)(F)	383 (E)	384	B390*	13	A13	43	218
ANSI/AA	360.0	A360.0	380.0	A380.0	383.0	384.0	B390.0	413.0	A413.0	C443.0	518.0

Mechanical Properties

Ultimate Tensile Strength											
ksi	44	46	46	47	45	48	46	43	42	33	45
(MPa)	(303)	(317)	(317)	(324)	(310)	(331)	(317)	(296)	(290)	(228)	(310)
Yield Strength (A)											
ksi	25	24	23	23	22	24	36	21	19	14	28
(MPa)	(172)	(165)	(159)	(159)	(152)	(165)	(248)	(145)	(131)	(97)	(193)
Elongation											
% in 2in. (51mm)	2.5	3.5	3.5	3.5	3.5	2.5	<1	2.5	3.5	9.0	5.0
Hardness (B)											
BHN	75	75	80	80	75	85	120	80	80	65	80
Shear Strength											
ksi	28	26	28	27	—	29	—	25	25	19	29
(MPa)	(193)	(179)	(193)	(186)	—	(200)	—	(172)	(172)	(131)	(200)
Impact Strength											
ft-lb (J)	—	—	3 (4)	—	3 (D) (4)	—	—	—	—	—	7 (9)
Fatigue Strength (C)											
ksi	20	18	20	20	21	20	20	19	19	17	20
(MPa)	(138)	(124)	(138)	(138)	(145)	(138)	(138)	(131)	(131)	(117)	(138)
Young's Modulus											
psi x 10 ⁶	10.3	10.3	10.3	10.3	10.3	—	11.8	10.3	—	10.3	—
(GPa)	(71)	(71)	(71)	(71)	(71)	—	(81)	(71)	—	(71)	—

Physical Properties

Density											
lb/in ³	0.095	0.095	0.099	0.098	0.099	0.102	0.098	0.096	0.096	0.097	0.093
(g/cm ³)	(2.63)	(2.63)	(2.74)	(2.71)	(2.74)	(2.82)	(2.71)	(2.66)	(2.66)	(2.69)	(2.57)
Melting Range											
°F	1035-1105	1035-1105	1000-1100	1000-1100	960-1080	960-1080	950-1200	1065-1080	1065-1080	1065-1170	995-1150
(°C)	(557-596)	(557-596)	(540-595)	(540-595)	(516-582)	(516-582)	(510-650)	(574-582)	(574-582)	(574-632)	(535-621)
Specific Heat											
BTU/lb °F	0.230	0.230	0.230	0.230	0.230	—	—	0.230	0.230	0.230	—
(J/kg °C)	(963)	(963)	(963)	(963)	(963)	—	—	(963)	(963)	(963)	—
Coefficient of Thermal Expansion											
m in/in °F	11.6	11.6	12.2	12.1	11.7	11.6	10.0	11.3	11.9	12.2	13.4
(m m/m °K)	(21.0)	(21.0)	(22.0)	(21.8)	(21.1)	(21.0)	(18.0)	(20.4)	(21.6)	(22.0)	(24.1)
Thermal Conductivity											
BTU/ft hr °F	65.3	65.3	55.6	55.6	55.6	55.6	77.4	70.1	70.1	82.2	55.6
(W/m °K)	(113)	(113)	(96.2)	(96.2)	(96.2)	(96.2)	(134)	(121)	(121)	(142)	(96.2)
Electrical Conductivity											
% IACS	30	29	27	23	23	22	27	31	31	37	24
Poisson's Ratio											
	0.33	0.33	0.33	0.33	0.33	—	—	—	—	0.33	—

(A) 0.2% offset. (B) 500 kg load, 10mm ball. (C) Rotary Bend 5 x 108 cycles. (D) Notched Charpy. Sources: ASTM B85-92a; ASM; SAE; Wabash Alloys. (E) A 0.3% Mg version of A380 and 383 have been registered with the Aluminum Association as E380 and B383. (F) Higher levels of Mg and the addition of Sr to alloy A380 have shown positive results. The limited data on pages 3-7 - 3-11 shows the effect.

* Two other aluminum alloys, 361 and 369, are being utilized in limited applications where vibration and wear are of concern. There are also other heat treatable specialty alloys and processes available for structural applications, such as the Silafonts and AA365 (Aural 2), and high ductility, high strength alloys such as Mercalloy and K-Alloy. Contact your alloy producer for more information. More information can also be obtained from Microstructures and Properties of Aluminum Die Casting Alloys Book, NADCA Publication #215 and the High Integrity Aluminum Die Casting Book, NADCA Publication #307.

Aluminum Die Castings - T6 Heat Treated

Historically die castings have always been used in the as-cast condition, and even today the vast majority of die castings are not heat treated. The reason is due to gasses entrapped in die castings, which tend to expand and cause surface blistering when the castings are heated to elevated temperatures during the heat treatment. However, research performed at CSIRO in Australia has shown that conventional die castings can be fully heat treated to the T6 temper as long as the time at the solution heat treatment is kept short, or that the solution heat treatment is performed at a slightly lower temperature.

Figure 4.10 shows the three steps used during T6 heat treating, and typical parameters suggested by CSIRO for conventional die castings are listed in Table 4.11. For T6 heat treating, the first step is to re-heat the castings to a temperature close to the alloy’s melting (solidus) temperature. For die casting alloys, this is normally in range of 480-505°C (895-940°F). To minimize blistering, the time between 420°C (788°F) and the maximum temperature should ideally not exceed 10 minutes, or that the total immersion time not exceed 15 minutes. After completion of the solution heat treatment, the castings should be water quenched using either hot or cold water. The castings are then aged at a lower temperature, at either 150°C or 180°C (302°F or 356°F).

Figure 4.10 Three steps during T6 heat treatment

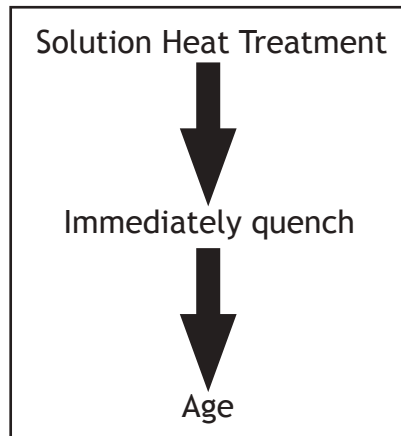


Table 4.11 Typical conditions used for the T6 heat treatment of conventional die castings

Optimum Solution Treatment	Quench	Aging
480-505°C (895-940°F). Note that the time between 420°C (788°F) and the maximum temperature ideally should not exceed 10 minutes (e.g., 15 minutes total immersion)	Hot or cold water quench from the solution heat treatment furnace	150°C (302°F) for 16-24 hours (best). However, 180°C (356°F) for 2½ to 4 hours may be preferred for some alloys

Typical mechanical properties of standard die casting alloys after T6 heat treating are listed in Table 4.11. Note that C380/D380 has a higher allowable magnesium concentration than A380, which accounts for the higher strength. Alloy A360 has lower strength due to its lower copper concentration than any of the 380-type alloys.

Table 4.12 Mechanical properties for conventional die castings heat treated to the T6 temper(3)

Alloy	A380	C380/D380	A360
Ultimate Tensile Strength			
ksi	62 - 67	65 - 70	48 - 53
MPa	430-460	450-485	330-365
0.2% Yield Strength			
ksi	49 - 55	54 - 61	41 - 48
MPa	340-380	370-420	285-330
Elongation			
%	3.0	2.0	3.5
Hardness			
Brinell†	127 - 138	138 - 154	114 - 118

† Brinell hardness - 500 kg load & 10 mm ball

Aluminum Die Castings - T5 Heat Treated

Although T6 heat treating provides the highest level of mechanical properties for conventional die castings, there are processing issues associated with performing solution heat treatments, so it is often easier to simply give the castings a T5 heat treatment. This normally involves water quenching the castings immediately after ejection from the casting die followed by a low temperature aging treatment (typically at temperatures between 150°C and 200°C - 302°F and 392°F). Research has been recently performed to characterize mechanical properties after T5 heat treatment for both conventional die castings, as well as die casting alloys containing lower levels of iron (0.25 to 0.40% Fe) . As noted earlier, iron is purposely added to conventional die casting alloys to minimize soldering to the die, but the iron reduces the ductility of the castings. Recent work has shown that strontium additions can also minimize die soldering, which allows the iron levels in the alloys to be reduced.

Typical mechanical properties of both conventional alloys and low-iron alloys after T5 heat treating are listed below. Note that the low-iron alloys have higher levels of elongation (ductility). All castings were T5 heat treated at 180°C (356°F) for 4 hours.

- **Conventional Alloys** - The mechanical properties of T5 heat treated conventional die castings with regular levels of iron (about 1.0% Fe) are listed in Table 4.13.

Table 4.13 Mechanical properties of T5 heat treated for conventional die castings containing normal levels of iron(4,5)

Property	E380	A360
Ultimate Tensile Strength		
ksi	52	46
MPa	360	315
0.2% Yield Strength		
ksi	37	38
MPa	255	260
Elongation		
%	2.0	1.5

- **Conventional Alloys Containing Low Levels of Iron** - The mechanical properties of T5 heat treated conventional die castings with lower levels of iron (0.25% to 0.40% Fe) are listed in Table 4.14. The alloys were treated with higher levels of strontium (approximately 0.08% Sr) to minimize die soldering.

Table 4.14 Mechanical properties of T5 heat treated conventional die castings containing low levels of iron (0.25-0.40% Fe)(4,5)

Property	E380	A360
Ultimate Tensile Strength		
ksi	48	49
MPa	330	340
0.2% Yield Strength		
ksi	31	36
MPa	215	250
Elongation		
%	3.5	3.5

4.6 Magnesium Alloys

The element magnesium (Mg) has a specific gravity of 1.74, making it the lightest commonly used structural metal. When used as a base for die casting alloys, magnesium is alloyed with various combinations of elements from a group including aluminum, zinc, manganese and silicon. Other elements present in the alloys are generally regarded as impurities, and maximum limits (expressed as single numbers) are specified.

