INTERZINC

ZINC CASTING

A SYSTEMS APPROACH

INTERZINC greatly appreciates the contributions of time and effort donated by the following people and companies towards the creation and production of this manual:

- John Grach, Doug Gross: Cominco Ltd.
- Derek Cocks: Eastern Alloys Inc.
- Tom Lewinson: Noranda Sales Corp.
- Dale Nevison: Zinc Information Centre Ltd.

TABLE OF CONTENTS

Components involving zinc die castings have been benefiting people for over 50 years. Their broad range of excellent mechanical and physical properties, easy castability, and broad range of available finishes have established zinc as the fourth most commonly used metal in the world.

Today, designers can also benefit from the added performance of a whole new family of high performance zinc alloys, the "ZA" alloys. These alloys complement the traditional "Zamak" alloys and further expand the already wide range of applications in which zinc has been successfully used.

Selection of Manufacturing Process

Decisions about whether a part should be cast, forged, stamped, fabricated, or produced in some other manner usually depends on the characteristics of the preferred process, such as tolerance range, production rate, repeatability, tooling cost, and final component cost. Many factors also enter into materials selection, including mechanical and physical properties, required finish, ease and speed of production, availability and cost.

Advantages of Die Casting as a Process

Of all metal-fabrication methods, die casting represents the shortest distance from molten metal to finished part. For sound economic and functional reasons, die casting outranks stamping, sand casting, forging, and screw-machine production in many applications. See Table 1 for complete process comparison.

Advantages of Zinc Die Castings

Just as die casting offers advantages over other manufacturing processes, zinc provides advantages over other die casting alloys. Die castings in zinc alloys are stronger, tougher, and more ductile than die castings in aluminum or magnesium. Zinc alloys can be die cast larger, smaller, and with greater complexity. They can be cast smoother, easier, more accurately, and at lower cost. Zinc die castings can be readily painted and more easily plated than any aluminum or magnesium alloy. The melting point of zinc alloys is lower, saving on fuel cost and prolonging die life.

The major advantages of zinc compared to aluminum and magnesium die casting alloys are:

- lowest cost in suitable applications
- closest tolerances
- fastest production cycle times
- thinnest wall sections
- highest tensile strength
- highest impact strength
- most malleable
- easiest finishing

Selection of Die Casting Alloy

The decision to manufacture a component as a zinc die casting depends on a number of factors; total component cost is usually the most important. Cost advantage, combined with production or functional advantages, usually determines the material of construction and how a part will be made.

Zinc's Second Life

As discussed, zinc alloys offer a unique range of engineering properties making them suitable for a variety of applications. However, zinc alloys also have a few additional properties which are beneficial to all.

Zinc die casting alloys are completely recyclable and are currently being recycled. In fact, about 30 percent of the zinc consumed annually comes from recycled zinc. Zinc castings are usually recycled as zinc oxide, or used for the production of brass.

Additionally, zinc is essential to both our physical and mental health. The U.S. Food and Drug Administration has established a recommended daily allowance of 15 mg for zinc.

Zinc is a truly environmentally friendly engineering material.

TABLE 1
Die Casting versus Alternate Processes

DIE CASTING	FORGING
1. Die casting can produce shapes not forgeable.	1. Forgings are usually denser and stronger than die castings.
2. Parts can be more complex.	2. May be produced in ferrous metals and alloys not die castable.
3. Closer tolerances can be achieved.	3. Larger and heavier parts can be forged.
4. Thinner walls can be cast.	
5. Allows coring not feasible in forging.	
6. Eliminates some secondary machining operations	

DIE CASTING	SCREW-MACHINING
1. Die casting can produce parts of almost any shape.	1. Tooling is simple.
	2. Set-up time is short.
	3. Production may be very fast.
	4. Alloys not die castable may be used.

NOTE: Screw-machine products have severe limitations since they must be symmetrical along a longitudinal axis. Scrap losses are high in screw-machine production, except in simple, regularly shaped parts

TABLE 1
(continued)

DIE CASTING	STAMPING
1. Die casting can produce shapes not producible as stampings.	1. Can be made in steel and other alloys not die castable.
2. More complex forms can be produced.	2. Production of some simple shapes is faster.
3. Less material is wasted as scrap.	3. Parts may weigh less than die castings.
4. Permits much greater variation in section thickness.	
5. Fewer component parts in an assembly.	
6. Reduced assembly operations.	
7. Tooling and die costs are often less.	

DIE CASTING	SAND CASTING
1. Die castings may be produced much faster than sand castings.	1. More economical for small production runs.
2. Labor cost is substantially less.	2. Can produce shapes not feasible for die casting.
3. Fewer secondary operations are needed.	3. May be larger.
4. Dies will produce hundreds of thousands, even millions of parts without replacement.	4. May employ alloys not die castable.
5. Thinner walls can be cast.	5. Initial tooling cost is less.
6. Much closer tolerances can be held.	
7. Smoother as-cast surfaces are achieved.	
8. Inserts more readily incorporated.	
9. Considerable materials savings.	

DIE CASTING	PERMANENT MOLD CASTING
1. Die casting may be much faster than permanent mold castings.	1. Tooling costs are lower since they are made in fewer and simpler shapes.
2. Labor cost is less.	2. Castings can be made in alloys not die castable.
3. Cost per finished part is often less.	
4. Closer tolerances can be held.	
5. Thinner sections can be cast.	
6. Smoother as-cast surfaces are provided.	
7. Cored holes are more readily provided.	
8. Considerable materials savings.	

DIE CASTING	PLASTIC MOLDING
1. Faster production rates.	1. Products do not require finishing operations.
2. Better high/low temperature performance.	2. Products may not require an applied finish.
3. *Stronger in tension and compression.*	3. May be obtained in transparent, translucent, and opaque forms in any color.
4. Higher impact strength and hardness.	4. Much lighter than metal.
5. More dimensionally stable.	5. Excellent dielectric properties.
6. Closer tolerances can be held.	6. Low thermal conductivity.
7. Much greater thin-wall strength.	7. Certain plastics may be electroplated, although they must be free from molding stresses. (Plated scrap cannot be recovered for use in quality moldings.)
8. Superior heat and electrical conductivity.	
9. Readily finished by electroplating or organic finishes.	

Zinc Casting Alloys: Specifications and Processing

This section reviews traditional and newer zinc-based casting alloys used in functional and decorative applications. It describes compositions and standard alloy specifications and offers recommendations for casting process selection and prototyping of applications.

COMPOSITIONS

Of the many zinc casting alloys available in North America, some have only very specialized applications and will not be discussed here (i.e., slush castings, forming dies, and sacrificial anodes). Alloys of main interest for functional castings are shown in Table 1. Aluminum is the major alloying element in each of these alloys. Adding aluminum to zinc increases castability and results in finer grain-size castings and improved mechanical properties.

Zinc alloys fall into two groups. The first group includes the traditional alloys, Nos. 2, 3, 5, and 7. These alloys, often referred to as Zamak alloys in North America, were originally developed in the 1930s. All contain nominally 4 percent aluminum and a small amount of magnesium. (Magnesium is added to improve strength and hardness and to protect castings from intergranular corrosion.)

Alloys 2 and 5 also contain copper, which further strengthens and improves wear resistance of castings but at the expense of stability (dimensional and property), especially when copper content exceeds 1 percent.

The No. 7 alloy is a special high-purity alloy, which some casters have found to be useful for die castings requiring optimum surface finish (i.e., decorative applications). The high purity and small nickel addition permit the magnesium content to be lowered for maximized fluidity and ductility.

This group of zinc alloys are predominantly pressure die-cast with No. 3 being the most widely used alloy in North America. It offers the best combination of mechanical properties, castability, and economics. Other alloys, being slightly more expensive, are used only where their specific properties are required.

The second group consists of the relatively new, high-aluminum or ZA® alloys: ZA-8, ZA-12, and ZA-27. These alloys contain substantially more aluminum than the first group, with the number representing the alloy's approximate percentage of aluminum content. Each also contains copper and magnesium to optimize castability and mechanical properties.

TABLE 1
Nominal Composition of Zinc Casting Alloys (wt.%)

Alloy (ASTM) Designation

Element	**No. 2 (-)**	**No. 3 (Z33521)**	**No. 5 (Z35530)**	**No. 7 (Z33522)**	**ZA-8 (Z25630)**	**ZA-12 (Z35630)**	**ZA-27 (Z35840)**
Aluminum	4	4	4	4	8.4	11	27
Magnesium	0.035	0.035	0.055	0.013	0.023	0.023	0.015
Copper	3	–	1	–	1.0	0.88	2.25
Nickel	–	–	–	0.013	–	–	–
	Hot Chamber Pressure Die Casting				Hot Chamber	Cold Chamber	
					Gravity Casting		

Development of ZA alloys began during the 1960s under the direction of the International Lead Zinc Research Organization (ILZRO). Research was conducted to expand the range of zinc casting alloys. This work resulted in the introduction of the ZA-12 alloy, which exhibited good gravity-casting properties. ZA-8 and ZA-27 were subsequently developed in the late 1970s to meet specific needs identified during the marketing of ZA-12; ZA-8 was designed for improved metal permanent-mold castability and ZA-27 for maximum strength and elongation.

SPECIFICATIONS

The physical and mechanical properties of ZA alloy castings are greatly affected by the presence of small amounts of specific metal impurities (i.e., lead, tin, and cadmium). Zinc casting alloys contaminated by these metals will result in severe intergranular corrosion when exposed to hot, humid environments. Figure 1 shows the severity of intergranular corrosion that can occur when a zinc alloy casting is contaminated with lead.

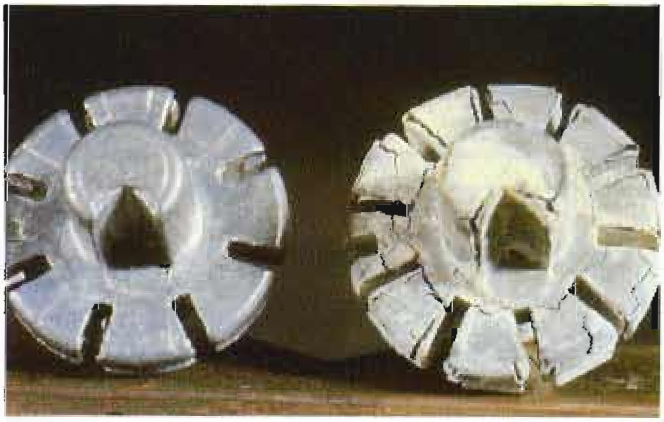


FIGURE 1
Zinc alloy castings exposed in a hot, humid environment.
Left - Casting meets recognized specification for alloy chemistry
Right – Casting contaminated with lead.

The rapid growth of the zinc-casting industry was made possible by the development of strict alloy specifications based on high purity (99.99%) zinc ensuring stable, corrosion-resistant castings.

Reference to a recognized specification should always be included when specifying or ordering zinc alloy castings to ensure the appropriate chemical quality.

Today, nationally and internationally recognized standards determine the chemistry of zinc casting alloys. Table 2 shows the specifying body and specifications for the Nos. 3 and 5 alloys in several industrialized countries. In North America, ASTM specifications for both Zamak and ZA alloys are used. The SAE designations for the Nos. 3 and 5 alloys are SAE 903 and 925, respectively, with their chemical compositions being the same as ASTM.

TABLE 2
Zinc Die Casting Alloy Specifications

Country	Specifying Organization	Specifications	
		Ingots	Castings
Australia	SAA	AS 1881	
Canada	CSA	HZ.3	HZ.11
Germany	DIN	DIN 1743	
Japan	JIS	H2201	H5301
United Kingdom	BSI	BS 1004	
United States	ASTM	B240	B86

As Table 2 shows, zinc alloys generally have two types of specifications, one to cover the alloy ingot and one to cover the castings. Table 3 presents the ASTM chemical requirements for Nos. 3 and 5, comparing alloy ingots with die castings. Ingot specifications have tighter ranges for alloying additions and lower impurity limits. This allows for some loss of alloying elements and minor pick-up of impurities during casting operations.

The chemical requirements for zinc alloy ingots, as specified in ASTM B669, are shown in Table 4. Table 5 shows the chemical composition for ZA alloy castings as specified in ASTM B791. As for all zinc

TABLE 3
Chemical Requirements for No. 3 and No. 5 Die Casting Alloys as per ASTM

Element	Composition (wt.%)			
	Alloy Ingot (B240)		Die Castings (B86)	
	No. 3	No. 5	No. 3	No. 5
Aluminum	3.9 – 4.3	3.9 – 4.3	3.5 – 4.3	3.5 – 4.3
Magnesium	0.025 – 0.05	0.03 – 0.06	0.020 – 0.05	0.03 – 0.08
Copper	0.10 max.	0.75 – 1.25	0.25 max.	0.75 – 1.25
Iron (max.)	0.075	0.075	0.100	0.100
Lead (max.)	0.004	0.004	0.005	0.005
Cadmium (max.)	0.003	0.003	0.004	0.004
Tin (max.)	0.002	0.002	0.003	0.003
Zinc (99.99)	remainder	remainder	remainder	remainder

TABLE 4
ASTM (B669) Chemical Requirements for ZA Alloys Ingots

Element	Composition (wt.%)		
	ZA-8	ZA-12	ZA-27
Aluminum	8.2 – 8.8	10.8 – 11.5	25.5 – 28.0
Copper	0.8 – 1.3	0.5 – 1.2	2.0 – 2.5
Magnesium	0.020 – 0.030	0.020 – 0.030	0.012 – 0.020
Iron (max.)	0.065	0.065	0.072
Lead (max.)	0.005	0.005	0.005
Cadmium (max.)	0.005	0.005	0.005
Tin (max.)	0.002	0.002	0.002
Zinc (99.99)	remainder	remainder	remainder

TABLE 5
ASTM (B791) Chemical Requirements for ZA Alloys Castings

Element	Composition (wt.%)		
	ZA-8	ZA-12	ZA-27
Aluminum	8.0 – 8.8	10.5 – 11.5	25.0 – 28.0
Copper	0.8 – 1.3	0.5 – 1.2	2.0 – 2.5
Magnesium	0.015 – 0.030	0.015 – 0.030	0.010 – 0.020
Iron (max.)	0.075	0.075	0.075
Lead (max.)	0.006	0.006	0.006
Cadmium (max.)	0.006	0.006	0.006
Tin (max.)	0.003	0.003	0.003
Zinc (99.99)	remainder	remainder	remainder

Note: Casters order material to Alloy Ingot specification, i.e., ASTM B240, B669. Designers and end-users specify to castings specifications, i.e., ASTM B86, B791.

casting alloys, stringent impurity levels exist for lead, cadmium, and tin, for the reason noted previously.

CASTING PROCESSES

Zinc casting alloys enable the product engineer and designer to produce components using a wide range of casting processes, and to supply quantities from one up to millions per year. In fact, zinc alloys surpass all other ferrous and nonferrous alloys in casting-process flexibility.

Table 6 provides a general overview of the more common processes used to cast zinc alloys. Die casting, permanent-mold casting, graphite permanent-mold casting, sand casting, and shell-mold casting are used for commercial component manufacturing, while plaster-mold casting is usually restricted to prototyping. Zinc casting processes not shown in the table but used to a lesser degree include investment, low-pressure permanent-mold, centrifugal, continuous, and rubber-mold casting.

A detailed discussion of process-selection guidelines is beyond the scope of this section, since they depend on a number of variables that differ for individual applications. In general, however, die

TABLE 6
Casting Process Selection Guidelines for Zinc-Aluminum Casting Alloys

Process	Advantages	Limitations	Zinc Alloys Used	Casting Size	Typical Quantity/Yr.
Pressure die casting	• very smooth surfaces • excellent dimensional accuracy • very high production rate • best near-net shape	• high initial die costs • limit to part size	Zamak & ZA	• generally less than 3 sq. ft. • fraction of an ounce to 15 lb. typical	• 20,000 to millions
Permanent-mold casting	• good surface finish • good dimensional accuracy • fast production rate • low scrap loss	• high initial mold costs • shape, size and intricacy limited	ZA normally	• up to 2' x 2' typical • one ounce to 150 lb. typical	• 5,000 to 50,000
Graphite permanent-mold casting	• low die cost compared to permanent mold • very good surface finish (close to die casting) • good dimensional accuracy	• molds are fragile • low to medium production runs	ZA	• up to 14" x 18" x 7" • one ounce to 10 lb. typical	• 500 to 30,000
Sand casting	• virtually no size, weight or shape limitations • low mold cost • most direct route from pattern to casting	• some machining always necessary • close tolerances difficult to achieve • long, thin projections not practical • relatively slow production rate	ZA	• unrestricted size and weight	• 1 to 1,000s
Shell-mold casting	• faster production rate than sand • good dimensional repeatability	• expensive pattern equipment • part size limited	ZA	• mold area limited to about 500 sq. in. • 1 ounce to 50 lb.	• 500 to 1,000s
Plaster-mold casting	• high dimensional accuracy • excellent surface finish • almost no limit to intricacy	• part size limited • long mold-making time, slow production rate • limited to prototypes and low volume requirements	Zamak & ZA	• normally up to 500 sq. in. • 1 ounce to 20 lb.	• low volume prototyping • 1 to 100

casting yields the lowest per-piece cost, followed by permanent-mold and then sand casting.

Die-cast tooling is the most expensive, but it provides intricate detail, excellent dimensional tolerances, and by far the fastest production rate. When tooling costs can be amortized over many thousands of castings, die casting will result in the lowest overall per-piece cost. Sand casting generally offers the lowest total piece price for low-volume applications.

Die Casting

The vast majority of zinc alloy castings are produced by pressure-die casting following two basic processes, hot chamber and cold chamber. The hot chamber process (Figure 2) employs a metal pump, called a gooseneck, which is immersed in a molten bath. Metal is pumped from the gooseneck through a nozzle and into the die. After solidification, the die opens, ejecting the finished part.

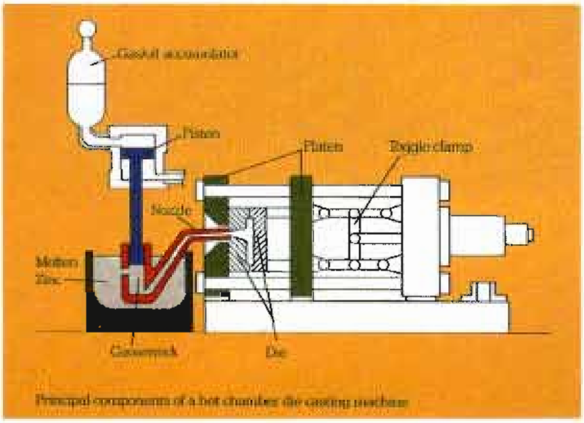


FIGURE 2
Hot-chamber die casting machine.

Hot chamber die casting is used mainly with the Zamak alloys and ZA-8. It produces castings with intricate detail and excellent surface finishes at high production rates (Figure 3). For larger components, 200-500 shots per hour are typical, while for smaller components, 400-1000 shots per hour are common.

FIGURE 3
Hot-chamber die cast No. 3 security lock components.

Extremely small castings (i.e., up to a few ounces) are produced on special hot-chamber machines with very high cycle times (2000-3000 shots per hour). The machines are capable of producing flash-free, zero-draft, very close tolerance castings that require no secondary trimming or machining operations. The components shown in Figure 4 are examples of castings produced with these machines.

FIGURE 4
Miniature zinc castings produced using special hot-chamber die casting machines.

The cold-chamber process (Figure 5) must be used where casting temperature and reactivity of molten metal with iron or steel components prohibit hot-chamber construction. It is similar to the hot-chamber process except that metal must be ladled, either manually or automatically, into a shot sleeve for each machine cycle. This ladling action results in considerably slower cycle times compared to the hot-chamber process, especially with smaller castings and machines. Typical cycle times for cold-chamber machines are 50-150 shots per hour. ZA-12 and ZA-27 are used in this process because they require higher casting temperatures than other zinc alloys. Examples of cold-chamber ZA alloy castings are shown in Figure 6.

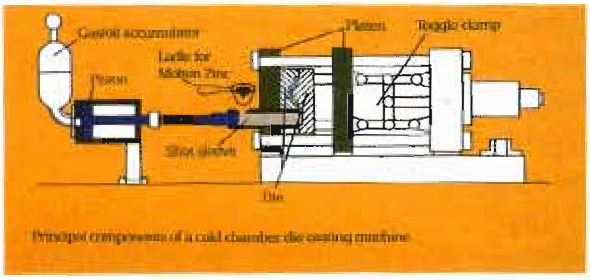


FIGURE 5
Cold-chamber die casting machine.

FIGURE 6
Cold-chamber ZA-27 die castings used in a table-top strapping machine.

Permanent-Mold Casting

Permanent-mold casting is a common near-net shape process that usually employs cast iron or steel molds. Compared to sand casting, it provides superior tolerances and surface finishes and often reduces machining costs. The lower tooling cost versus die casting permits economical production of zinc alloy castings for low- or medium-volume requirements.

All three ZA alloys can be cast using the process, with ZA-12 preferred for most applications because of its good castability and desirable mechanical properties. ZA-8 is recommended for decorative parts requiring a chrome-plated finish. Figure 7 shows examples of ZA alloy permanent-mold castings.

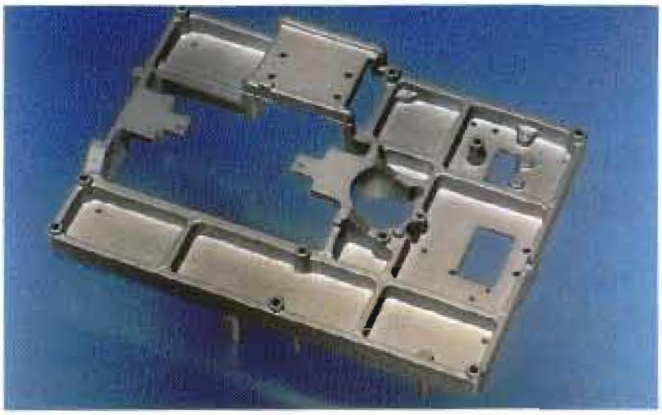


FIGURE 7
ZA-12 and graphite permanent-mold casting satisfied two important manufacturing process requirements – stiffness and minimal machining for this optical drive deck.

Graphite Permanent-Mold Casting

Graphite permanent-mold casting is a relatively new commercial casting process developed in the 1970s. It employs high-density, fine-grained graphite molds. Compared to conventional permanent-mold casting, the process offers significantly lower tool cost, better dimensional accuracy, increased productivity, and superior surface finish and tolerances.

It is an ideal process for relatively simple, medium-sized castings requiring cored holes, good dimensional tolerances, and volumes up to 20,000 pieces annually. ZA-12 is used almost exclusively in the process, with molds lasting from 20,000 to 40,000 shots, depending on complexity. Figure 8 shows examples of parts cast using this process.

FIGURE 8
Graphite permanent-mold cast ZA-12 Go-Kart components.

Sand Casting

Sand casting is the oldest and most used commercial casting process. It provides the greatest configurational flexibility and the lowest mold cost. For zinc alloy castings, sand casting is recommended only for low-volume production requirements, since medium- and high-volume requirements are better satisfied by permanent mold or pressure-die casting.

ZA-12 and ZA-27 can be readily cast using existing nonferrous melting equipment and sand systems. ZA-12 has better castability, but both alloys have excellent fluidity for producing thin-walled, fine-detail castings. Figure 9 shows examples of ZA alloy sand casting.

FIGURE 9
Sand cast ZA-12 fluid handling components for the petroleum industry.

Prototyping

The objective of prototyping is to duplicate, or at least closely approximate, the requirements of a product without incurring the expense and time required for production tooling. Prototyping ZA alloy components prior to gravity-casting presents few problems, since prototypes can be readily produced in the designated ZA alloy using sand or plaster-mold casting.[1] The following discussion is limited to prototyping zinc alloy die castings because it is more difficult to evaluate actual product performance without investing in expensive die-casting tooling.

Traditional zinc alloy (Nos. 2, 3, 5, and 7) die castings can be prototyped as a gravity casting either in the designated alloy or the ZA alloys, depending on the specific property of interest. For appearance or conceptual studies, plaster-mold castings in No. 3 alloy can be used, but their mechanical properties will be inferior to those of die castings. If tensile and yield strengths are the major factors in prototyping traditional alloy die castings, ZA-12 gravity castings can be used. However, their ductility and impact strength will be lower, and wear resistance will be much higher.

When only a few prototypes are needed, plaster casting is a good choice. For a large number of prototypes, either sand or graphite permanent-mold casting should be considered.

For example, the transmission shift-selector housing shown in Figure 10 was prototyped in a graphite mold. Several mold modifications were required during the development program before the part was approved for production as a No. 3 alloy die casting. If both the strength and ductility of a No. 3 alloy die casting are required, gravity-cast ZA-27 components heat treated at 610°F (320°C) for three hours and furnace cooled can be used.

---

[1] Detailed information contained in the book, "Designing in Zinc," published by the International Lead Zinc Research Organization, Research Triangle Park, NC.

For prototyping ZA alloy die castings, gravity casting in the appropriate ZA alloy is recommended. The properties of gravity-cast prototypes are slightly inferior to those of their pressure die-cast counterparts, but they are usually high enough to meet the end-use service requirements.

FIGURE 10
Transmission shift-selector housing prototype cast in graphite mold.

Another method of prototyping die castings is to machine prototypes from a piece of solid material. This method is especially useful when a limited number of parts with relatively simple features are required.

Semicontinuously cast Zamak or ZA alloy bar stock is an excellent material for machining prototypes. Table 7 shows that the mechanical properties of semicontinuously cast zinc alloy bar stock are similar to those of die castings produced in the same alloy. Therefore, the prototyping bar stock should be of the same alloy as that being considered for the production die castings.