The magnesium industry offers several alloys that are widely used for die casting. They are most commonly designated by a system established by ASTM for all magnesium alloys, which covers both chemical compositions and tempers. The first two positions in the ASTM designation are capital letters representing the two major alloying elements, and arranged in decreasing percentages. The letters are followed by numerals indicating the respective percentages rounded off to whole numbers. A letter in the next position indicates a slight variation in composition not reflected in the preceding characters, such as a minor alloying element variation. Temper designations, which normally follow, are generally not used for die casting alloys because porosity in the die casting, even in relatively small amounts, can cause blistering at heat treating temperatures.

The major elements used in magnesium die casting alloys are designated as follows:

- A - Aluminum
- M - Manganese
- S - Silicon
- Z - Zinc

Alloy AZ91D, which contains nominally 9% aluminum and 1% zinc, is the workhorse of the magnesium die casting alloys in that it is most often specified. It exhibits an excellent combination of mechanical properties, castability, and corrosion resistance. Corrosion resistance is achieved by enforcing strict limits on three metallic impurities. Iron, copper and nickel are limited to very low levels (see Table 4.15) making it necessary to use primary magnesium in the production of AZ91D alloy.

Alloy AZ91B is made from secondary metal, which gives it a slight price advantage over AZ91D. The ingot limit for nickel is ten times as high as for AZ91D, copper is 17 times as high, and there is no limit specified for iron. It is an acceptable alternative to AZ91D when atmospheric corrosion is not a factor.

Companion gravity casting alloys have been developed, and designated AZ91C and AZ91E. These alloys are similar in chemical content to each other and to AZ91B and AZ91D, and they develop similar mechanical properties. AZ91E is a high purity alloy, with very low limits on iron, copper and nickel. It exhibits corrosion resistance similar to AZ91D, and is used as a prototyping alloy when corrosion resistance must be evaluated.

Alloy AM60A, which nominally contains 6% aluminum and less than 1% manganese, has better elongation and toughness, but lower tensile and yield strengths than AZ91D. These properties have made it the choice for automotive wheels and archery equipment.

A high purity form of AM60A has been developed, designated AM60B. Iron, nickel and copper contents are held to very low levels, similar to AZ91D, (see Table 4.15) and the minimum level for manganese is slightly higher.

Table 4.15 Limits of Undesirable Elements in High Porosity Magnesium Alloys

Alloy		Element	Composition, % (ppm)
AZ91D	Ingot	Iron	.004 (40)
	Casting	Iron	.005 (50)
	Ingot	Nickel	.001 (10)
	Casting	Nickel	.001 (20)
	Ingot	Copper	.015 (150)
	Casting	Copper	.030 (300)
AM60B	Ingot	Iron	.004 (40)
	Casting	Iron	.005 (50)
	Ingot	Nickel	.001 (10)
	Casting	Nickel	.002 (20)
	Ingot	Copper	.008 (80)
	Casting	Copper	.010 (100)

Alloy AS41A, which nominally contains 4% aluminum and 1% silicon, has creep strength at elevated temperatures that is superior to the other magnesium die casting alloys, and has good elongation, yield, and tensile strength. These properties make it the choice for crankcases of air cooled automotive engines. A high purity form of this alloy has recently been introduced. The comparative characteristics of commercially available magnesium alloys are given in Table 4.16.

Table 4.16 Die Casting and Other Characteristics: Magnesium Alloys
(1 = most desirable, 5 = least desirable)

Commercial:	Magnesium Die Casting Alloys						
	AZ91D	AZ81	AM60B	AM50A	AM20	AE42	AS41B
Resistance to Cold Defects ^(A)	2	2	3 ^(G)	3 ^(G)	5 ^(G)	4 ^(G)	4 ^(G)
Pressure Tightness	2	2	1 ^(G)	1 ^(G)	1 ^(G)	1 ^(G)	1 ^(G)
Resistance to Hot Cracking ^(B)	2	2	2 ^(G)	2 ^(G)	1 ^(G)	2 ^(G)	1 ^(G)
Machining Ease & Quality ^(C)	1	1	1 ^(G)	1 ^(G)	1 ^(G)	1 ^(G)	1 ^(G)
Electroplating Ease & Quality ^(D)	2	2	2 ^(G)	2 ^(G)	2 ^(G)	—	2 ^(G)
Surface Treatment ^(E)	2	2	1 ^(G)	1 ^(G)	1 ^(G)	1 ^(G)	1 ^(G)
Die-Filling Capacity	1	1	2	2	4	2	2
Anti-Soldering to the Die	1	1	1	1	1	2	1
Corrosion Resistance	1	1	1	1	2	1	2
Polishing Ease & Quality	2	2	2	2	4	3	3
Chemical Oxide Protective Coating	2	2	1	1	1	1	1
Strength at Elevated Temperature ^(F)	4	4	3	3	5	1	2

^(A) The ability of alloy to resist formation of cold defects; for example, cold shuts, cold cracks, non-fill “woody” areas, swirls, etc. ^(B) Ability of alloy to withstand stresses from contraction while cooling through the hot-short or brittle temperature range. ^(C) Composite rating based on ease of cutting, chip characteristics, quality of finish and tool life. ^(D) Ability of the die casting to take and hold on electroplate applied by present standard methods. ^(E) Ability of castings to be cleaned in standard pickle solutions and to be conditioned for pest paint adhesion. ^(F) Rating based on resistance to creep at elevated temperatures. ^(G) Rating based upon limited experience, giving guidance only. Sources: ASTM B94-92, International Magnesium Association.

* There are additional magnesium alloys that have been and are being developed for elevated temperature and creep resistant applications. Contact your alloy producer for more information.

Although the magnesium die casting alloys exhibit a range of mechanical properties, they do have two in common, deriving from their common magnesium base:

- The tensile and compressive yield strengths for each alloy are substantially equal.
- All of the alloys exhibit the same modulus of elasticity, shear modulus, and Poisons' ratio.

The magnesium industry is involved in ongoing research and development programs in alloy development and metal handling. Examples of this work are the introduction of high-purity alloys, described above, and the introduction of inert gas shielding of the molten magnesium. More recent examples include the development of creep resistant alloys. Inert gas shielding of molten magnesium is now used by all U.S. die casters to prohibit oxidation at the surface of the metal. Inert gas shielding offers three benefits:

- Reduced melt losses to a level commensurate with zinc and aluminum.
- Virtually eliminates noxious and corrosive fumes from the magnesium die casting plant.
- Eliminates the possibility of contaminating the casting with flux and creating a corrosion problem.

Delivery of high-purity alloy to the die caster is one of two factors essential to high metal purity in the casting. The second is the metal handling practices employed by the die caster. The die caster must be especially careful to ensure that the very low impurity levels shown in Table 4.15 are attained in the casting. Suppliers of magnesium die castings should be selected from those who employ industry-recommended metal handling practices and maintain specified levels of metal purity.

Magnesium Die Casting Properties

Table 4.17 shows typical properties in the as-cast condition of the magnesium alloys commonly produced by conventional die casting. Again it is worth noting that ASTM Specification B557 provides a shape for an as-cast tensile bar for die castings, and that properties listed in Table 4.17 are for separately die cast tensile bars, not for specimens cut from production die castings.

Table 4.17 Material Properties for Magnesium Die Casting Alloys

	Magnesium Die Casting Alloys						
Commercial:	AZ91D	AZ81	AM60B	AM50A	AM20	AE42	AS41B
Mechanical Properties							
Ultimate Tensile Strength [®]							
ksi	34	32	32	32	32	27	33
(MPa)	(230)	(220)	(220)	(220)	(220)	(185)	(225)
Yield Strength [®] [®]							
ksi	23	21	19	18	15	20	20
(MPa)	(160)	(150)	(130)	(120)	(105)	(140)	(140)
Compressive Yield Strength [®]							
ksi	24	N/A	19	N/A	N/A	N/A	20
(MPa)	(165)		(130)				(140)
Elongation [®]							
% in 2 in. (51mm)	3	3	6-8	6-10	8-12	8-10	6
Hardness [®]							
BHN	75	72	62	57	47	57	75
Shear Strength [®]							
ksi	20	20	N/A	N/A	N/A	N/A	N/A
(MPa)	(140)	(140)					
Impact Strength [®]							
ft-lb	1.6	N/A	4.5	7.0	N/A	4.3	3.0
(J)	(2.2)		(6.1)	(9.5)		(5.8)	(4.1)
Fatigue Strength [®]							
ksi	10	10	10	10	10	N/A	N/A
(MPa)	(70)	(70)	(70)	(70)	(70)		
Latent Heat of Fusion							
Btu/lb	160	160	160	160	160	160	160
(kJ/kg)	(373)	(373)	(373)	(373)	(373)	(373)	(373)
Young's Modulus [®]							
psi x 10 ⁶	6.5	6.5	6.5	6.5	6.5	6.5	6.5
(GPa)	(45)	(45)	(45)	(45)	(45)	(45)	(45)
Physical Properties							
Density							
lb/in ³	0.066	0.065	0.065	0.064	0.063	0.064	0.064
(g/cm ³)	(1.81)	(1.80)	(1.80)	(1.78)	(1.76)	(1.78)	(1.78)
Melting Range							
°F	875-1105	915-1130	1005-1140	1010-1150	1145-1190	1050-1150	1050-1150
(°C)	(470-595)	(490-610)	(540-615)	(543-620)	(618-643)	(565-620)	(565-620)
Specific Heat B							
BTU/lb °F	0.25	0.25	0.25	0.25	0.24	0.24	0.24
(J/kg °C)	(1050)	(1050)	(1050)	(1050)	(1000)	(1000)	(1000)
Coefficient of Thermal Expansion [®]							
m in/in °F	13.8	13.8	14.2	14.4	14.4	14.5 [®]	14.5
(m m/m °K)	(25.0)	(25.0)	(25.6)	(26.0)	(26.0)	(26.1)	(26.1)
Thermal Conductivity							
BTU/ft hr °F	41.8 [®]	30 [®]	36 [®]	36 [®]	35 [®]	40 B [®]	40 [®]
(W/m °K)	(72)	(51)	(62)	(62)	(60)	(68)	(68)
Electrical Resistivity [®]							
μ Ω in.	35.8	33.0	31.8	31.8	N/A	N/A	N/A
(μ Ω cm.)	(14.1)	(13.0)	(12.5)	(12.5)			
Poisson's Ratio	0.35	0.35	0.35	0.35	0.35	0.35	0.35

n/a = data not available. [®] Rotating Beam fatigue test according to DIN 50113. Stress corresponding to a lifetime of 5 x 10⁷ cycles. Higher values have been reported. These are conservative values. Soundness of samples has great effect on fatigue properties resulting in disagreement among data sources. [®] At 68oF (20oC). [®] At 212-572oF (100-300oC). [®] ASTM E 23 unnotched 0.25 in. die cast bar. [®] 0.2% offset. [®] Average hardness based on scattered data. [®] Estimated. [®] 0.1% offset. Source: International Magnesium Assn.

* There are additional magnesium alloys that have been and are being developed for elevated temperature and creep resistant applications. See the data table on page 3-20. Contact your alloy producer for more information.

4.7 Zinc

The element zinc, with a specific gravity of 7.0, is among the heavier of the common structural metals. It is somewhat less dense than iron (7.7) and copper (9.0). When used as a base for die casting alloys, zinc is alloyed with aluminum, copper and magnesium as the Zamak (an acronym for zinc, aluminum, magnesium and copper) alloys. These alloys, with their ASTM designations, are:

- Zinc 2 ASTM AC43A
- Zinc 3 ASTM AG40A
- Zinc 5 ASTM AC41A
- Zinc 7 ASTM AG40B

The nominal aluminum content of each alloy is 4%. Aluminum improves the alloy's mechanical properties, particularly tensile and impact strengths. The relatively low concentration gives the alloys very low melting points and makes them easy to cast. Copper, in small amounts, increases tensile strength and hardness, but reduces ductility, particularly in the aged condition. Zinc 2 and 5 have nominal copper contents of 3% and 1% respectively. Copper is restricted to a maximum of 0.25% in zinc 3 and 7. Magnesium, in very small amounts, also increases hardness and reduces ductility. Its main purpose is to offset the effects of metallic impurities, particularly cadmium, lead and tin. Iron, cadmium, lead and tin have been identified as undesirable elements and are restricted to low or extremely low levels. Higher iron contents form undesirable intermetallic particles. Cadmium, lead and tin, even in very low concentrations, can cause intergranular corrosion in the zinc-aluminum alloy system when magnesium is absent. The allowable levels of these elements are shown in Table 4.18.

Table 4.18 Allowable Levels of Undesirable Elements in Zinc Alloys

Concentration, % (parts per million)				
	Iron	Cadmium	Lead	Tin
Zinc 2	0.075 (750)	0.003 (30)	0.003 (30)	0.001 (10)
Zinc 3 and 5	0.075 (750)	0.004 (40)	0.003 (30)	0.002 (20)
Zinc 7	0.075 (750)	0.002 (20)	0.002 (20)	0.001 (10)

These high-purity limits can be maintained only by using special high-grade zinc, with a purity of 99.990%, as a base. Zinc suppliers, through many years of development, routinely produce primary metal that meets this purity standard. All of the zinc (and ZA) alloys produced in the U.S. and Canada are made from primary metal that meets the purity specification.

As with magnesium, good metal handling practices of the die caster are essential for maintaining high purity in the resulting castings. Remelted scrap must be kept clean and separate from other scrap generated in the same plant.

Zinc 3 and 5 were introduced in the 1930's, and zinc 7 was introduced approximately 20 years later. Since their introduction, purity of the base zinc has been increasing to its current level of 99.990%, decreasing the undesirable elements and reducing the levels of magnesium which is required to offset them. These improvements have led to higher ductility and more consistent quality.

The mechanical properties of the alloys have been extensively characterized. Long-term data on creep and aging have been developed, allowing the designer to predict with confidence the performance of alloy die castings over the projected product life. Zinc 3 is the workhorse alloy of this group, specified most frequently. Many zinc die casters use only this alloy, making it unnecessary for them to segregate in-house scrap. It has a slight cost advantage over zinc 5, and since more die casters use it, price quotations are potentially more competitive. Zinc 5 offers high tensile strength, hardness, and creep resistance as compared to zinc 3, and somewhat lower ductility. It is preferred whenever these properties are required. Some die casters use only zinc 5, which is usually an acceptable alternative to zinc 3.

Zinc 7 is essentially a high purity form of zinc 3 with slightly higher ductility and lower hardness. The other mechanical properties are identical to zinc 3. The alloy also exhibits higher fluidity than zinc 3 or 5, which theoretically allows slightly higher production rates and thinner walls. Die casters generally feel that these benefits are difficult to realize, and additional care is required to process in-house scrap to maintain metal purity. Zinc 7 may be specified when high ductility is required.

Zinc alloys 3, 5 and 7 have a number of properties in common, deriving from their common zinc base and similar composition.

- **Mechanical properties.** All alloys exhibit the same modulus of elasticity, shear modulus and Poissons' ratio. Compressive strength is approximately 50% higher than tensile. The room temperature impact strength of zinc alloys is the highest of all die cast alloys.
- **Temperature effects.** Data for mechanical properties are taken at room temperature, and some vary significantly with relatively minor changes in temperature. The effect of temperature on the properties of zinc 3 and 5 have been documented and published by the zinc industry.
- **Casting properties.** Zinc alloys exhibit little tendency to attack steel at casting temperatures. This property, combined with the relatively low casting temperature, results in low die maintenance and long die life. These properties also allow zinc alloys to be cast using the hot-chamber method.
- **Platability.** Zinc alloys can be economically plated to achieve a bright, durable chrome finish. This makes zinc the die casting material of choice for hardware applications.
- **Aging.** The die casting process is characterized by very rapid metal solidification. The phenomenon locks zinc alloys into a crystal structure that is not stable at room temperature. Over time, the metal atoms slowly migrate to a stable pattern, a condition known as aging, with two effects:
 - Ductility is increased slightly, and tensile strength, impact strength and hardness are somewhat decreased.
 - There is some slight shrinkage.

Changes in ductility and tensile strength occur over a period of approximately 10 years at room temperature. Shrinkage is 0.0007 mm/mm, of which 0.0005 mm/mm occurs within five weeks at room temperature. If the castings are quenched, an additional 0.004 mm/mm of shrinkage occurs.

If desirable, the aging process can be accelerated by oven heating according to the following schedule:

- 3 hours at 212°F (100°C)
- 5 hours at 185°F (85°C)
- 10 hours at 158°F (70°C)

Recent research has resulted in zinc alloys of higher temperature resistance (creep resistance) and an alloy of higher fluidity than zinc 7 for thinner wall applications. The comparative characteristics of commercially available zinc alloys are given in Table 4.19.

**Table 4.19 Die Casting and Other Characteristics:
Zinc Alloy
(1 = most desirable, 5 = least desirable)**

	Zamak Die Casting Alloys				ZA-8	ZA-12	ZA-27
	No. 2	No. 3 AG-40A	No. 5 AG-41A	No. 7 AG-40B			
Resistance to Hot Cracking [ⓑ]	1	1	2	1	2	3	4
Pressure Tightness	3	1	2	1	3	3	4
Casting Ease	1	1	1	1	2	3	3
Part Complexity	1	1	1	1	2	3	3
Dimensional Accuracy	4	2	2	1	2	3	4
Dimensional Stability	2	3	3	2	2	2	1
Corrosion Resistance	2	3	3	2	2	2	1
Resistance to Cold Defects [Ⓐ]	2	2	2	1	2	3	4
Machining Ease & Quality [ⓒ]	1	1	1	1	2	3	4
Polishing Ease & Quality	2	1	1	1	2	3	4
Electroplating Ease & Quality [ⓓ]	1	1	1	1	1	2	3
Anodizing (Protection)	1	1	1	1	1	2	2
Chemical Coating (Protection)	1	1	1	1	2	3	3

[Ⓐ] The ability of alloy to resist formation of cold defects; for example, cold shuts, cold cracks, non-fill “woody” areas, swirls, etc. [ⓑ] Ability of alloy to withstand stresses from contraction while cooling through the hot-short or brittle temperature range. [ⓒ] Composite rating based on ease of cutting. Chip characteristics, quality of finish and tool life. [ⓓ] Ability of the die casting to take and hold an electroplate applied by present standard methods. Source: International Lead Zinc Research Organization.

Zinc Die Casting Properties

Table 4.20 shows typical properties in the as-cast condition of the zinc alloys commonly produced by conventional die casting.