One exception occurs when evaluating a No. 3 alloy die casting application and ductility is an important

TABLE 7
Cast Zinc Alloy Properties

Alloy	Tensile Strength, ksi (MPa)		Yield* Strength, ksi (MPa)		Elongation % in 2 in. (51 mm)		Hardness, Brinell (500/10/30)	
	Con-Cast	Die Cast	Con-Cast	Die Cast	Con-Cast	Die Cast	Con-Cast	Die Cast
No. 3								
As Cast	45.6 (314)	41.0 (283)	38.1 (262)	32.0 (221)	1.6	10.0	101	82
Aged**	32.2 (222)	35.0 (241)	25.0 (172)	—	3.2	1.6	76	67
No. 5								
As Cast	46.7 (322)	48.0 (331)	40.7 (281)	39.0 (269)	1.7	7.0	100	91
Aged**	36.6 (252)	39.0 (269)	31.4 (216)	—	1.8	13.0	86	80
ZA-8								
As Cast	61.0 (467)	54.5 (376)	50.7 (349)	42.0 (290)	2.2	8.0	126	103
Aged**	41.3 (285)	43.1 (297)	32.7 (225)	32.5 (224)	4.3	19.5	88	91
ZA-12								
As Cast	67.5 (467)	58.5 (403)	53.3 (367)	46.5 (321)	2.5	5.5	130	100
Aged**	45.5 (314)	45.0 (310)	35.6 (245)	35.0 (241)	11.0	10.0	93	91
ZA-27								
As Cast	76.0 (524)	61.5 (424)	58.3 (402)	53.5 (369)	5.3	2.8	138	119
Aged**	49.8 (343)	52.2 (360)	39.8 (271)	46.1 (318)	14.7	3.0	98	100

*0.2% Offset

**Aged 10 days at 203°F (95°C)

Source: Cominco Metals Product Technology Centre (Con-Cast), Various published literature (Die Cast) property. In this case, heat-treated ZA-12 bar stock should be used for the prototyping stage. Its ductility is virtually the same as that for No. 3 alloy die castings (11% versus 10% respectively).

The technique of using cast bar stock for die-cast prototyping is discussed in greater detail in a paper presented at North American Die Casting Association's (NADCA) 15th International Die Casting Congress and Exposition.[2]

SUMMARY

Zinc die castings are widely used in virtually every industry, including automobiles, machinery, building, and electronics. In North America, the No. 3 alloy is preferred for most die-cast zinc components. Development of ZA alloys with their improved properties enables zinc to be selected for more demanding die-cast applications and for parts to be gravity cast. Zinc die castings can be prototyped using several techniques depending on the specific properties of interest. The availability of these new zinc alloys and enhanced prototyping techniques presents an excellent opportunity for designers and end-users to re-evaluate zinc for their product requirements.

---

[2] "Prototypes from Con-Cast Zinc Aluminum Alloys," Paper No. G-T89-091, 15th Congress Transactions, published by North American Die Casting Association, Rosemont, IL.

Properties of Zinc Castings

A basic design principal is the consideration of all aspects of a part's requirements with respect to applied stresses, environmental and operating conditions, and economic constraints. Physical and mechanical properties as well as other material attributes such as corrosion resistance and machinability must also be considered.

Zinc alloys are very durable, have good dimensional stability, provide superior surface quality, achieve high strength in thin sections and have excellent resistance to deformation under load (Figure 1).

FIGURE 1

Zinc alloys are suitable for a wide range of component sizes. Typical components can be as small as the head of a pin, or as large as a truck axle tube

Typical Properties Profile of Zinc Casting Materials

Zinc alloys are not suited for heavy continuous stresses or high-temperature service in the broad engineering sense, but perform well under conditions of moderate continuous loading and of high short-term or impulse load. Their thermal and electrical conductivity properties are favorable for wide-ranging applications. Zinc alloys have impact values comparable with gray cast iron at room temperature and even aluminum and magnesium die casting alloys at 40° F.

At elevated temperatures, there is some decrease in tensile strength, an increase in ductility, and an increase in creep. Zinc alloys are not recommended for stressed applications over 200°F. In unstressed applications, zinc castings can normally tolerate continuous exposure to 300°F.

The differences between Zamak alloys 3 and 5 are not significant, so the lower-cost alloy 3 is used for the majority of applications in North America. Zamak 3 is characterized by good impact strength and long-term dimensional stability. Zamak 5 exhibits somewhat higher tensile strength and creep resistance than Zamak 3, but has lower impact strength at elevated temperatures.

Addressing the increased demand for high-performance castings, a new family of zinc-based engineering casting alloys has been developed. The three members in this family are generally identified industry wide as ZA-8, ZA-12, and ZA-27.

ZA-8 can be hot chamber die cast. It offers excellent machinability, is anti-sparking and has the best finishing characteristics of the ZA alloys for decorative parts.

ZA-12 is the general-purpose alloy and is typically the first choice when converting from iron, brass or aluminum. Usually cast in sand molds, it performs well in all gravity cast systems and can be cold chamber die cast (the aluminum process). The alloy has excellent pressure tightness, is anti-sparking, easily machined, and has excellent bearing and wear characteristics.

ZA-27 is the high-performance member of the family, offering the highest strength and hardness, and is generally cold chamber die cast. It has excellent machinability and the best bearing and wear properties.

Physical Properties

Melt temperature gives an indication of the useful operating temperature of the material. Zinc alloys have a substantially lower melting point than the other major casting metals (Figure 2). The zinc alloys begin to melt at about 710°F accounting for their maximum suggested operating temperature of 300°F.

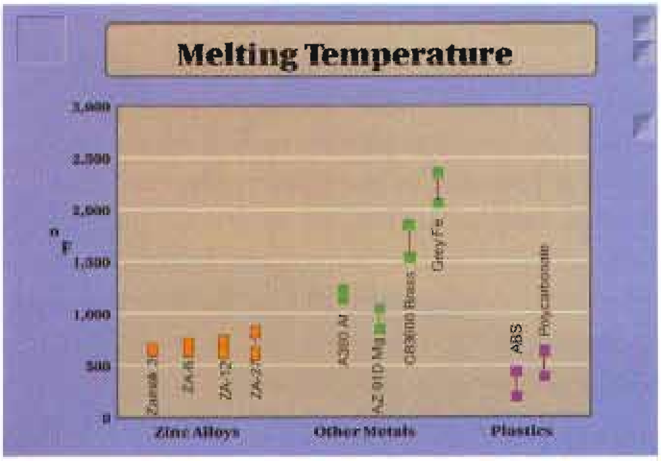


FIGURE 2

Zinc's low melting point also translates into low energy requirements (Figure 3). In fact, a pound of zinc only requires a third of the energy required to melt a pound of aluminum. More importantly, less energy means that less heat needs to be removed from the molten metal before the casting machine ejects the part. Production times for zinc alloys are much faster than for aluminum, iron, or bronze. A part can be produced in zinc up to twice as fast as in aluminum.

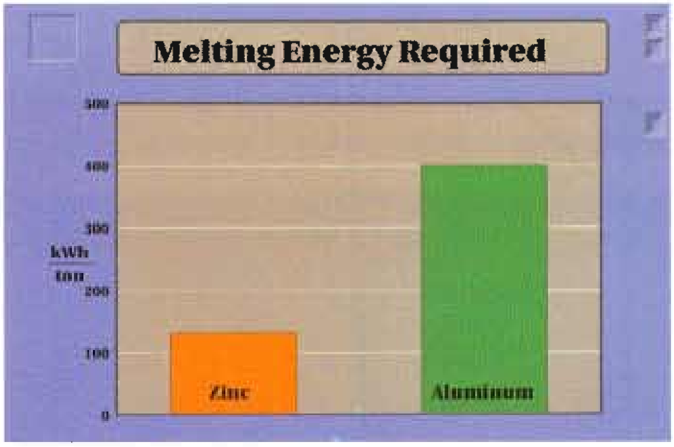


FIGURE 3

Density is becoming a very important criterion in today's "lets make it portable" society. While zinc alloys are heavier than plastics, aluminum, and magnesium, they are considerably lighter than bronze and cast irons (Figure 4). Also, zinc alloys vary in density; ZA-27 is 25% lighter than Zamak 3. However, a component's weight is not always directly proportional to its density. Aspects such as minimum wall thickness, material strength, stiffness—even EMI shielding—can play an important role in the design of the component, and thus its final weight.

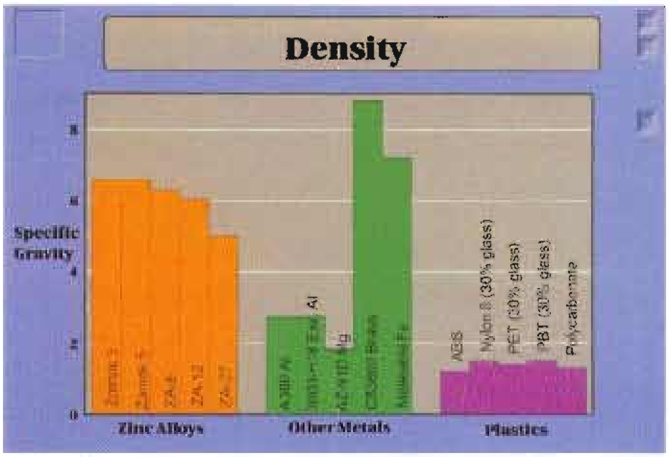


FIGURE 4

Thermal conductivity of a material is an indication of its heat-transfer capability. Since heat build-up can distort a part, this factor must be considered in design.

The very low values for polymers are negligible compared to those for the metals (Figure 5). The superiority of zinc alloys over copper and aluminum casting alloys is also immediately apparent.

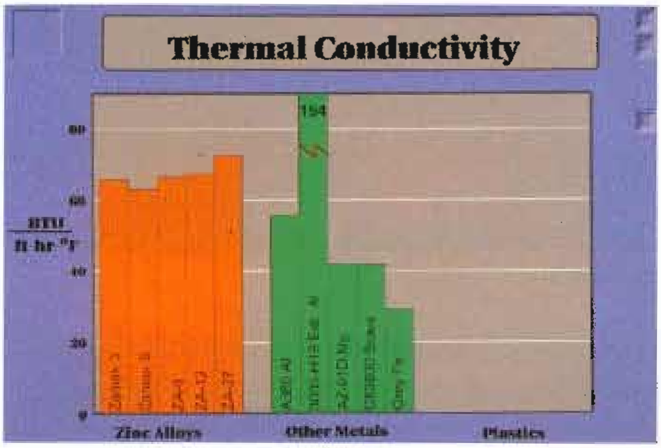


FIGURE 5

Thermal conductivity, like density, is not an independent property. An effective heat sink requires a large surface area. Zinc die casting's ability to produce extremely thin walls makes zinc superior to extruded aluminum as a heat-sink material, even though aluminum's thermal conductivity is twice as great (Figure 6).

FIGURE 6
The above illustrates a novel design for a heat sink. This 1.25" x .25" heat sink has 76 fins positioned radially.

Electrical conductivity is an indication of a material's ability to transmit an electrical charge. This property is especially important in applications that require shielding from electromagnetic interference (EMI) and prevention of electrostatic discharge (ESD) damage (Figure 7).

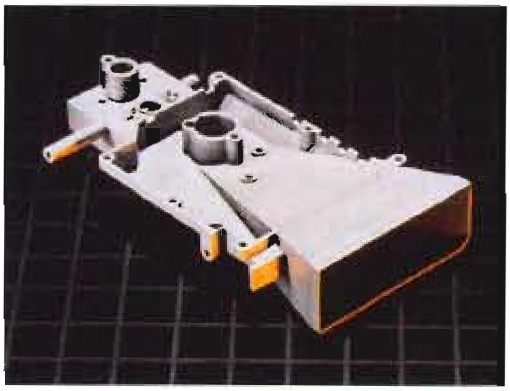


FIGURE 7
This intricate casting is a horn antenna from an automotive radar detector. EMI shielding, as well as thin walls (.018"), are mandatory for this application.

ESD occurs when a concentrated electrical charge builds up on an insulating material such as plastic. It then discharges to another body at a sufficiently different potential, in many cases great enough to damage neighboring circuits. In certain situations, ESD actually presents an explosive hazard. On the other hand, conductive materials like the zinc alloys dissipate a charge. They distribute it along their surface and bleed it off to the air and ground.

Zinc alloys are excellent conductors of electricity and are superior to aluminum and copper casting alloys and cast iron (Figure 8).

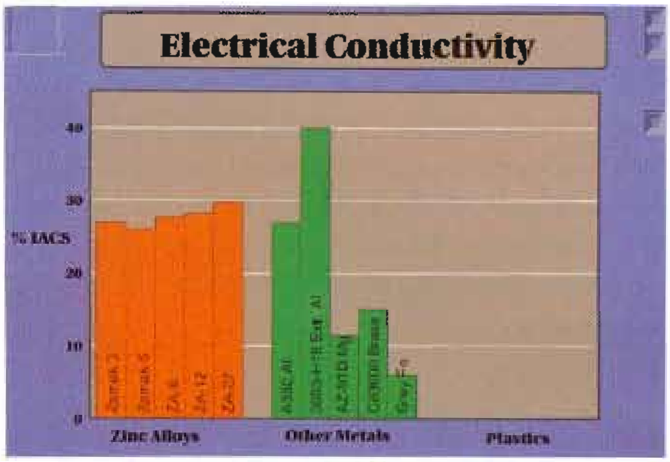


FIGURE 8

Plastics can be compounded with 30 to 40 percent-by-volume metal flakes or a lesser amount of metal fibers to improve their conductivity. Alternatively, a zinc arc spray can be used to give the plastic sufficient surface conductivity to permit EMI shielding. Both of these processes, however, introduce additional costs that can make components prohibitively expensive.

Mechanical Properties

Mechanical properties differ from physical properties in that they describe the performance of a material under load—both elastic and plastic. This aids in predicting the suitability of a material for a specific application (Figure 9).

FIGURE 9

Snap-on Tools found that the strength, rigidity, and finishing characteristics of ZA alloys fit the bill for the die cast ZA-27 air wrench.

Tensile strength is generally accepted as an indication of a material's overall strength. It is the most commonly used method for comparing materials.

The tensile strength superiority of zinc alloys is immediately apparent when compared to other casting materials (Figures 10 – 12). Zinc alloys offer a 20,000-psi range of tensile strengths meeting a range of design and engineering needs. This versatility allows analysis of application requirements and selection of the alloy that most closely matches desired specifications. ZA alloys deliver the highest strength among the most widely used nonferrous alloys and match or exceed the strength of many cast irons.

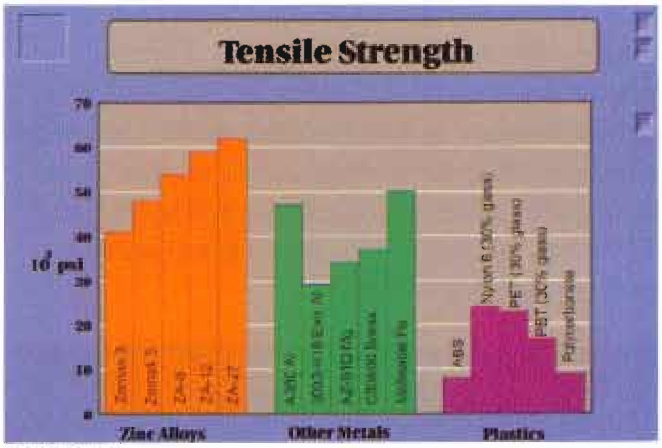


FIGURE 10

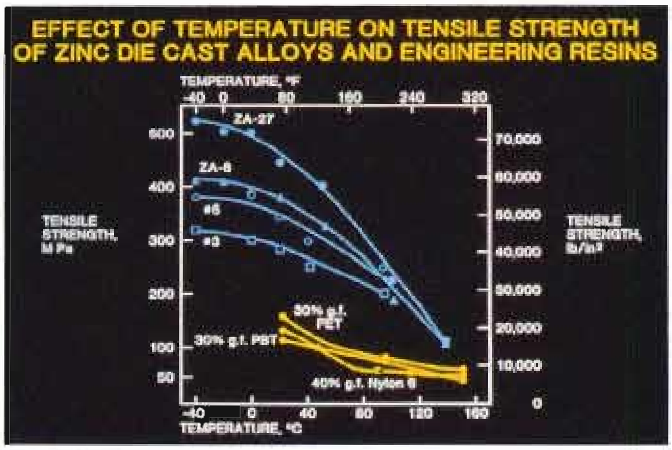


FIGURE 11

The tensile strength of zinc alloys at elevated temperatures greatly outperforms plastics.

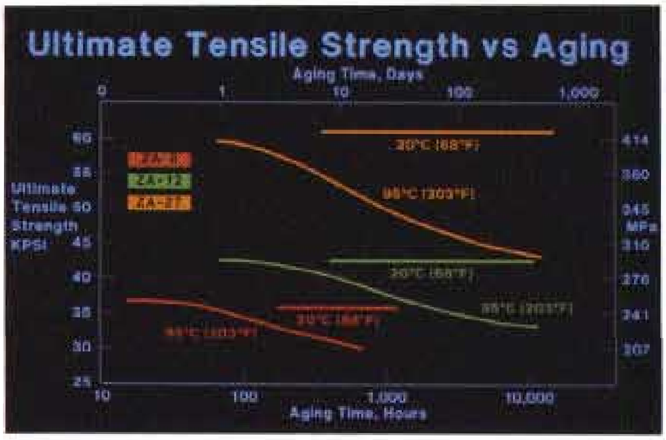


FIGURE 12

Aging at higher temperatures reduces zinc's ultimate tensile strength.

Yield strength, closely related to tensile strength, indicates the elastic limit of the material under load. It is frequently used as a design criterion.

Zinc alloys have superior ability to withstand applied stresses without plastic deformation (Figure 13). Plastics are not included in this figure since they do not have separate, distinguishable elastic and plastic regions on their stress-strain curves as most metals do. ZA alloys can have a yield strength as high as 55,000 psi, roughly twice that of most commonly used casting alloys (Figure 14).

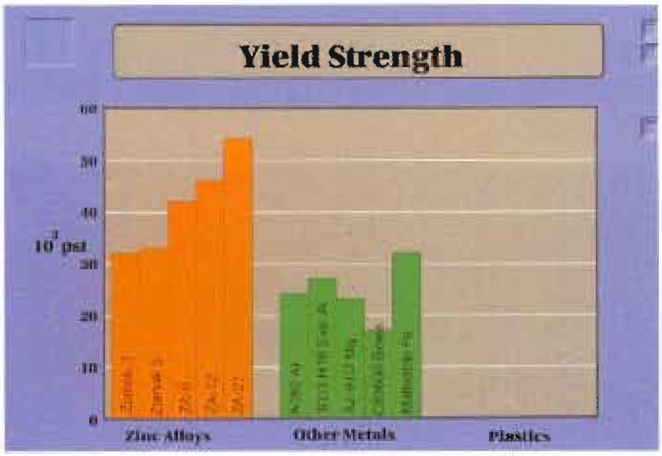


FIGURE 13

Creep of a material is a design consideration regardless of ambient operating temperature. The industry has developed a measure known as creep modulus for plastics. This is the upper design stress limit at a given temperature. It is usually based on a 1,000-hour test, which assumes a relatively constant secondary creep rate.

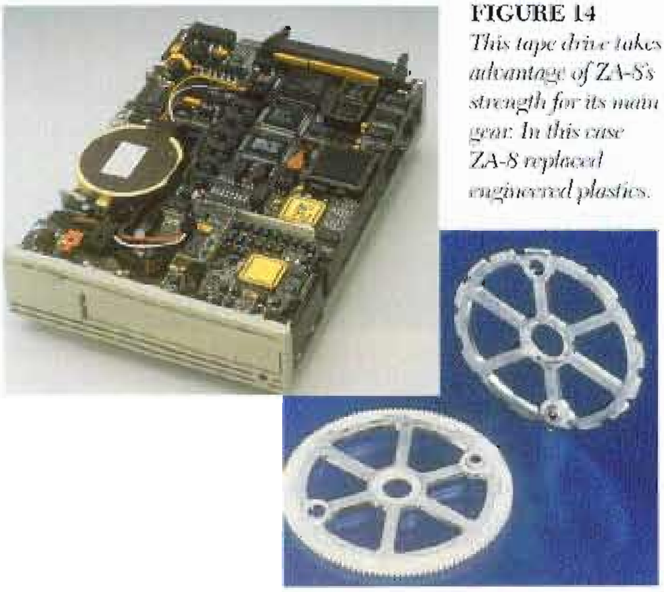


FIGURE 14
This tape drive takes advantage of ZA-8's strength for its main gear. In this case ZA-8 replaced engineered plastics.

To compare zinc alloys and plastics, the creep data for ZA-27 were converted to creep moduli at varying temperatures. The tremendous superiority of ZA-27 is illustrated at 71°F, with a value of five times the creep modules of the closest plastic (Figure 15). Zamak 3 and ZA-12 have secondary creep properties similar to ZA-27 while ZA-8 has triple the creep strength of ZA-27. Zinc alloys continue their superiority over competing plastics at 212°F (Figure 16).

Figure 17 shows additional comparative creep data for various zinc alloys and injection-molded nylon.

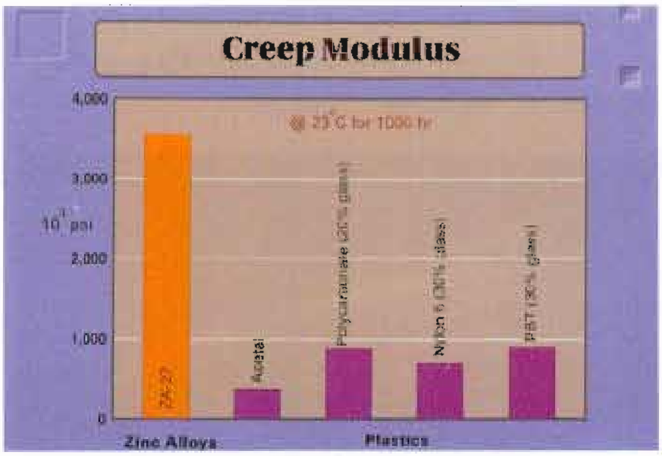


FIGURE 15

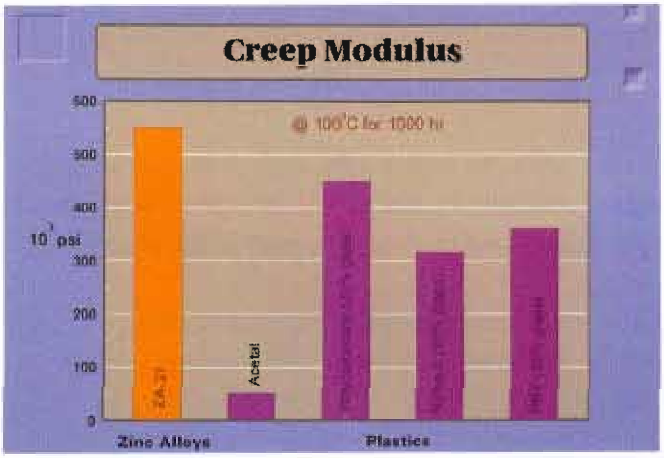


FIGURE 16

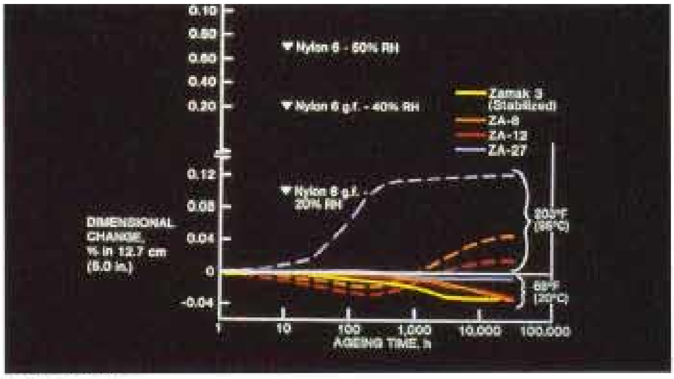


FIGURE 17

Dimensional change as a function of aging time at 20 and 95°C (68 and 203°F) for pressure die-cast ZA-8, ZA-12, ZA-27 and injection-molded nylon.

The true creep performance of Zamak 3, ZA-8, and ZA-27 are shown in Figures 18–20, respectively.

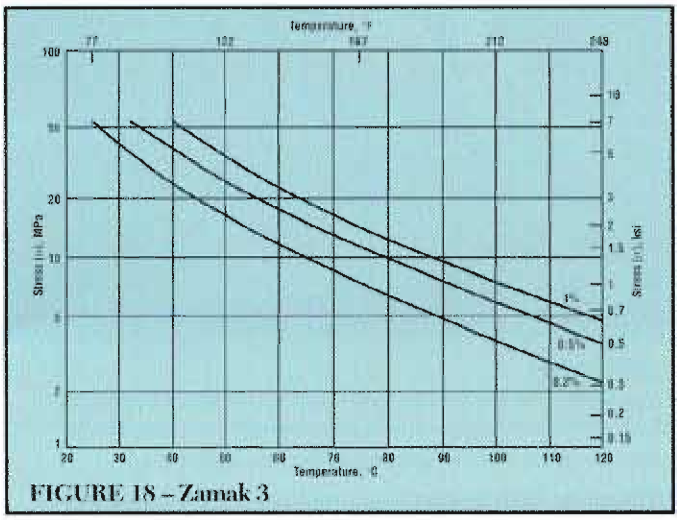


FIGURE 18 – Zamak 3

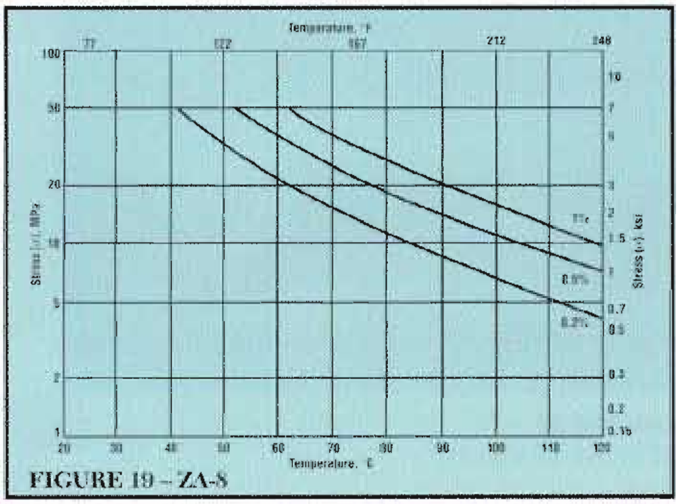


FIGURE 19 – ZA-8

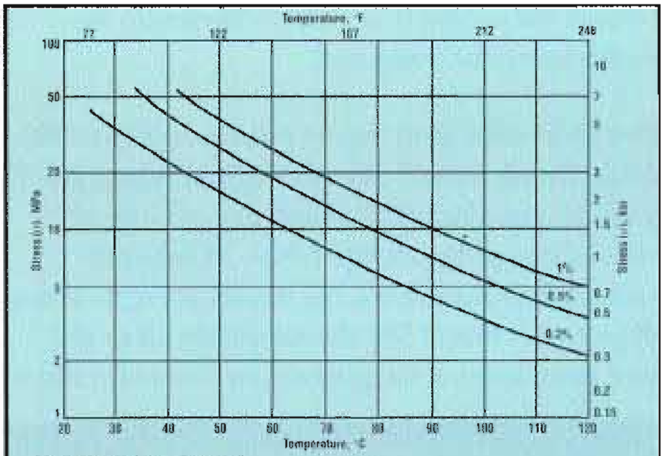


FIGURE 20 – ZA-27

FIGURES 18–20

Elongation of various pressure die-cast zinc alloys at various combinations of stress and temperature for a service life of 3 x 10⁴ h. Source: AM&S Europe Ltd

Fatigue strength measures a material's ability to withstand cyclic-reverse or on/off loading without failure. Fatigue testing is a demanding evaluation of a material.