Table 4.20 Material Properties for Zinc and ZA Die Casting Alloys

Commercial:	Zamak Die Casting Alloys				ZA Die Casting Alloys		
	No. 2	No. 3 AG-40A	No. 5 AG-41A	No. 7 AG-40B	ZA-8	ZA-12	ZA-27
Mechanical Properties							
Ultimate Tensile Strength							
As-Cast ksi (MPa)	52 (359)	41 (283)	48 (328)	41 (283)	54 (372)	59 (400)	62 (426)
Aged ksi (MPa)	48 (331)	35 (241)	39 (269)	41 (283)	43 (297)	45 (310)	52 (359)
Yield Strength ^(A)							
As-Cast ksi (MPa)	41 (283)	32 (221)	39 (269)	32 (221)	41-43 (283-296)	45-48 (310-331)	52-55 (359-379)
Aged ksi (MPa)					32 (224)	35 (245)	46 (322)
Compressive Yield Strength ^(B)							
As-Cast ksi (MPa)	93 (641)	60 (414) ^(C)	87 (600) ^(C)	60 (414) ^(C)	37 (252)	39 (269)	52 (358)
Aged ksi (MPa)	93 (641)	60 (414)	87 (600)	60 (414)	25 (172)	27 (186)	37 (255)
Elongation							
As-Cast % in 2 in. (51mm)	7	10	7	13	6-10	4-7	2.0-3.5
Aged % in 2 in. (51mm)	2	16	13	18	20	10	3
Hardness ^(D)							
As-Cast BHN	100	82	91	80	100-106	95-105	116-122
Aged BHN	98	72	80	67	91	91	100
Shear Strength							
As-Cast ksi (MPa)	46 (317)	31 (214)	38 (262)	31 (214)	40 (275)	43 (296)	47 (325)
Aged ksi (MPa)	46 (317)	31 (214)	38 (262)	31 (214)	33 (228)	33 (228)	37 (255)
Impact Strength							
As-Cast ft-lb (J)	35 (47.5)	43 ^(E) (58)	48 ^(E) (65)	43 ^(E) (58)	24-35 ^(E) (32-48)	15-27 ^(E) (20-37)	7-12 ^(E) (9-16)
Aged ft-lb	5	41	40	41	13	14	3.5
Fatigue Strength ^(F)							
As-Cast ksi (MPa)	8.5 (58.6)	6.9 (47.6)	8.2 (56.5)	6.9 (47.6)	15 (103)	—	21 (145)
Aged ksi (MPa)	8.5 (58.6)	6.9 (47.6)	8.2 (56.5)	6.8 (46.9)	15 (103)	—	21 (145)
Young's Modulus							
psi x 10 ⁶ (GPa)	^(G)	^(G)	^(G)	^(G)	12.4 (85.5)	12 (83)	11.3 (77.9)
Physical Properties							
Density							
lb/in ³ (g/cm ³)	0.24 (6.6)	0.24 (6.6)	0.24 (6.6)	0.24 (6.6)	0.227 (6.3)	0.218 (6.03)	0.181 (5.000)
Melting Range							
^(F) (^(C))	715-734 (379-390)	718-728 (381-387)	717-727 (380-386)	718-728 (381-387)	707-759 (375-404)	710-810 (377-432)	708-903 (372-484)
Specific Heat							
BTU/lb ^(F) (J/kg ^(C))	0.10 (419)	0.10 (419)	0.10 (419)	0.10 (419)	0.104 (435)	0.107 (450)	0.125 (525)
Coefficient of Thermal Expansion							
m in/in ^(F) (m m/m ^(K))	15.4 (27.8)	15.2 (27.4)	15.2 (27.4)	15.2 (27.4)	12.9 (23.2)	13.4 (24.1)	14.4 (26.0)
Thermal Conductivity							
BTU/ft hr ^(F) (W/m ^(K))	60.5 (104.7)	65.3 (113)	62.9 (109)	65.3 (113)	66.3 (115)	67.1 (116)	72.5 (122.5)
Electrical Conductivity							
m Ω in.	25.0	27.0	26.0	27.0	27.7	28.3	29.7
Poisson's Ratio							
	0.30	0.30	0.30	0.30	0.30	0.30	0.30

^(A) 0.2% offset, strain rate sensitive, values obtained at a strain rate of 0.125/min (12.5% per minute). ^(B) 0.1% offset. ^(C) Compressive strength. ^(D) 500 kg load, 10 mm ball. ^(E) ASTM 23 unnotched 0.25 in. die cast bar. ^(F) Rotary Bend 5 x 10⁸ cycles. ^(G) Varies with stress level; applicable only for short-duration loads. Use 107 as a first approximation. Source: International Lead Zinc Research Organization.

4.8 ZA Alloys

The ZA (or zinc-aluminum) alloys have existed in various forms, primarily as gravity casting alloys since 1959. Research and development since 1959 has refined the chemical composition and adapted this alloy group to die casting, where they have proven very successful. ZA alloys are specified by the letters ZA followed by a hyphen and numerals which indicated the approximate nominal aluminum content. There are three alloys in this group: ZA-8, ZA-12, and ZA-27. The ZA alloys, like 3, 5 and 7, are based on the zinc-aluminum alloy system, with higher aluminum and copper contents. The other alloying element is magnesium. This common alloy system gives the ZA alloys several characteristics in common with the zinc alloy group:

- The three alloying elements have essentially the same effect on alloy properties.
- Iron, cadmium, lead and tin are also undesirable, and are held to essentially the same limits.
- The high purity required the use of primary zinc at 99.990% purity.

As aluminum content, and consequently casting temperature, increases, these alloys become more aggressive to iron and steel, reducing die life and increasing maintenance cost somewhat. High aluminum and copper contents give these alloys several distinct advantages over the zinc alloys, including:

- High Strength
- Superior wear resistance
- Superior creep resistance
- Lower densities

ZA-8, with a nominal aluminum content of 8.4% and copper content of 1%, has the lowest aluminum content, and consequently the lowest melting point and highest density of the three. Its casting temperature is low enough to permit die casting by the hot-chamber method. It has the highest strength of any hot-chamber zinc alloy and the highest creep strength of any zinc alloy. It can be chrome plated using the same processes employed for zinc alloys.

ZA-12, with a nominal aluminum content of 11% and copper content of 1%, has an aluminum content higher than ZA-8 and lower than ZA-27. Its properties are therefore between the two. It can be chrome plated, but the aluminum content makes it advisable to modify somewhat the processes employed for zinc alloys. Its casting temperature requires die casting by the cold-chamber method. ZA-27, with a nominal aluminum content of 27% and 2.2% copper content has the highest aluminum content, and consequently the highest strength, highest melting point, and lowest density of the three. The alloy is not generally chrome plated. Its relatively high casting temperature requires the cold-chamber process.

The higher aluminum contents of ZA-12 and 27 require special metal handling practices beyond those required for zinc alloys. Where die casters (or foundries, when the alloys are used for prototyping) are not experienced using ZA alloys, it is essential that the alloy supplier be consulted to advise the die caster on approved metal handling procedures. The comparative characteristics of commercially available ZA alloys are given in Table 4.19.

4.9 Early Designer-Die Caster Interaction

Comprehensive standards for traditional die cast products, miniature die castings, high vacuum castings, squeeze castings and semi-solid metal castings are published in NADCA Product Specification Standards for Die Castings, and NADCA Product Specification Standards for High Integrity and Structural Die Casting Processes, which defines the product design criteria that should apply for die casting production under varying manufacturing conditions. These volumes include standards for draft requirements; dimensions for fillets, ribs, and corners; and criteria for flash removal, with geometric dimensioning guidelines.

Designers can realize the full benefits of high-technology die casting by discussing the functional form of the product with their die caster in advance. The designer should review designs together with the die caster to eliminate most, if not all, finish-machining operations and reduce product cost.

The cycle of advanced research, technology transfer and application is an ongoing process that is keeping the die casting industry competitive. Product designers who work closely - and early - with their custom die caster will maximize material and process benefits and enhance their position in the marketplace.

For additional information on die casting processes, contact the North American Die Casting Association.

4.10 Alloy Selection

The four families of die casting alloys (aluminum, magnesium, zinc, ZA) offer a wide latitude for trade-offs in design and economic factors. The following comparison in nine categories will assist in the selection of the optimum die casting alloy:

- Alloy cost
- Process cost
- Structural properties
- Minimum weight
- Impact strength
- Surface finish
- Corrosion resistance
- Bearing properties and wear resistance
- Machinability

Alloy cost

Alloy cost is an important factor in overall product cost, particularly among die casting alloys. Alloy prices tend to fluctuate with market conditions, so that any comments must be general in nature. Prices are quoted on the basis of weight, but design is based on volume of material. The volume of metal in a die casting, whether optimized for aluminum, magnesium, zinc or ZA, will usually be nearly constant. Therefore, cost per cubic inch is a good first approximation of relative material cost.

Aluminum alloys usually have the lowest cost per cubic inch, which accounts for the widespread use of aluminum. Magnesium, zinc and ZA alloys regain some of the material cost differential in applications where wall thicknesses are controlled by casting rather than functional constraints; die casters are currently casting thinner walls in these alloys than in aluminum.

Process cost

Process costs are another important component of overall product cost and closely related to alloy selection. Four factors are important:

- Alloys that can be hot-chamber cast usually require smaller die casting machines that run at faster rates than equivalent size castings run on cold-chamber machines.
- The initial die manufacturing cost is essentially the same, regardless of the alloy being cast. However, die maintenance and replacement costs vary. They are lowest for zinc alloys because, as noted above, zinc alloys do not attack die steels and they are cast at relatively low temperatures. These costs increase with magnesium and ZA alloys, and increase further with aluminum alloys.
- Magnesium, zinc and ZA alloys may reduce or eliminate finish machining operations when precision features are required, such as zero draft and press fit tolerances, which can often be as-cast in these alloys.
- Zinc alloys and ZA-8 tend to be the material of choice for very small die castings (typically less than one ounce, or 28 gm). This advantage is attributed to die casters who have developed special purpose, highly automated machines that produce small, “miniature” die castings at very low process costs.