ZA-27 compares favorably to the other metals in this area (Figure 21). Plastics do not come close to approaching the values of metals. Their fatigue strengths are more than an order-of-magnitude lower.

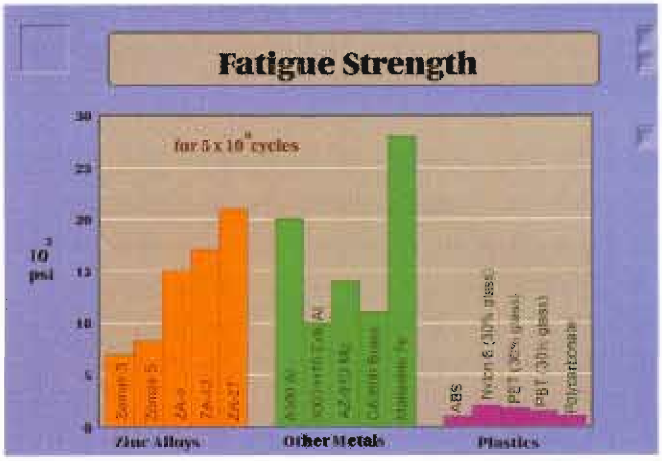


FIGURE 21

Impact strength measures the energy required to fracture a material under impact loading. It would be interesting to compare the impact resistance of polymers to that of the metals. Unfortunately, because the polymers are tested differently, the results cannot be compared.

Zinc alloys offer good impact resistance (Figure 22). While Zamak 3 and 5 offer the highest values, ZA-27 is still far superior to 380 aluminum and copper-based alloys at room temperature. At sub-zero centigrade temperatures, the impact strength of zinc alloys equals that of 380 aluminum. ZA alloys also have more fracture toughness than aluminum alloys.

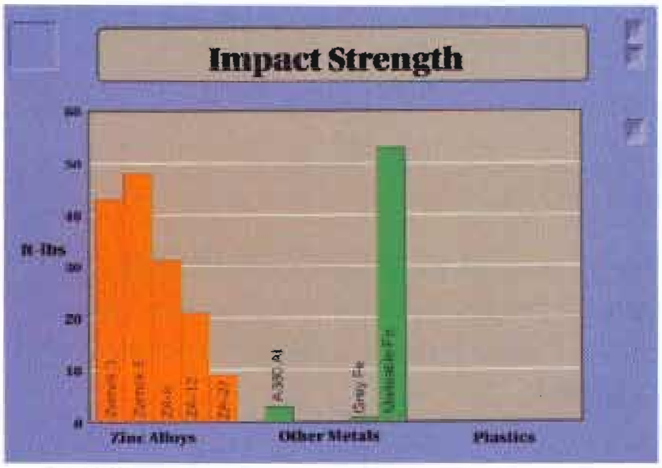


FIGURE 22

Elongation of a material describes its ability to deform plasticly under load. With excessively low elongation, the metal is either brittle or the casting is very porous. Excessively high elongation suggests a lack of dimensional stability.

Zinc alloys have a range of elongation values, each with different benefits, with selection depending on the application's requirements. Zinc alloys have elongation values equal to or exceeding certain competing materials; the values for copper alloys and unfilled polymers are higher (Figure 23).

A motorcycle shift lever illustrates the combined value of impact strength and elongation for proper material and process selection (Figures 24 and 25).

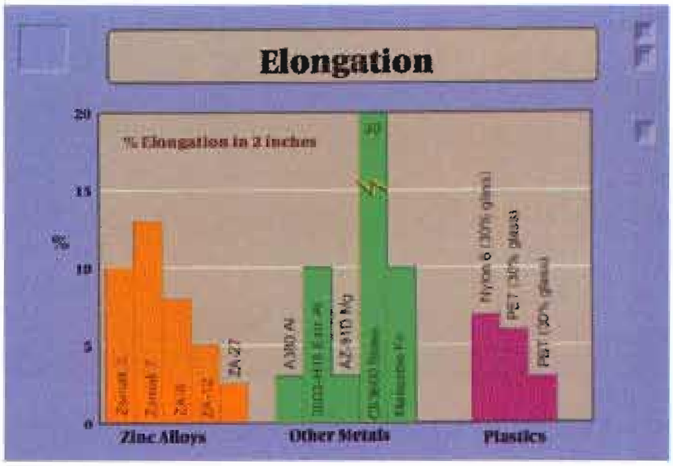


FIGURE 23

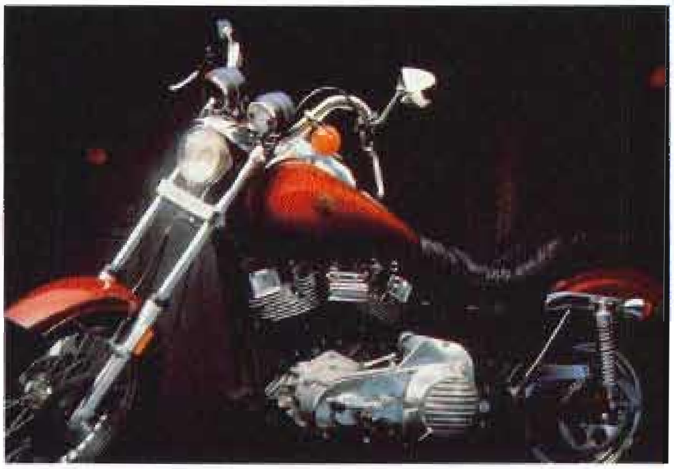


FIGURE 24
This Harley Davidson motorcycle uses a ZA-12 die-cast shift lever, below. The part requires good impact strength and elongation to allow for the lever to be tightened around the splined shaft.

FIGURE 25
ZA-12 die cast shift lever.

Young's modulus, which indicates a material's rigidity, is the ratio between the stress applied and the elastic strain that results. The Young's moduli of zinc alloys exceed those of aluminum and magnesium alloys and are an order of magnitude greater than those of engineering plastics (Figure 26).

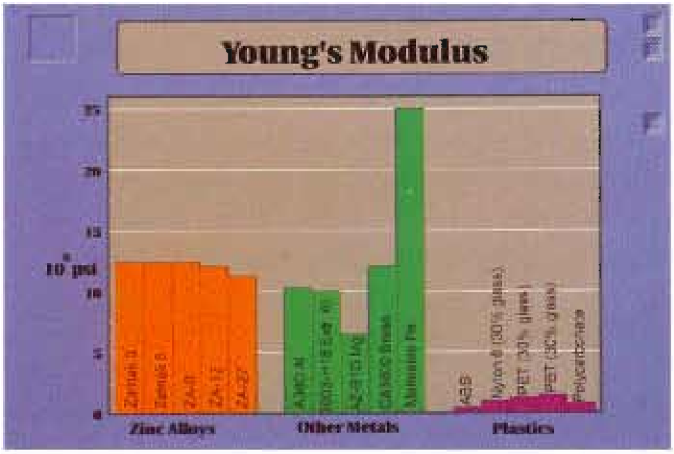


FIGURE 26

Hardness is the ability to resist deformation, usually point loading. It can also indicate resistance to scratching or abrasion.

All ZA alloys are hard—more so than most competing materials. This provides, in part, for their superior bearing and wear resistance but in no way impairs their excellent machinability (Figure 27). Plastics are too soft to be measured even using a Brinell hardness tester.

FIGURE 27

Other Material Attributes

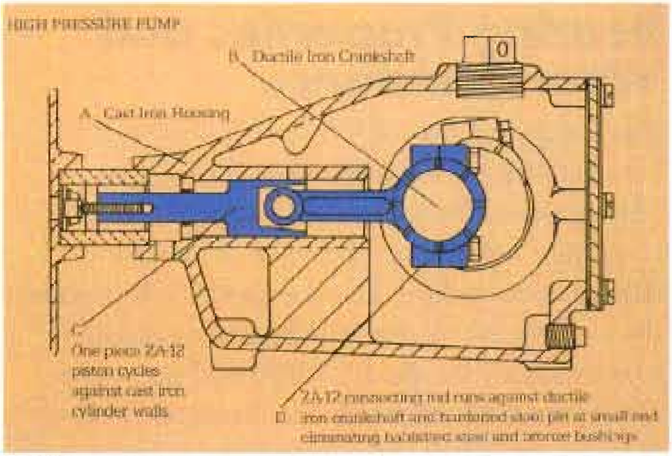
In addition to the above properties, all zinc alloys are highly regarded for their good bearing and wear resistance, high damping capabilities, good corrosion resistance, excellent machinability and ease of finishing.

Bearing Properties and Wear Resistance

The new zinc alloys—ZA-8, ZA-12, and ZA-27—have outstanding bearing and wear resistance. This quality refers to a material's ability to survive continuous, moving contact without sustaining damage to its surface. ZA alloys perform best under dry and lubricated wear conditions as compared to the industry standard, C93200 lead-tin bronze. Zinc's low coefficients of friction and good load-bearing capabilities make them suitable for a variety of applications (Figures 29 – 31).

As a bearing material, ZA alloy castings are 25–45 percent lighter than copper alloy bearings.

FIGURE 28
Black & Decker used the good bearing properties of Zamak 3 for its cordless screwdriver. The hardened steel shaft rides right on the zinc cast surface, without lubrication.



FIGURES 29, 30
Connecting rod and piston for commercial high-pressure water pump utilize ZA-12's excellent bearing and wear properties.

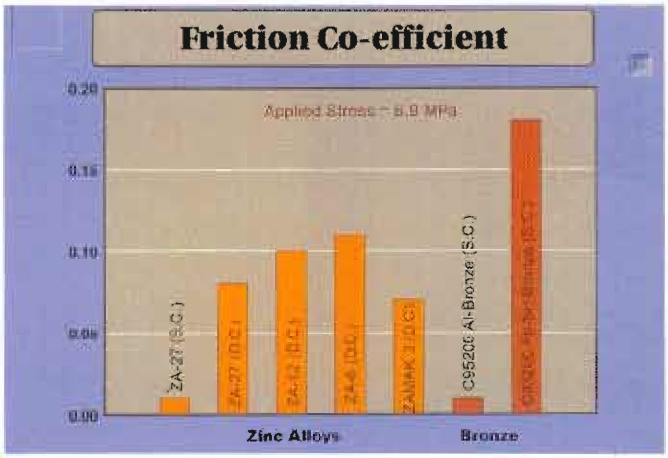


FIGURE 31

Damping Properties

Damping is a material property that has only recently begun to receive attention. Damping is a material's ability to dissipate energy caused by mechanical vibration, thus reducing the effects of externally-induced stresses. Mechanical vibration causes a great deal of damage and equipment downtime. The damping capability of zinc alloys is five times greater than 380 aluminum at room temperature. Furthermore, the damping capacity of these alloys increases with temperature. At under-hood temperatures, zinc alloys can be classified as HIDAMATS (High Damping Materials).

Machinability

Machinability is also one of zinc alloys' strong points. They will accept a relatively wide range of machining conditions. Surface finish and chip formation are excellent. Zinc's low cutting force requirement results in low tool wear, permitting high machining speeds, high productivity, and minimal tooling costs (Figure 32).

FIGURE 32
This ZA-12 TV radar dish component is permanent mold cast and then machined over 100% of its surface

The Zamak alloys are the easiest to machine, followed by ZA-8. ZA-12 and ZA-27 are the most difficult to machine; however, all the zinc alloys allow higher cutting speeds and less tool wear than aluminum or brass (Figure 33).

FIGURE 33

Anti-sparking

Except for ZA-27, zinc alloys have excellent anti-sparking characteristics. Aluminum castings, in contrast, do not. This is an important consideration when components are used in potentially explosive environments.

Corrosion Resistance

Zinc-based alloys resist corrosion well in normal atmospheric conditions, in aqueous solutions having a pH of 6-11.5, and when used with petroleum products. ZA-8 is best suited to mildly alkaline conditions, while ZA-27 is good in acidic environments down to pH 4. When required, chromate or phosphate treatment enhances corrosion resistance, and anodizing can substantially improve it.

Finishing

While Zamak 3 and 5 are the most commonly plated zinc alloys, the four-wheel-drive locking hub cover is an example of the excellent platability of the ZA-8 alloy (Figure 34). All zinc alloys readily accept a wide variety of decorative and corrosion-resistant surface finishes. Components can be painted to match adjacent parts, chrome-plated to offer a durable luster, or brush-finished and plated to take on the rich appearance of brass, bronze, or stainless steel at a small fraction of the cost (Figure 35).

FIGURE 34
These hub covers for GM's 4X4 truck need the hardness of ZA-8 to resist deformation from stones thrown up by the tires.

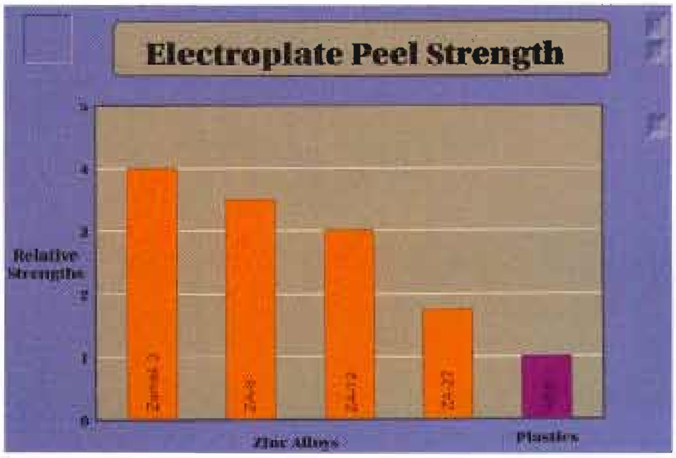


FIGURE 35
Zinc's high electroplate peel strength was also a key selection criteria for the 4X4 chrome-plated hubs, helping them maintain a highly decorative appearance.

SUMMARY

Zinc alloys offer a number of design advantages. They exhibit high density and superior heat-transfer capability and electrical conductivity, and they outperform other casting materials in numerous mechanical functions. Zinc alloys also have excellent damping capacity and machinability, making them attractive for a variety of commercial, industrial and consumer applications.

COMPETITIVE PERFORMANCE CHART: ZINC ALLOYS AND OTHER CASTING METALS

ALLOY PROPERTY		ZINC														ALUMINUM			MAGNESIUM	BRONZE/BRASS		IRON	
		ZAMAK 2**	ZAMAK 3**	ZAMAK 5**	ZAMAK 7**	ZA-8***			ZA-12***			ZA-27***				380	319	356-T6	AZ-91D	SAE 660 C93200	SAE 40 C83600	Class 30	32510
		Die Cast	Die Cast	Die Cast	Die Cast	Sand Cast	Perm Mold	Die Cast	Sand Cast	Perm Mold	Die Cast	Sand Cast	Sand Cast HT*	Perm Mold	Die Cast	Die Cast	Sand Cast	Sand Cast	Die Cast	Sand Cast	Sand Cast	Grey Cast Iron	Malleable Iron
MECHANICAL																							
Ultimate Tensile Strength	psi x 10³ MPa	52 359	41 283	48 331	41 283	38 263	35 240	54 374	43 299	45 328	59 404	61 421	46 318	64 441	62 426	47 324	27 186	33 228	34 234	35 241	37 255	31 214	50 345
Yield Strength 0.2% Offset	psi x 10³ MPa	NA	32 221	33 228	NA	29 198	30 208	42 290	31 211	39 268	46 320	54 371	37 257	55 379	54 371	24 165	18 124	24 165	23 159	18[3] 124	17[3] 117	18 124	32 221
Elongation (% in 2")		7	10	7	13	1.7	1.3	8	1.5	2.5	5	4.6	8.4	2.5	2.5	3.0	2	3.5	3	20	30	nil	10
Young's Modulus	psi x 10⁶ MPa x 10³	≥12.4 ≥85.5	≥12.4 ≥85.5	≥12.4 ≥85.5	≥12.4 ≥85.5	12.4 85.5	12.4 85.5	12.4 85.5	12.0 82.7	12.0 82.7	12.0 82.7	11.3 77.9	11.3 77.9	11.3 77.9	11.3 77.9	10.3 71.0	10.7 73.8	10.5 72.4	6.5 44.8	14.5 100	12.0 82.7	13-16 89.6	25 172.4
Torsional Modulus	psi x 10⁶ MPa x 10³	≥4.8 ≥33.1	≥4.8 ≥33.1	≥4.8 ≥33.1	≥4.8 ≥33.1	4.8 33.1	4.8 33.1	4.8 33.1	4.6 31.7	4.6 31.7	4.6 31.7	4.3 29.6	4.3 29.6	4.3 29.6	4.3 29.6	3.9 26.9	4.0 27.6	3.9 26.9	2.4 16.5	NA	NA	NA	9.3 64.1
Shear Strength	psi x 10³ MPa	46 317	31 214	38 262	31 214	NA	35 241	40 275	37 253	35 241	43 296	42 292	33 228	NA	47 325	27 186	22 152	26 179	20 138	NA	NA	43 296	45 310
Hardness (Brinell)		100	82	91	80	85	87	103	94	89	100	113	94	114	119	80	70	70	63	65	60	170-209	110-156
Impact Strength	ft-lb J	35 47	43 58	48 65	43 58	15 20	NA	31 42	19 25	NA	21 29	35 48	43 58	NA	9 13	3 4	4 5	8 11	2.7 3.7	6 8	11 15	nil	40-65 54-88
Fatigue Strength Rotary Bend (5 x 10⁸ cycles)	psi x 10³ MPa	8.5 58.6	6.9 47.6	8.2 56.5	6.8 46.9	NA	7.5 51.7	15 103	15 103	NA	17 117	25 172	15 103	NA	21 145	20 138	10 69	8.5 58.6	14 97	16 110	11 76	14 97	28 193
Compressive Yield Strength 0.1% Offset	psi x 10³ MPa	93 641	60 414	87 600	60 414	29 199	31 210	37 252	33 230	34 235	39 269	48 330	37 257	NA	52 359	NA	19 131	25 172	22 150	46 317	37.5 259	109 752	NA
PHYSICAL																							
Density	lb/in³ Kg/m³	0.24 6600	0.24 6600	0.24 6700	0.24 6600	0.227 6300			0.218 6030			0.181 5000				0.098 2713	0.101 2796	0.097 2685	0.066 1827	0.322 8913	0.318 8802	0.25 6920	0.26 7198
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			708-903 376-484				1000-1100 538-593	960-1120 516-604	1035-1135 557-613	875-1105 468-596	1570-1790 854-977	1570-1850 854-1010	≈2150 ≈1177	≈2250 ≈1232
Electrical Conductivity (% IACS)		25	27	26	27	27.7			28.3			29.7				27	27	39	11.5	12	15	NA	6
Thermal Conductivity	Btu/ft·hr·°F W/m·K	60.5 104.7	65.3 113.0	62.9 108.9	65.3 113.0	66.3 114.7			67.1 116.1			72.5 125.5				55.6 96.2	65.5 113.4	87 151	41.8 72.3	34 59	41.6 72	28-30 48-52	NA
Coef. of Thermal Expansion (68-212°F)	1/°F x 10⁻⁶ 1/°C x 10⁻⁶	15.4 27.7	15.2 27.4	15.2 27.4	15.2 27.4	12.9 23.3			13.4 24.2			14.4 26.0				11.8 21.2	11.9 21.4	11.9 21.4	14 25.2	10 18	10 18	6.7 12.1	6.6 11.9
Pattern Shrinkage	in/in or mm/mm	0.006	0.006	0.006	0.006	0.010		0.007	0.013		0.0075	0.012			0.008	0.006	NA	NA	NA	0.018	0.016	0.010	0.010

* 3 hrs at 610°F and furnace cooled.
** Complies with ASTM specification B86.
*** Complies with ASTM specification B669.

[1] 10mm unnotched Charpy [2] ¼ in unnotched Charpy [3] at ½% elong [4] Izod [5] notched Charpy [6] compressive strength [7] at 10% permanent set NA - Not Available

Designing Zinc Die Castings

This discussion is meant to provide a better understanding of the zinc die casting process and to facilitate designs that take full advantage of the process.

A cross-section of a typical die is shown in Figure 1. To allow removal of castings from the die, it is constructed in two halves, known as the fixed, or cover half, and the moving, or ejector half. The two meet at a plane. The cover half of the die is attached to the fixed platen of the die-casting machine.

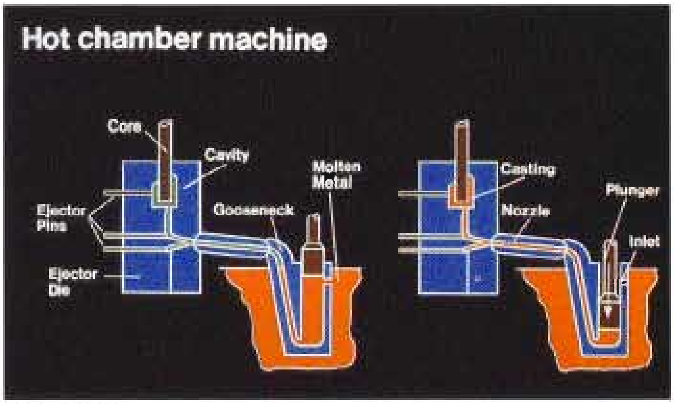


FIGURE 1
Schematic of hot-chamber casting machine showing method of filling die cavity.

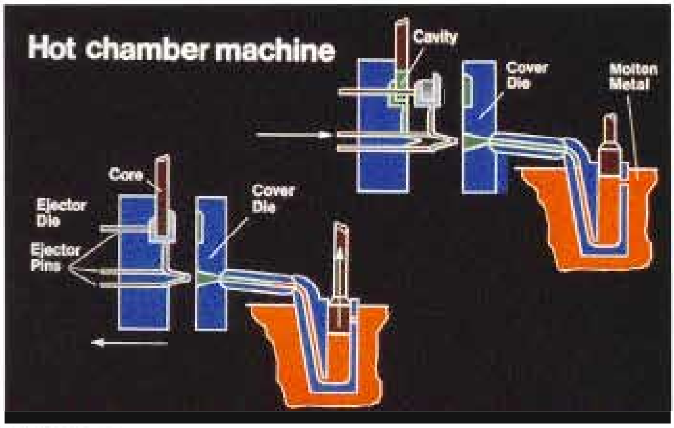


FIGURE 2
Schematic of hot-chamber die-casting machine illustrating die opening and casting ejection.

To allow the die to be opened, the moving half is mounted on the moving platen of the die-casting machine. Hydraulically or pneumatically operated toggles control movement.

The die impression is machined into both die halves, usually with the cavity portion of the impression in the moving half and the core portion of the impression in the fixed half. This ensures that when the die is opened, the casting will remain in the cavity and be carried out with the moving half of the die. Ejector pins are then used to eject the casting from the cavity (Figure 2).

Types of Dies

A large portion of dies are made with a single cavity to produce one casting per "shot." When parts of favorable shape and size are required in large quantities, automatic die casting machines using dies having several cavities offer cost savings. Multiple cavity dies produce different, unrelated shapes. A combination die is used to cast separate, but related components. The combination die is particularly suited for the production of different die castings to be used in a single product assembly.

Parts required in differing quantities may be economically produced in unit dies which are smaller die blocks made to fit standard bolsters. Quick-release unit dies may be readily changed to suit production requirements.

Parting Line

The term parting line refers to the seam on the casting created by the parting plane of the two die halves (Figure 3).

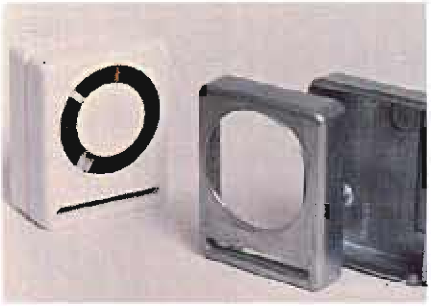


FIGURE 3
The casting design for an alarm clock puts the parting line at the maximum diameter of the casting. The casting also displays thin walls and rounded corners.

In many instances, a natural parting line will be established either by the shape of the part or by a previous fabrication method. Given a drawing for a new part, a die caster will first select a parting line that will yield the flattest die surface. This selection depends on the following factors:

1. The best gating location to achieve complete filling of the die cavity consistent with strength and surface-finish requirements.
2. The simplest die with a minimum of undercuts formed by separate, movable members.
3. Easy removal of the casting from the die on completion of the casting cycle.
4. Maximum utilization of the casting machines' locking force. (Generally, the plane of the casting's largest projected area should coincide with or be parallel to the parting plane.) This is most crucial when large slides are required.
5. Most advantageous use of the principal die movement in coring.
6. The desirability of positioning of close tolerance elements in the same halves of the die.
7. The surface-finish requirements may indicate that a particular parting line is objectionable.

Ejector pins will leave small marks on the surface of castings. The die should be designed where possible with ejector pins positioned so that these marks do not appear on significant surfaces of finished castings.

See Design Tips at end of section for more information on parting line geometry.

Tolerances

Die casting is the most accurate of the casting processes. The reason for this is that the zinc alloy is molded in steel dies machined to very tight dimensional tolerances.

The tightest die casting tolerances are held for features formed in the same die part. Typically, tolerance for non-critical linear dimensions is ±0.010 in. for the first inch and ±0.0015 in. for each additional inch up to 12 inches. Typical tolerance for critical linear dimensions is ±0.003 in. for the first inch and ±0.001 in. for each additional inch up to 12 inches.