Mechanical and Physical Properties

Comparative mechanical and physical properties of die casting alloys are presented in Tables 4.3 and 4.10. Aluminum alloys exhibit the highest modulus of elasticity of the four alloy groups. Their relatively high strength and low density make them the frequent choice for medium-to-large die castings with structural requirements. Magnesium, with lower strength and rigidity, has been competitive with aluminum in some applications by developing systems of thin, strategically located reinforcing ribs. In applications where maximum strength is required within a specified space, ZA alloys, which offer the highest ultimate and yield strengths, are the best choice.

Aluminum alloys maintain their structural properties over a wider temperature range than the other alloy groups. Their stability often makes them the material of choice at elevated temperatures, particularly where minimum or no creep is permissible.

The creep characteristics of zinc and ZA alloys, which are similar to visco-elastic behavior of thermoplastics, must be taken into account when long-term sustained loads induce moderate to high stress levels. Data is available that enable the designer to predict alloy behavior and modify the design when necessary.

Minimum weight

Magnesium alloys are the dominant choice when weight must be minimized. Where weight is a major factor and other criteria such as mechanical properties or cost are important, aluminum alloys are often competitive.

Impact strength and dent resistance

The zinc alloys offer the highest impact strength of the four groups. However, as noted above, the impact strength of the zinc alloys begins to diminish sharply as temperature is reduced below 32°F (0°C). The impact resistance of aluminum and magnesium alloys vary within each alloy group.

Dent resistance, as noted above, is indicated by the ratio of yield strength to modulus of elasticity. For identical features with equal wall thicknesses, ZA-27 offers the highest dent resistance, followed by ZA-12 and ZA-8. The zinc alloys have a lower yield strength, but their nonlinear modulus of elasticity allows them to store more elastic energy than the yield strength to modulus of elasticity ratio indicates, and increases their dent resistance. They may be considered slightly below ZA-8, and somewhat superior to aluminum and magnesium. The yield strength to modulus of elasticity ratios are nearly equal for aluminum and magnesium alloys.

Surface finish

The compatibility of magnesium, zinc and ZA alloys with the die steel means that a high quality finish can be maintained over long production runs with these alloys. (Die surface quality is essential to casting surface quality.) There are economical processes in place for depositing a bright, durable chrome finish on zinc, ZA-8 and ZA-12 die castings when this type of finish is required.

Corrosion resistance

The major differences in corrosion resistance occur within the alloy groups, particularly aluminum and magnesium. Aluminum alloys vary according to chemical composition, particularly copper content. Magnesium alloys vary with metal purity. The more resistant alloys offer moderate corrosion resistance, as noted above. The corrosion resistance of all die casting alloys can be improved, as required, with a variety of low-cost surface treatment systems.

Bearing properties and wear resistance

All die castings alloys can be used for hydrodynamic bearing applications, where oil is fed to the bearing under pressure, and a full oil film is maintained by rotation of the journal in the bearing. Where only partial lubrication is available, the ZA alloys and 390 aluminum offer very good resistance to abrasion and wear.

Machinability

Die casting alloys offer good to excellent machining characteristics when machining operations are required. Aluminum alloys exhibit moderate variation. Magnesium offers the best machinability of any structural metal in terms of tool life, minimum energy consumption, and low cutting forces. In some cases, deep finish cuts are made on magnesium alloys that would require two cuts (rough and finish) on any other alloy.

Most die castings are easier to machine than low carbon steel. The range of magnesium die casting alloys has the best machinability of the all the generally available die casting alloys. Zinc and ZA alloy die castings have very good machinability, with some decrease as aluminum increases in these alloys. Aluminum die casting alloys have good machinability, but there is some variability in machinability across the available alloy range. Die castable copper alloys have a wide range of machinability. Copper alloys 857, 858, 997 and 997.5 have good machinability, alloy 878 has medium machinability and alloy 865 has the lowest machinability; however alloys 878 and 865 may be machined successfully with carbide cutters and appropriate cutting oil. See Table 4.21.

Table 4.21 Relative Die Casting Alloys Machinability Index		
Alloy Group	Specific Alloy	Machinability
Magnesium	All	Excellent
Zinc	No. 3, 5, 7	Very Good
ZA	ZA-8, ZA-12, ZA-27	
Aluminum	360, 380	Good
	383, 384, 518	
Copper	857, 858, 997, 997.5	
Aluminum	413, 443	Medium
	390	
Copper	878, 865	
Aluminum MMC	All	Low

This chart is based on shop floor machining experience and compilation and review of references 5, 6 and 7.

Alloy Supply

Early in the product development process the designer must assess the question of material supplies and pricing, not only for current conditions, but also over the expected production life of the product. The processes employed to produce, distribute and cast die casting alloys are essentially safe and environmentally compatible. Because of this, the industry is not subject to sudden changes in operating practices and the associated manufacturing interruptions and increased costs arising from government regulations relating to the safety of workers or environmental pollution.

The price of die casting alloys, like other commodities, tends to fluctuate with economic conditions. However, die casting alloys are not as sensitive to supply problems as are other many materials, because the supply sources for aluminum, magnesium and zinc enjoy stability that is matched by few materials.

Aluminum Supply

Aluminum die casting alloys are made from recycled metal. Secondary (recycled) aluminum is more economical to produce than primary because it requires only 5% as much energy to produce a pound. Current projections indicate that the supply of recycled aluminum will be adequate to meet the needs for aluminum die casting in to foreseeable future. Used beverage cans (UBC) comprise a large portion of the aluminum available recyclers. The supply has been enhanced by the many states that have imposed deposits on beverage cans, which encourages their collection and recycling. Aluminum smelters, widely dispersed across the continental United States, are supplying die casting alloys and supporting die casters with technical assistance and other support services.

Magnesium Supply

Magnesium die casting alloys are made from primary and secondary metal, with primary metal accounting for the largest portion. Recycled magnesium, similar to aluminum, requires only a small fraction as much energy to produce as does primary. Therefore, alloys made from recycled metals cost slightly less than alloys made from primary. However, they are lower in purity and should be specified only in applications where lower purity is tolerable.

Magnesium “ore” is considered to be limitless, and it is readily accessible to any nation with an ocean shoreline. The primary source is sea water, which is 0.13% magnesium. Other salt water sources, such as brine wells and the Great Salt Lake, offer viable supplies. Dolomite, a second source sometimes used in combination with sea water, is in abundant supply internationally. These natural sources ensure that magnesium suppliers are readily available.

Zinc Supply

Zinc die casting alloys require high metal purity in all applications. Therefore, they are made only from high-purity (99.990%) primary zinc. The mines and smelters that supply the zinc used by U.S. die casters do not generally operate at full capacity. Zinc is used in a variety of industries, including corrosion protection for steel (galvanizing). The broad use of zinc and the margin in production capacity contribute to a stable supply of the metal for zinc and ZA die casting alloys.

Zinc and ZA alloys are produced and distributed by alloyers dispersed across the continental United States. They also offer technical support for the alloys they distribute. Zinc alloyers have been a major force in the successful introduction of ZA alloys through their close liaison and technical support to product designers and die casters.

Restriction of Hazardous Substances

For Restriction of Hazardous Substances (RoHS) compliance of all die casting alloys it is recommended to obtain certification of restricted materials levels from your die caster or alloy supplier. The RoHS six restricted materials and concentrations are listed in Table 4.22.

Table 4.22 RoHS Restricted Material Concentrations

Material	Max Concentration % by weight in homogeneous materials
Lead (Pb)	0.1
Mercury (Hg)	0.1
Hexavalent Chromium ((Cr-VI)	0.1
Polybrominated Biphenyls (PBB)	0.1
Polybrominated Diphenyl Ethers (PBDE)	0.1
Cadmium (Cd)	0.01

It should be noted that Annex 6 of the RoHS related Directive 2002/95/EC should not be applied to aluminum die casting alloys. Lead is not a purposeful alloying element in commonly used aluminum die casting alloys. Directive 2002/95/EC states the following: “Lead as an alloying element in steel containing up to 0,35 % lead by weight, aluminum containing up to 0,4 % lead by weight and as a copper alloy containing up to 4 % lead by weight.” However, lead is a purposeful alloying element in some copper die casting alloys, so Annex 6 may be applicable to some copper die casting alloys.

The cross reference designations shown are for alloy specifications according to widely recognized sources. References apply to the metal in the die cast condition and should not be confused with similar specifications for metal ingot. A “—” in a column indicates that the specific alloy is not registered by the given source.

Table 4.23 Cross-Reference Designations: Alloy Specifications for Die Castings

Aluminum Alloy Specifications							
Comm'l	UNS	ANSI AA	ASTM B85	Former SAE J452	Federal QQ-A-591 (B)	DIN (G) 1725	JIS H5302
360	A03600	360.0	SG100B	—	(B)		
A360 (A)	A13600	A360.0	SG100A	309	(B)	233	ADC3
380 (C)	A03800	380.0	SC84B	308	(B)		
A380 (A) (C)	A13800	A380.0	SC84A	306	(B)	226A (E)	ADC10 (C) (D)
383	A03830	383.0	SC102A	383	(B)	226A (E)	ADC12 (C) (D)
384	A03840	384.0	SC114A	303	(B)		ADC12 (C) (D)
A384 (A)	—	A384.0	—	—	(B)		ADC12 (C) (D)
390	A23900	B390.0	SC174B	—	(B)		
13	A04130	413.0	S12B	—	(B)		
A13 (A)	A14130	A413.0	S12A	305	(B)	231D (F)	ADC1 (C)
43	A34430	C443.0	S5C	304	(B)		
218	A05180	518.0	G8A	—	(B)	341	

(A) Similar to preceding entry with slight variations in minor constituents. (B) The Federal specification for aluminum alloy die castings uses the Aluminum Association designations for individual alloys. Military designations superseded by Federal specifications. (C) NADCA and Japanese specifications allow 0.3 magnesium maximum. (D) Japanese specifications allow 1.0 zinc maximum. (E) DIN 1725 spec allows 1.2 max zinc and up to 0.5 max magnesium. (F) DIN 1725 spec allows 0.3 max magnesium. (G) Alloy compositions shown in DIN 1725 tend to be “primary based” and have low impurity limits making it difficult to correlate directly to U.S. alloys.