Parting line tolerance for dimensions perpendicular to the parting plane is additional to linear dimension tolerances. Typically, for die castings with projected area of up to 50 square inches, the parting line tolerance is ±0.004 inch.

Moving die-part tolerance is also additional to linear dimension tolerances. Typically, ±0.004 in. is required for die castings with projected areas up to 10 square inches.[1]

The specifications listed here and in the following sections are meant as guidelines. Exact specifications are dependent on the specific application. For more information consult the die caster of your choice.

Size of the Die Casting

In general, the smaller the size, the lower the cost of both die and casting. Increased size means higher metal costs and reduced casting rates. However, provided the shape is not unduly difficult to cast, a single large zinc die casting costs less than two smaller ones cast separately and assembled.

A casting's maximum size depends on the size of the die-casting machine available. There is no limit on minimum size; in fact, zinc die castings weighing 1 gram (1/300 ounces) or less are in regular production. Small components may be produced in multiple-cavity or combination dies to contain costs.

---

[1] For more information on die casting tolerances, see "Product Standards for Die Castings," published by North American Die Casting Association.

Section Thickness

Zinc die castings should be designed for the thinnest practical wall thickness consistent with strength and stiffness requirements (Figure 4). Thin wall sections provide the following function/economic benefits:

1. Cost savings: Metal saved through thinner sections cuts the cost of the casting. The die casting machine cycle time is reduced and production rate is increased, providing further cost savings.
2. Weight savings: Since thinner sections can be cast in zinc, it is often practical to produce a lighter product in zinc than in metals that have a lower density. Wall sections as thin as 0.020 in. to 0.025 in. (0.50mm to 0.64mm) are practical for many small zinc die castings and 0.040 in. to 0.050 in. (1.00mm to 1.25mm) for larger castings. Wall sections as thin as 0.015 in. (0.37mm) may be cast in zinc in certain situations. Section thickness can be retained where necessary for strength or impact resistance, or supported and strengthened by ribs.
3. In general, thin sections in a zinc die casting are relatively tougher than thick sections, with higher impact and fatigue strengths. These improved properties result from the superior grain structure of thin sections.

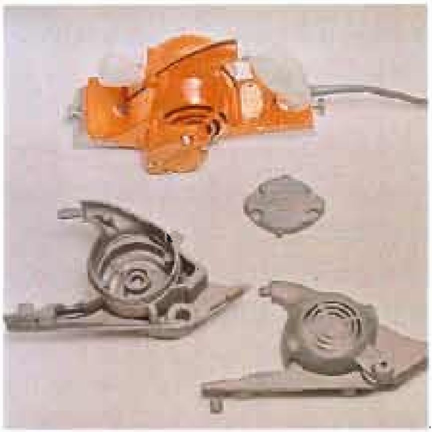


FIGURE 4
A power plane casing displays uniform section thickness with gradual transitions.

The uniform fine grain structure of the surface layer, normally present as the "skin" of a zinc die casting, occupies the full thickness of thin sections up to approximately 0.040 in. (1mm). The thin section consists entirely of a fine dendritic structure of alpha phase and a uniform eutectic network. The thicker 0.080 in. (2mm) section has only a thin skin of uniform structure below which is a coarser dendritic formation of zinc-rich solid solution and less uniformly dispersed eutectic.

Often the wall stock specified for other casting processes depends more on filling the casting than it does on the part's mechanical function. More extensive coring and thinner walls will, therefore, result in a lighter part at a lower cost when produced as a die casting.

See Design Tips at end of section for more information on die filling.

Minimum practical thickness for a new casting can be realized by designing sections to be as thin as possible and tooled accordingly (Figure 5). Should certain areas require greater thickness, cutting out the die is relatively inexpensive. In contrast, it is expensive and usually difficult to build up a die to reduce the section thickness of a too-heavy casting.

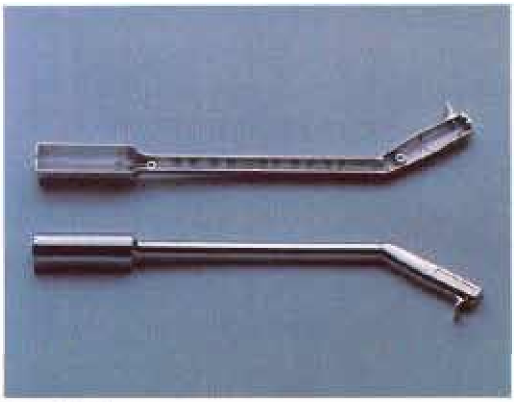


FIGURE 5
This pick-up arm has a minimum wall thickness of 0.023 in. strengthened by cast-in ribs.

Variation in Section Thickness

Sectional thickness should be as uniform as possible. Where variations in section thickness are necessary, the transition should be gradual. Thin sections cool more rapidly than thick ones, and in extreme cases unequal contraction of nonuniform sections may cause distortion or cracking of the casting. Careful design will minimize the effects of distortion.

Judicious use of cores often aids in maintaining section thickness uniformity. "Metal saver" cores, used in parts of the casting that otherwise would be needlessly filled, aid in achieving uniform section thickness.

Draft

Draft is required on all surfaces of a casting normal to the parting line of a die and on all surfaces parallel to the line of pull of movable members. The amount of the draft angle varies with the depth of draw and depends on whether the surface is an outside or an inside surface.

When molten metal solidifies, it shrinks away from the walls of the cavity and onto steel protruding into the cavity. Therefore, outside surfaces require less taper than inside surfaces. Generally, one-half-degree minimum should be specified on outside surfaces of the casting.

The extent to which internal surfaces require draft is more involved. It depends on the method used to strip the casting off the internal surface—either ejector pins (internal surfaces rigidly fixed in the ejector die), or stationary surfaces (in the case of a movable member). In the cover die, it is difficult to provide a stripper mechanism and a minimum of one degree taper is desirable on internal surfaces.

For best economy, the designer should provide for the maximum taper that the part's performance will permit.

Ribs

Ribs can add considerable strength and stiffness to a zinc die casting, reducing shrinkage stress during cooling and adding to casting stiffness both in processing and service (Figure 6). A thin section reinforced by ribs will usually provide lower overall weight than unribbed sections of greater thickness with equivalent strength.

FIGURE 6
This concentric stereo speaker shows thin ribs, tapered and blended into the main body of the speaker providing an exceptionally rigid unit.

Bosses subject to load concentrations in service should be supported where possible by ribs to distribute loads over a larger area of the casting. Carefully positioned ribs will also improve the casting by providing extra passages through which metal can flow into thin sections during the casting operation.

In thin-wall castings, rib thickness should not exceed the section thickness of the area it adjoins and must not produce sharp corners at the joint. Ribs should not be placed where they complicate removal of the casting from the die.

See Design Tips at end of section for more information on strength and material economy.

Corrugations

In suitable applications, corrugations will add considerable strength and stiffness to thin, flat sections in zinc die castings. Corrugated profiles used around the perimeter of flat plates will usually provide stiffness comparable or superior to ribs or edge beading, with less weight.

Fillets and Radii

Fillets facilitate the metal flow, prevent stress concentration due to shrinkage, and add strength to the casting. Corner radii extend the life of the die, since the sharper the corner the likelier it is to develop a crack.

Since thin sections cool more rapidly than heavier ones and their contraction is generally restricted, high shrinkage stresses are apt to occur where sections of unequal thickness meet. At these junctions, fillets should be provided to yield a gradual transition. The magnitude of the radius should approximately equal the average of the joining wall thickness.

The most generous fillets practical should be provided to eliminate sharp corners, a source of weakness. Even the smallest fillet has an appreciable strengthening effect. A radius of 0.15 in. (0.40mm) minimum is suggested in place of sharp corners and larger radii are desirable when conditions permit. Fillets of 0.015 in. (0.40mm) radius are barely noticeable even on outside edges and an 0.030 in. (0.80mm) radius is seldom evident except on close inspection. Figure 7 shows how fillets combine with radii.

FIGURE 7
This fishing rod reel demonstrates the use of blends and fillets.

It is common die casting practice to use a fillet having a minimum radius of 0.060 in. (1.50mm) on inside edges. A slight radius on outside corners of castings reduces die cost, eases buffing and polishing, and enhances the durability of any subsequent finish. Sharp corners are difficult to polish without damaging their outline, while organic finishes tend to thin out along sharp edges. Fillets also aid metal flow in casting.

Cored Holes and Recesses

The intricacy and accuracy of coring irregular shapes that die casting permits is the largest single factor in its selection over alternative processes. This coring often eliminates machining operations (Figure 8).

FIGURE 8
This fuel pump cover is cast with a moving core at right angles to the die movement.

Any shape may be die cast if the casting design reflects the limiting conditions imposed by withdrawal of the solid core and holding it in the correct position during the casting operation. Square, round, hexagonal, oblong, splined, and other odd shapes are no more difficult to cast than a diameter of equal perimeter. After the initial cost of constructing the more complicated coring, no additional costs arise, since the time required for the molten metal to solidify is the same.

Cylindrical cores are the simplest to make since conventional grinding equipment can produce a very accurate, smooth finish. Because of the precision with which such cores can be made, cast holes can be tapped to 60-75 percent full thread without prior drilling. The strength of these threads will be greater than threads of a drilled hole where the denser surface metal of the die casting has been removed.

Recommendations on the ratio of core depth to diameter for the common die cast alloys are given in Table 1. Smaller and deeper cored holes are possible depending on overall part geometry. It is recommended that a die caster be consulted for recommendations.

TABLE 1
Ratio of Core Depth to Diameter

Alloy	Diameter (inches)	Maximum depth in relation to diameter
Zinc	Smaller than 0.093	Not generally cored
	0.092 to 0.250	3 to 8 times diameter
	0.250 to 1.000	6 to 8 times diameter

See Design Tips at end of section for more information on cored holes.

Machining Allowances

Zinc die castings may be cast to very close tolerances, often eliminating the need for machining. Where machining is necessary, the cuts required are usually light and the operation is eased by the free machining qualities of zinc die casting alloys.

Design drawings should indicate a datum line from a fixed point on the casting to show how much metal is to be removed. Surfaces to be machined should be of minimum area, consistent with other requirements, and when possible, should be positioned to simplify machining.

For example, flats can often be trued by sanding or other simple grinding, provided that the surfaces to be ground are accessible. Placing flats such as boss faces all in one plane expedites grinding. Such surfaces should be slightly above surrounding areas that do not require machining.

When the number of castings to be produced from one die is small, the die cost can usually be kept low. In such cases, it is sometimes preferable to save on die cost and perform additional machining on the castings.

Eliminating machining through more intricate and accurate coring permits major cost reductions when converting parts to die casting. Where machining operations are unavoidable, the highest accuracy is generally achieved through milling, boring, and reaming, with only a finish cut necessary for minor machining allowances. Minimized machining allowances are not only desirable from a cost standpoint but are recommended where sound metal is required for bearing loads, sealing surfaces, and pressure tightness.

A primary consideration to insure minimum stock removal is the positioning of the initial machine locating points. Locators should be provided in the portion of the casting containing the majority of the machine operations.

In designing the casting die, die components with machined surfaces should be positioned to hold the minimum tolerances relative to the section containing the locators. Using this criteria, locators are usually positioned in the ejector die.

Flat plates which are die cast, and require very tight tolerances on corner to corner flatness, will require further machining. The amount of stock which must be allowed for in the final machining is governed by the overall surface area created by the extremities of the component (larger components will distort, bend and twist more than small components). The Machine Stock Allowance recommendations in Table 2 are generous and in many cases can be reduced by good die casting practice.

TABLE 2
Finish Stock Allowance

Extreme Area	Machine Stock (inches)
≤ 20 square inches	0.010-.020
≥ 20 square inches but ≤ 60 square inches	.030
≥ 60 square inches but ≤ 120 square inches	.047
≥ 120 square inches but ≤ 250 square inches	.060

All holes should be cored if at all possible and only a reaming, boring, or tapping allowance provided. When a hole taper is objectionable, it is advisable to core the hole and either drill or ream to remove the taper. Table 3 provides recommendations governing the machining allowance for cored holes. This is particularly important when diameter accuracy is more important than the location of the hole.

When the location tolerance of an as-cast hole is unsatisfactory and the hole needs to be machined, then the machining allowance given in Table 3 should be increased by the difference between the cast tolerance and machined tolerance.

TABLE 3
Machine Stock Allowance For Cored Holes

Diameter	Machining Allowance on Diameter (inches)
≤ 1 inch diameter	.015 plus taper
1-2 inches	.020 plus taper
2-3 inches	.030 plus taper
3-6 inches	.050 plus taper
6-9 inches	.075 plus taper
9-12 inches	.100 plus taper

Drill points are commonly provided when it is impossible to core holes or impracticable to cast them. These points eliminate the need for drill jibs unless the tolerance on the hole location is extremely close. Drilling to die-cast drill points can be consistently done within 0.005 in. tolerance.

Inserts

Inserts are incorporated to achieve cost-effective engineering or functional value. They are generally used for one or more of the following reasons:

1. To provide greater strength, hardness, wear resistance, or some other property not possessed by zinc die casting alloys.
2. To provide shapes of parts or passages that cannot be cored or cast, or that are cheaper or better as inserts.
3. To attach an assembly which would be less efficiently produced otherwise.

Inserts commonly take the form of threaded studs, grooved studs, plain spindles, and bushes. Inserts may be placed in the die so that they are "cast-in" or they may be later driven into cored or drilled holes in the casting. A cast-in insert is used to achieve greater anchoring security or positioning that would otherwise be inaccessible.