Table of Symbols

- UNS** — Unified Numbering System
- ANSI** — American National Standards Institute
- ASTM** — American Society for Testing and Materials
- AA** — Aluminum Association
- SAE** — Society of Automotive Engineers
- FED** — Federal Specifications
- MIL** — Military Specifications
- JIS** — Japanese Industrial Standard
- DIN** — German Industrial Standard

Magnesium Alloy Specifications						
Comm'l	UNS	ASTM B93 & B94	Former SAE J465B	Federal	DIN 1729	JIS H2222 & H5303
AZ91B	M11912	AZ91B	501A	QQ-M38	3.5912.05	MDI1B
AZ91D	M11916	AZ91D	—	—	—	MDI1D
AZ81	—	—	—	—	—	—
AM60A	M10600	AM60A	—	—	3.5662.05	MDI2A
AM60B	M10602	AM60B	—	—	—	MDI2B
AM50	—	—	—	—	—	—
AE42	—	—	—	—	—	—
AS41A	M10410	AS41A	—	—	3.5470.05	MDI3A
AS41B	M10412	AS41B	—	—	—	—
AM20	—	—	—	—	—	—

Zinc and ZA Alloy Specifications						
Comm'l	UNS	ASTM B86	Former SAE J469	Federal QQ-Z363a	DIN	JIS
2	Z35541	AC43A	921	AC43A	1743	
3	Z33520	AG40A	903	AG40A	1743	ZDC-2
5	Z355310	AC41A	925	AC41A	1743	ZDC-1
7	Z33523	AG40B	—	AG40B		
ZA-8	Z35636	—	—			
ZA-12	Z35631	—	—			
ZA-27	Z35841	—	—			

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5

High Integrity Die Castings

High Integrity die casting represents a new range of processes which combine many of the traditional benefits associated with conventional high pressure die casting with novel approaches to produce high quality, heat treatable, lightweight components. High integrity die casting processes must minimize casting defects caused by issues of entrapped gas, solidification shrinkage voids and hydrogen porosity, to produce castings having high strength and high ductility, which can be used in structural, safety-critical, or pressure-tight applications. There are three main high integrity die casting processes - high vacuum die casting, squeeze casting and semi-solid casting, and each are described in more detail below.

5.1 High Vacuum Die Casting

Although vacuum assist has been used in the die casting industry for many years, a new process called high vacuum die casting allows the production of aluminum die castings that are being used in safety-critical applications due to better strength, much higher elongation and excellent impact resistance. Figure 5.1 demonstrates the energy absorbing ability, showing a component produced by high vacuum die casting 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.

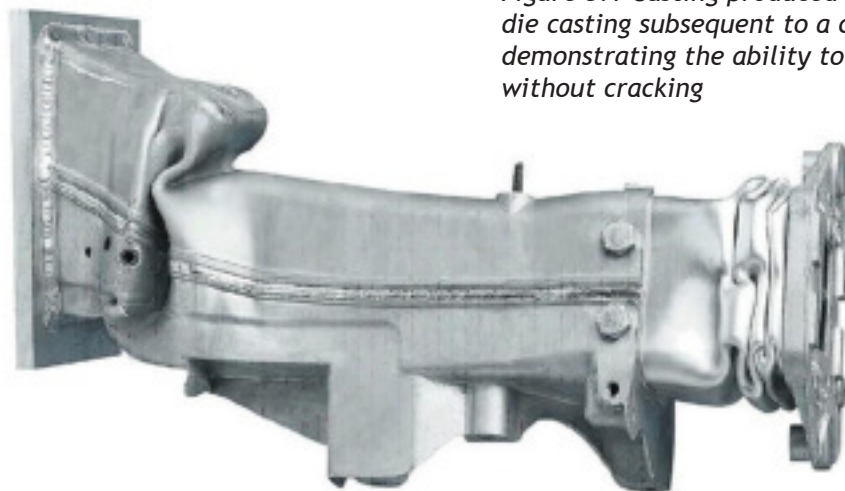


Figure 5.1 Casting produced by high vacuum die casting subsequent to a crash test(1), demonstrating the ability to absorb energy without cracking

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 50 milli-bar or less (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:

- 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.
- 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 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
- Robust die and gating designs
- Powerful vacuum systems, sealed die surfaces and advanced vacuum controls to achieved desired vacuum levels in the cavity
- Controlled thermal treatment of the castings to obtain strength-ductility combinations

These are discussed below in more detail.

Low-Iron Die Casting Alloys

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 5.2. 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 ($\leq 0.45\%$), which helps provide high levels of ductility (elongation). Note that the concentrations of other elements (manganese or strontium) have been increased to minimize soldering of the alloy to the die during the die casting process.

Table 5.2: 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	0.8	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	0.8	Sr: 0.01-0.018
Aural™-5	6.5-9.5	0.16-0.22	0.03	0.3-0.6	0.1-0.6	0.03	0.1	Sr: 0.01-0.018
Castasil 37	8.5-10.5	.015	0.05	0.35-0.6	0.06	0.07	0.1	Mo 0.3, Zr 0.3, Sr
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	0.1	0.20	Sr: 0.05-0.07
Magsimal 59	1.8-2.6	0.2	0.03	0.5-0.8	5.0-6.0	0.07	0.20	Be
Silafont 36	9.5-11.5	0.15	0.03	0.5-0.8	0.1-0.5	0.07	0.04-0.15	Sr

Mechanical properties of these alloys after high vacuum die casting are listed in Tables 5.3 - 5.5.

Metal Treatment and Handling to Optimize Metal Quality

As high vacuum die castings are normally used in structural application, greater care needs to be taken to optimize the quality of the metal. Therefore, the alloys are normally cleaned 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 inert 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).

Robust Die and Gating Designs

The gating system used with high vacuum die casting is modified from conventional die casting. High vacuum die 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.

Powerful vacuum systems

There are a number of commercial systems available for high vacuum die casting, including the High-Q-Cast process, Vacural and Alcoa Vacuum Die Casting (AVDC). Each of these processes have in common the use of powerful vacuum systems and advanced vacuum controls to quickly reduce the pressure in the cavity and shot sleeve below 100 milli-bar. In addition, to minimize vacuum leaks, seals are used on all die surfaces, making the dies much more complex than used for conventional die casting.

Controlled Thermal Treatments

Although the castings can be used in the as-cast condition, the significantly lower levels of entrapped gases allow high vacuum die castings to be heat treated without blistering. Components can be heat treated after casting to maximize strength, ductility or toughness.

Both T5 and T6 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 (150-200°C/300-390°F) aging treatment. T6 heat treating involves heating the castings to a temperature close to their melting (solidus) temperature, followed by a water quench and a low temperature age. Note that a streamlined T6 heat treatment has been developed for use with the Aural™ alloys, which has been named Auraltherm. 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.

Representative mechanical properties of commonly produced high vacuum die casting alloys in the various heat treatment conditions are listed in Tables 5.3 to 5.5.

Table 5.3 Mechanical properties of high vacuum die castings in the F-temper (as-cast)

Property	Aural™-2	Aural™-3	Mercalloy 367	Mercalloy 368	Silafont 36
Ultimate Tensile Strength					
ksi	36-45	36-45	39	38-40	36-42
MPa	250-310	250-310	270	260-276	240-290
Yield Strength					
ksi	17-22	19-23	17	18-20	17-22
MPa	120-150	130-160	115	125-140	120-150
Elongation					
% in 2 in (51 mm)	5-10	4-8	8	10-12	5-11

Table 5.4 Mechanical properties of high vacuum die castings heat treated to the T5-temper

Property	Aural™-2	Aural™-3	Mercalloy 367	Silafont 36
Ultimate Tensile Strength				
ksi	39-44	44-49	43-45	40-49
MPa	270-300	300-340	295-310	275-340
Yield Strength				
ksi	22-28	28-35	25-30	23-36
MPa	150-190	190-240	170-205	155-245
Elongation				
% in 2 in (51 mm)	6.5-9	4-6.5	5.0-9.0	4-9

Table 5.5 Mechanical properties of high vacuum die castings heat treated to the T6-temper

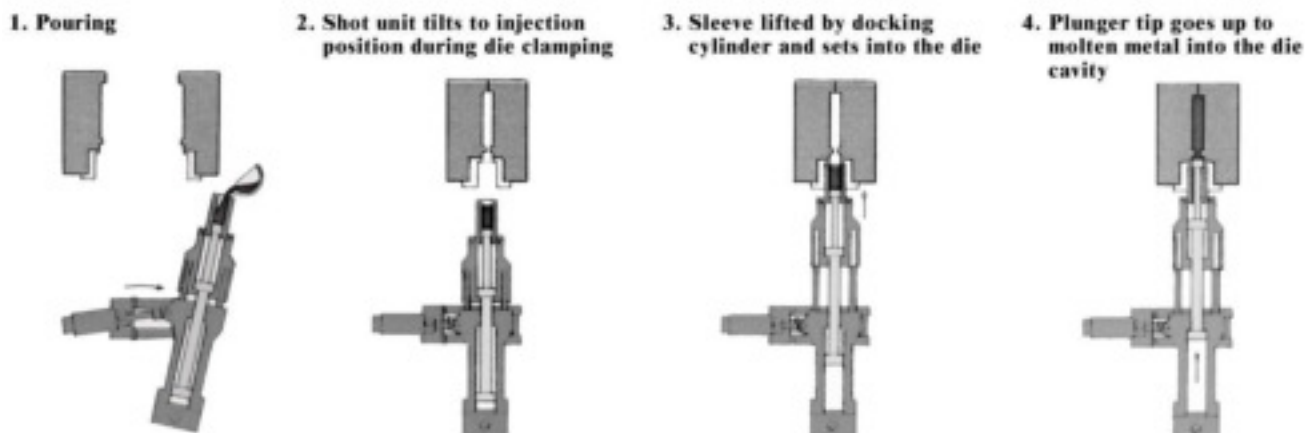
Property	Aural™-2	Aural™-3	Mercalloy 367	Mercalloy 368	Silafont 36
Heat Treatment	Auraltherm-2	Auraltherm-3	T6	T6	T6
Ultimate Tensile Strength					
ksi	29-32	31-41	41-45	41-43	42-49
MPa	200-220	210-280	285-310	280-295	290-340
Yield Strength					
ksi	17-20	20-32	33-35	27-29	30-41
MPa	120-140	140-220	230-245	185-200	210-280
Elongation					
% in 2 in (51 mm)	14-18	6-14	8-10	14-16	7-12

5.2 Squeeze Casting

Squeeze casting is a term used to refer to a process in which a liquid aluminum alloy is injected into the die at very slow speed to minimize turbulence and gas entrapment, and subsequently held at high pressure throughout the freezing cycle to yield high quality heat treatable components. The majority of commercially produced squeeze castings are produced on machines with a vertical (upwards) injection system, and the parting line of the dies can be orientated either horizontally or vertically. Figure 5.6 shows one variation of the squeeze casting process.

Squeeze casting machines and tools are designed to introduce clean molten metal into the tool in a precise, repeatable, controlled manner, filling the cavity relatively slowly (typically in 1-3 seconds) to minimize turbulence. Once the cavity is filled, high intensification pressures of around 15,000 psi (~100 MPa) are used to push more liquid metal into the cavity through large runners and gates, so that shrinkage porosity can be essentially eliminated. As the castings are filled so slowly, components produced by squeeze casting are normally thicker walled (minimum of 0.12-0.20 inches/3-5 mm) so that the liquid aluminum doesn't solidify before the casting is fully filled.

Figure 5.6 Schematic of the squeeze casting process



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 castings can be made from the full range of heat treatable (and non-heat treatable) alloys utilized in the permanent mold processes. As the cavities are filled slowly, squeeze casting alloys 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 ductility. The most commonly produced squeeze castings are from the primary alloy A356 (Al-7.0%Si-0.3%Mg) or the secondary alloy A380 (Al-8.5%Si-3.0%Cu-3.0%Zn-0.3%Mg). Squeeze castings are normally used in the fully heat treated T6 temper. Mechanical properties of alloy A356 after squeeze casting are listed below in Table 5.7.

Table 5.7 Mechanical properties of squeeze casting ally A356 after T6 heat treating

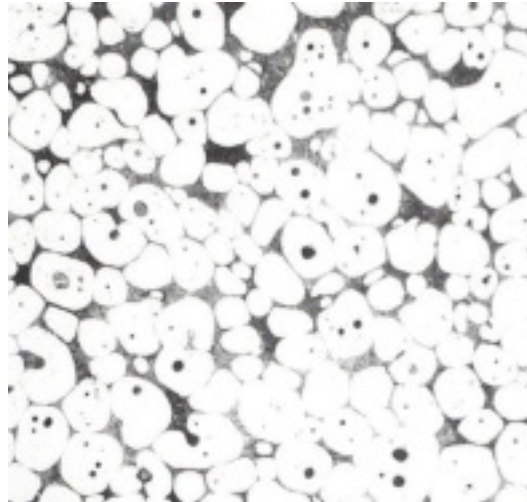
Property	A356
Ultimate Tensile Strength	
ksi	44
MPa	305
Yield Strength	
ksi	33
MPa	228
Elongation	
% in 2 in (51 mm)	12
Hardness	
BH	90

5.3 Semi-solid

Semi-solid metal (SSM) casting differs from all other casting processes as, rather than using a fully liquid feed material, semi-solid casting uses a feed material that is partially solid and partially liquid. However, similar to conventional die 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 5.8. At the casting temperature, the primary particles (the white-colored phase) must be spherical or globular in shape, and surrounded by liquid (the dark phase). 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.

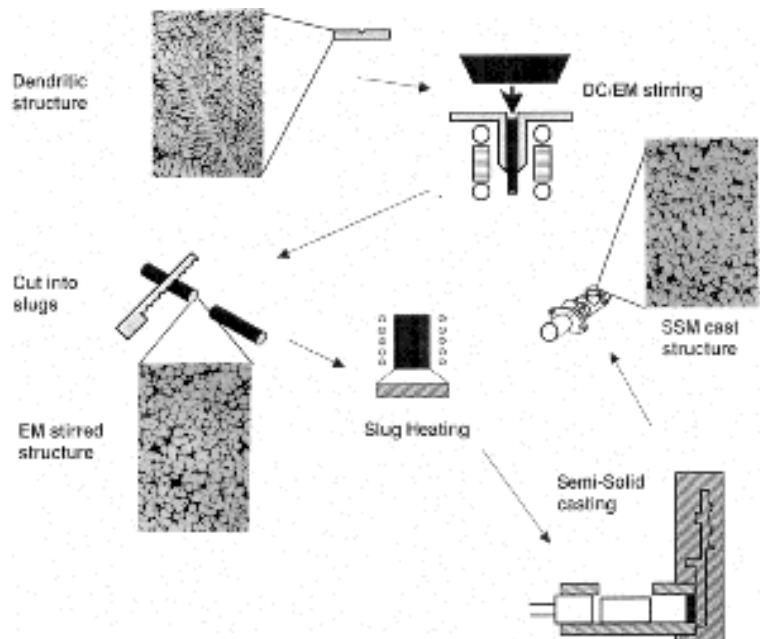
Figure 5.8: Globular microstructure required for semi-solid processing



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.

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

Figure 5.9 Schematic representation of the thixocasting process

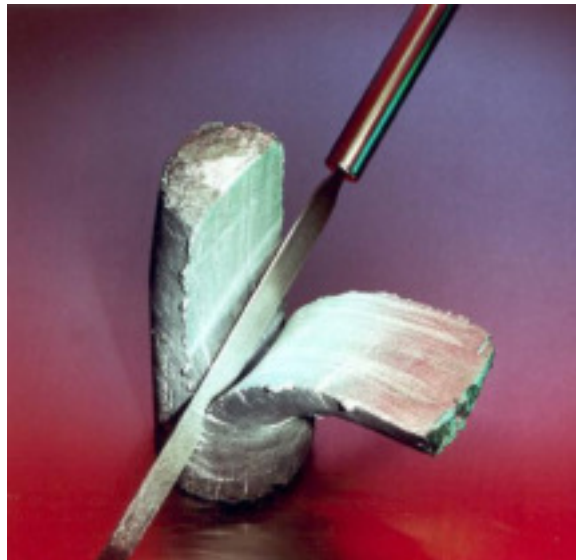


Thixoforming

The thixoforming process, which is shown schematically in Figure 5.9, 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.

The feedstock for the thixoforming process is typically produced on a direct chill 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. Slugs are then cut from the bars, and reheated to the semi-solid casting temperature using induction heating. Figure 5.10 shows the consistency of a re-heated thixocasting slug, which usually has a solid content of 40-50% (50-60% liquid). For alloy aluminum 357 (Al-7.0%Si-0.5%Mg) this corresponds to a temperature of about 580°C (1,076°F).

Figure 5.10 Consistency of alloy 357 slugs 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. Cycle rates 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. In addition, 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.

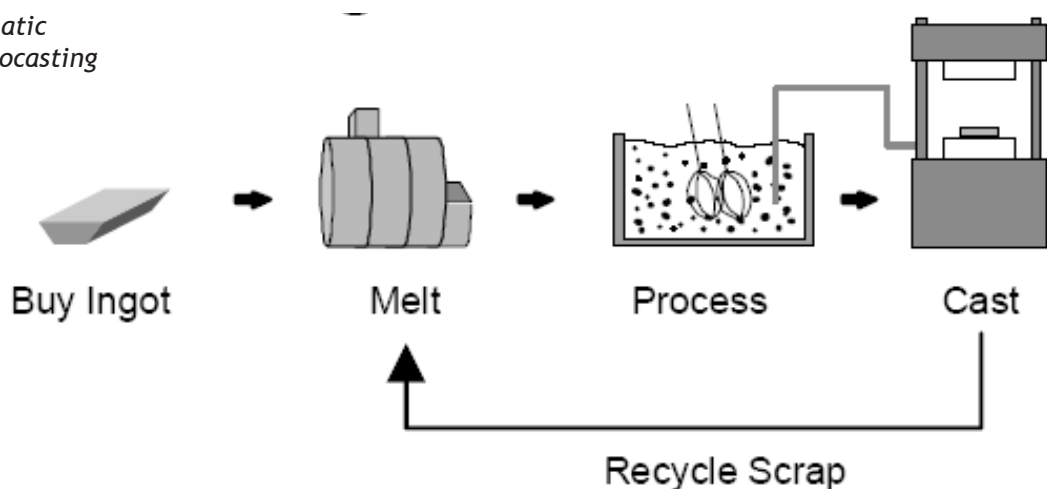
Although thixocast parts can be produced from a range of alloys, most of the commercial castings are being produced from heat-treatable aluminum foundry alloys such as A356, 357 and a high strength version of 319 (called 319S).

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 employed to make forging or rolling stock. Thixoforming billets have billet-to-billet and lot-to-lot chemistry, cleanliness and microstructural repeatability comparable to forging and rolling stock. Thus semi-solid components produced by the billet approach tend to have very consistent properties. The main disadvantage associated with thixocasting is its higher manufacturing cost, which arises from the premium attached to the price of the feedstock, as well as the inability to easily recycle biscuits and runners in-house.

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 5.11. 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.

Figure 5.11 Schematic drawing of the rheocasting process



Rheocasting first entered commercial production in the late 1990's. Today there are a number of different rheocasting processes in commercial production around the world. 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 5.11). However, especially when compared to thixocasting, much greater care must be taken by the caster 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 using a feed material close to 50% solid and 50% liquid. 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).

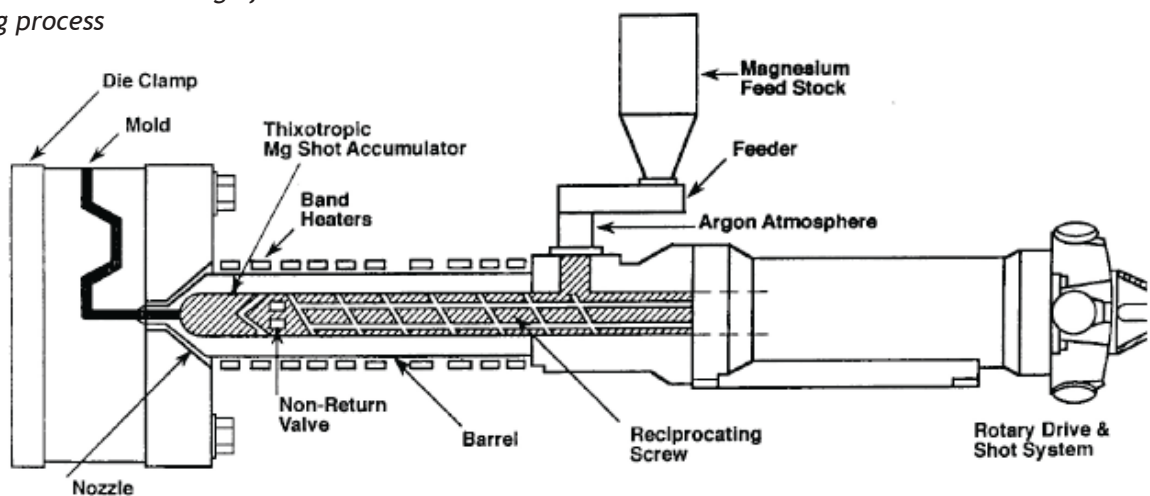
Aluminum alloys used for rheocasting include not only the foundry-type alloys (A356, 357, high strength 319S), but also alloys used more typically for die casting such as 380 and 383.

Thixomolding

Thixomolding, which 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 5.12. 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. Once the appropriate amount of slurry has been produced, 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.

Figure 5.12 Schematic drawing of the thixomolding process



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, change-over 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 magnesium 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 AZ91D, AM50 and AM60, and most thixomolded components are used in the as-cast F-temper.

Mechanical Properties - Aluminum Alloys

Aluminum semi-solid castings are used in either the T5 or T6 temper. Typical mechanical properties are listed in Table 5.13 (T5 temper) and Table 5.14 (T6 temper).

Table 5.13 Mechanical properties of aluminum alloy semi-solid castings heat treated to the T5 temper		
Property	A356	357
Ultimate Tensile Strength		
ksi	36	41
MPa	250	285
Yield Strength		
ksi	26	29
MPa	180	200
Elongation		
% in 2 in (51 mm)	10	8
Hardness		
(HB)	89	90
Fatigue Strength		
ksi	13.5	--
MPa	95	

Table 5.14 Mechanical properties of aluminum alloy semi-solid castings heat treated to the T6 temper

Property	A356	357	319s
Ultimate Tensile Strength			
ksi	44	50	58
MPa	305	345	400
Yield Strength			
ksi	33	41	46
MPa	230	285	315
Elongation			
% in 2 in (51 mm)	12	9	5
Hardness			
HB	--	--	119

Mechanical Properties - Magnesium Alloys

Magnesium semi-solid castings are normally used in the as-cast F-temper. Typical mechanical properties are listed in Table 5.15.

Table 5.15 Mechanical properties of magnesium alloy semi-solid castings in the as-cast condition

Property	AZ91D	AM-50	AM-60
Ultimate Tensile Strength			
ksi	34	32	32
MPa	235	220	220
Yield Strength			
ksi	23	18	19
MPa	160	125	130
Elongation			
(%)	3-6	6-13	6-9
Hardness			
HB	63	--	65
Fatigue Strength			
ksi	14	--	10-13
MPa	95		70-90

References

1. Zach Brown & Phil Burton, "High Integrity Die Cast Aluminum Body Components", 2007 SAE World Congress, Paper 2007-01-0460
2. David V. Neff, "Evaluating Molten Metal Cleanliness for Producing High Integrity Aluminum Die Castings", Die Casting Engineer, Sept. 2004, page 24

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.

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.

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.

Anodizing

To subject a metal to electrolytic action as the anode of a cell in order to coat with a protective or decorative film.

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."

ASTM

American Society for Testing and Materials.

Glossary

Atmospheric corrosion

Surface corrosion caused by exposure in the environment to gasses or liquids that attack the metal.

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.

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.

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.

Bright finish

A finish with a uniform nondirectional smooth surface of high specular reflectance.

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.

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.

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.

Glossary

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.

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.

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.

Chromate

A conversion coating consisting of trivalent and hexavalent chromium compounds.

Chromium plate

A coating of electrodeposited chromium metal which affords superior resistance to tarnishing and abrasion.

Glossary

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 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.

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.

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.

Glossary

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.

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.

Corrosion

Degradation of a metal by chemical or electrochemical reaction with its environment.

Cover; cover die

The stationary half of a die casting die.

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.

Damping

Ability of material to dampen vibration in components and thus lower noise levels.

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.

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.

Glossary

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**.

Dendrite

A crystal that has a tree-like branching pattern most evident in cast metals slowly cooled through the solidification range.

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.

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 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.

Glossary

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, family

A multi-cavity die that contains cavities of different shapes.

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.

Die, unit

A die into which a number of standard size blocks are fitted to provide for quick change-over between parts. Each die block contains one or more cavities.

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.

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.

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.

Dross

Metal oxides in or on the surface of molten metal.

Eject

To push the solidified casting out of the cavity of the die casting die.

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.

Ejector; ejector die

The movable half of a die casting die containing the ejector pins.

Glossary

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.

Elongation

Amount of permanent extension in the vicinity of the fracture in a tensile test, usually expressed as a percentage of original gage length.

Entrained air

Air or other gases that are mixed with the flowing molten metal as the die cavity is filling.

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.

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.

Fillet

Curved juncture of two surfaces; e.g., walls that would otherwise meet at a sharp corner.

Fin

See Flash.

Glossary

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.

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.

Fluidity

Having fluidlike properties. In die casting: the distance the molten metal will travel through a channel before it freezes, at a given temperature.

Form

The shape of a die casting.

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.

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.

Glossary

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.

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.

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.

Growth

(1) Volumetric increase of a casting as a result of aging, intergranular corrosion or both. (2) Growth is the opposite of shrinkage.

Glossary

Hard anodizing

A variation of the sulfuric acid anodizing process using lower temperatures and higher voltages.

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.

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.

Heat treatment, Auraltherm

A modified T6 heat treatment, used mainly with high vacuum die casting, which involves a partial solution heat treatment at a slightly lower temperature, followed by rapid air cooling (instead of water quenching).

Heat treatment, T5

This heat treatment process avoids the solution heat treatment used with T6 heat treating. It involves immediately water quenching the castings upon ejection from the casting die, and then aging at a temperature between 150 and 200°C (300 and 390°F).

Heat treatment, T6

The process where die castings are fully heat treated, to maximize either strength or ductility. This normally involves heating the castings close to their melting temperature for a pre-determined time (the solution heat treatment) and immediately water quenching. The castings are then aged at a lower temperature.

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.

Glossary

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.

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.

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.)

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 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.

Glossary

Metal saver

A core used primarily to reduce the amount of metal in the casting and to avoid sections with excessive thickness.

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.

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 Specification Standards for High Integrity Die Casting Process

Products standards for the high integrity die casting processes of high vacuum die casting, squeeze casting and semi-solid metal casting.

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.

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.

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.

Glossary

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.

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.

Platen

Portion of a casting machine against which die sections are fastened, or of trim presses against which trim dies are fastened.

Plunger

Combination of tip and rod that forces metal into the die.

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.

Pouring hole/slot

Port through which molten metal is ladled into the cold-chamber of a die casting machine.

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.

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.

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**.

Glossary

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.

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.

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.

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.

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.

Semi-Solid Metal Casting

A modified die casting process that uses a feed material that is partially solid and partially liquid.

Shot

Die filling or part of the casting cycle in which molten metal is forced into the die.

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.

Glossary

Shrinkage, solidification

Volume reduction that accompanies the freezing (solidification) of metal in passing from the molten to the solid state.

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.

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.

Squeeze casting

A modified die casting process in which a liquid aluminum alloy is injected into a die at very slow speed to minimize turbulence and gas entrapment, and subsequently held at high pressure throughout the freezing cycle to yield high quality heat treatable components.

SSM

Semi-solid metal casting

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.

Glossary

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.

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-pond to the thermally induced force.

Thixocasting

A semi-solid metal casting process, used mainly for aluminum alloys, where slugs that are prepared by MHD casting are re-heated to semi-solid casting temperature.

Thixomolding

A semi-solid process, used exclusively for magnesium alloys, using a specially designed machine similar to a plastic injection molder.

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.

Vacuum, high vacuum die casting

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 100 milli-bars or less.

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**.

Yield

See **Casting yield**.

Glossary

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.



NORTH AMERICAN DIE CASTING ASSOCIATION

3250 N. Arlington Heights Rd., Ste. 101
Arlington Heights, IL 60004
P: 847.279.0001 • F: 847.279.0002
www.diecasting.org