Inserts designed for casting-in-place should incorporate knurling, holes, or grooves to ensure firm anchorage. The casting thickness around the insert should be thick enough to give the required mechanical support. Inserts should be used that prevent the zinc alloy from overflowing surfaces that are intended to be exposed. A shoulder on the base of the insert usually accomplishes this.

The potential effect of differential thermal expansion between the insert and the casting must also be considered. For example, the situation where a large insert is incorporated into a small casting.

Plain Surfaces

Smooth, plain surfaces that are to be highly finished should be designed with a slightly convex surface or "crown." Crowning will mask minor surface imperfections and greatly improve product appearance. Normally, crowning will not be apparent in the finished product (Figure 9).

Crowning is necessary to counter the tendency for gloss paints and electroplated finishes to magnify even slight surface defects or the effects of uneven polishing over large, flat areas. An alternative to crowning is to break the surface with beads, steps, low relief, or texture.

FIGURE 9
The Ronson shaver and lighter demonstrate the effect of crowning which greatly improves surface finish appearance.

Letter and Engraving

Cast-in lettering, numerals, trademarks, diagrams, or instructions are readily incorporated in zinc die castings. Raised designs on the casting are preferred, since it is easier and cheaper to engrave a design into the die than to machine a raised design on the die surface (Figure 10). In addition, a raised design on the die is subject to greater wear from the molten alloy, reducing die life.

FIGURE 10
This compressed gas regulator knob with raised lettering illustrates the easier task of machining a design into a die surface rather than raising the design.

When it is undesirable to have lettering or marking projecting above the surrounding surface of a casting, raised engraving on a panel sunk into the surface of the casting can often be used. The panel may also include stippled areas.

Engraving should be done on surfaces parallel or nearly parallel to the die parting. It should never involve an undercut, which could interfere with part ejection. In many designs, engraving is used effectively for scale or graduation markings. Recessed designs may be filled with paint economically to provide contrast with surrounding areas.

Undercuts

Undercuts are used to avoid solid or unnecessarily heavy areas of metal where it may not be economical or feasible to remove the material after casting.

Undercuts generally raise the die cost and reduce casting rates dramatically and should be avoided except where there is no design alternative or where they provide relative cost or processing advantages. When undercuts are required on the exterior of a casting, slides or moveable cores must be used; otherwise, the casting cannot be ejected from the die. Undercuts on the interior of the casting commonly require the use of a loose piece, which is withdrawn from the die with the casting and must be replaced in the die for subsequent castings.

Shrink Marks

Bosses or similar metal concentrations that are heavier than adjacent thin walls result in unequal shrinkage. This sometimes gives rise in thin-wall castings to "shrink marks" or "shadow marks," shallow depressions on the face of a casting opposite the thicker section. Such marks may detract from the finished component, especially if the surface has a lustrous finish. The effect can be minimized by minimizing variations in thickness.

Shadow marks can be masked by ribs or low-relief designs and seldom occur in sections over 0.100 in. (2.5mm) thick.

See Design Tips at end of section for more information on structural soundness.

Through Holes in Thin Sections

Small through holes in sections up to 1/8 in. (3mm) are often drilled or punched instead of cored, since the flash from cored holes normally must be removed. It is almost as quick to drill or punch the full depth of the hole as it is to remove flash from the cored hole, unless this can be done during the normal trimming operation. The drilling or punching operation may be eased by spotting the hole position with a short conical pin in the die.

Bending and Forming Zinc Die Castings

The ductility of zinc die casting alloys can be used to advantage by designing parts to achieve their final shape through bending, forming, or spinning after casting (Figure 11).

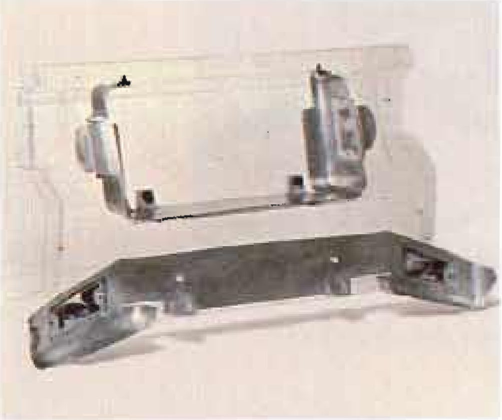


FIGURE 11
Zinc's ductility is illustrated in this number plate surround. It is cast first in a horizontal plane and bent to the required angle.

This ductility makes it possible to shape integral flanges and curving contours, bend hollow arms, spin out undercuts, upset odd projections, and twist casting components 90 degrees or more.

Simple bending and forming operations can often be carried out satisfactorily without preheating castings. The ductility of zinc die castings increases above 70°F (21°C); more involved bending and forming should be carried out above this temperature. Where severe deformation is required, preheating of parts up to approximately 212°F (100°C) will increase ductility. Bending and forming should be completed before electroplating or painting.

Trimming Zinc Die Castings

Castings should be designed to minimize the amount of flash and the cost of removal. Flash is the thin web or film of metal on the casting that occurs at die parting lines. Flash removal usually constitutes a considerable factor in a casting's cost. While practically unavoidable, the cost of flash removal can be minimized by positioning the parting to facilitate removal.

FIGURE 12
A drum tension ring is shown before and after it is trimmed.

To remove flash, a casting is typically pressed through a trim die (Figure 12). If the parting is in a single plane, preferably at right angles to the motion of the die, the flash is easily sheared. Cost increases when the parting is not in a single plane.

Where possible, design should confine flash to a flange or bead, rather than in a recess or on flat surfaces. Flash that runs along a flat surface and not at the extreme edge of the casting is difficult to remove cleanly without leaving tool marks on adjacent surfaces. Designs often allow for flash to occur on a surface or edge where machining is required, eliminating a separate flash removal operation.

Models to Assist in Design

Models are a useful design aid in visualizing products, assessing aesthetic qualities, checking tolerances, incorporating various design details, and die tooling. They can be made in wood, fiberglass, hard plaster, metals, and combinations of these.

Designers often get help visualizing by constructing even a rough model, although one made to scale is still better. The model often reveals design features that can be altered to lower die or piece cost. Constructing a model of a portion of the proposed design may help solve a particular detail problem.

Ordinary projection views show the part from just three positions. A model illustrates how the die might be built to fit around the part and how it might be easily removed from the die after casting.

The Zamak casting alloys do not produce good results in sand and plaster molds which are slow cooled. However, ZA-12 produces castings with properties little affected by cooling rates. Except for its impact strength and ductility, this alloy compares in mechanical properties with Zamak alloys and is useful for sand or plaster mold prototypes. These prototypes can be used to assess die casting for the proposed application. Gravity casting can be used for short production runs. ZA-12 castings can be machined, plated, or otherwise finished like pressure-die castings.

Means of Attachment

When two or more die castings are to be assembled, or when stampings or parts fabricated by other means are to be assembled to a die casting, they must be fastened by some method. Generally, a boss with a hole to be tapped later or to be used in conjunction with self-tapping screws is provided. Often, however, integral rivets or cast studs can be economically used as fastening and locating means.

These fastenings can be threaded and a nut added later, secured with a spring steel clip, or peened and headed over.

Quite often a boss is added providing greater bearing than could be achieved by having a hole pass through the casting wall. Adding several ribs to a boss adds strength and distributes stresses over a larger area. Coincidentally, the boss becomes easier to fill.

Studs formed as an integral part of the casting usually cost less than inserted studs and often constitute a highly economical means for fastening a casting to a mating part (Figure 13). Production rates slow considerably when separate inserts must be placed in hot dies before each shot.

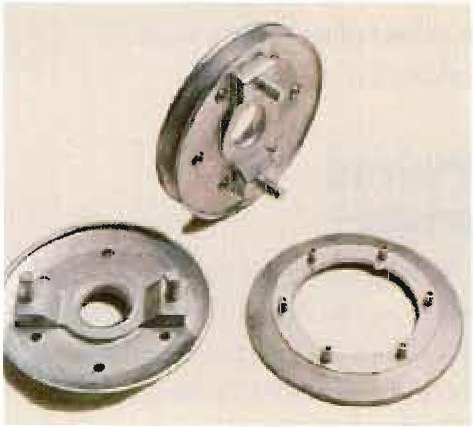


FIGURE 13
This washing machine pulley was cast in two sections and held together with cast-in studs.

Integral studs should be large enough to avoid handling damage. Stud diameters of at least 0.236 in. (6mm) for large or medium sized castings are recommended. With small, light castings, proportionately smaller studs can be safely used.

Ejector Pin Marks

Once the casting cycle finishes, the part must be removed from the die. Typically this is accomplished by pins fastened to a pair of ejector plates and mechanically or hydraulically passed through the ejector die. While ejector pins may take any shape that can be machined, pins that are circular in cross section are the least expensive. Depending on the size of the casting, ejector pins should be 1/8 – 1/2 inch in diameter.

Because ejector pins are movable, the casting surface has a slight seam around the perimeter of the pin, hence the term "ejector pin mark." Ejector pins are normally quite long, so small changes in temperature affect their length appreciably with marks that are raised or depressed on a casting.

Awareness of this condition is exemplified by an automotive timing chain cover. Heavy gaskets enabled the cover to be used without machining the ejector half of the casting.

Ejector pins are most effective and create the least distortion if they can be placed under a vertical wall. (Vertical in the sense that a major dimension length or width is parallel to the axis of the pin.) Since the wall thickness in a die casting is generally thinner than the diameter of the ejector pin, a boss on the casting may be required to clear the pin in its travel.

Threads, Gears, and Gear Teeth

Internal threads may be cast in zinc using a complex mechanism designed to rotate the core in the die. This allows casting a full thread to the bottom of a hole, something tapping cannot do since chip clearance is needed between the tap and the bottom. Casting an internal thread is also feasible if the thread is special and the cost of procuring and using special taps exceeds the additional cost of the slower cycle time.

FIGURE 14
External threads are usually more economical to cast than internal threads

External threads are much easier to cast (Figure 14). The most common practice is to machine the female thread in the separate die halves; in which case a seam appears across the thread parallel to the thread axis. This is not objectionable with most thread classes. Variations in metal shrinkage can create an error in the pitch, but if the thread is not excessively long, the total error will be slight. The finest threads that this method can successfully produce in zinc are 32-per-inch.

Any type of gear form that can clear the die can be die cast. In general, the teeth are acceptable as-cast and need not be machined (Figures 15 and 16).

Internal gears are as easily die cast as external gears, whereas internal gears made by other methods are much more expensive, especially if the gear is small and the teeth must run to the bottom of the hole.

FIGURE 15
Black & Decker Power Screwdriver.

FIGURE 16
The gear case for the Black & Decker Power Driver is cast net shape, including the ring gear.

In addition to strength, there is another factor to consider when using die cast gears. When one gear is cast, the mating gear should also be cast. Die cast gears generally cannot be expected to run smoothly with a gear that has been machined.

See Design Tips at end of section for more information on threaded components.

Design Points to Remember

Final selection of the parting line should be the responsibility of the caster. A number of factors will influence this decision including: ejection, configuration, coring, finish specifications, gating, type of die, and flash removal.

Cores and slides often save much more than they cost to incorporate. In addition, cores often allow high-volume production of complex parts that are ready for assembly.

Wall stock should be as thin as possible, consistent with strength and finish requirements.

The total quantity of castings as well as the volume per production run may have an important influence on part cost. This is especially true if machining and finishing operations are keyed into the production cycle. The longer the production run, the lower these costs will be for each individual casting.

Discuss the specific part requirements with the die caster so that the most practical alloy can be chosen for the application.

Small bosses or studs can be formed integrally simplifying assembly of the finished product. The automotive industry often does this with letters, escutcheons, and decorative trim. Assembly then can be completed simply by inserting the projections into prepunched or predrilled holes, securing the part with spring steel clips or other inexpensive means.

Irregular or eccentric gears or cams, difficult to machine from solid blanks, can be die-cast as easily as parts with uniform profiles.

Interchangeable die sections can produce castings with the same external shape and size but with different length, cavity, or hole requirements. This greatly reduces the tooling for similar parts, especially when one of the parts has low production requirements.

Elimination of machining is one of the greatest benefits of the die-casting process and every effort should be made to take advantage of the accuracy casting offers.

External threads can be cast either by positioning the part so that half of the thread circumference is formed in the cover die, the other half in the ejector die; or by using side slides to accomplish the same purpose. Loose die pieces or threaded inserts can also be employed.

The surface finish specifications should only be as good as is necessary for appearance and functional purposes. Ultrahigh quality increases die production and maintenance costs.

High injection pressures and the use of process control equipment and techniques produce die castings with little internal porosity.

Closest tolerances can be held between elements located in the same die component. Closer tolerances than those listed in the Die Casting Standards often can be held, but such customer requirements should be discussed with the die caster before the job is begun. Tolerances and limits are subject to variation, depending upon such features as the size and shape of the casting, the die construction, and the casting pressures employed.

Bimetal assemblies can be produced by using a precast component of one alloy as an insert or interlocking part of another casting.

Fillets and radii should be as generous as possible to aid metal flow and avoid stress concentrations.

Large, flat sections are more difficult to cast without surface imperfections than contoured or ribbed members. If the exterior must be flat, some degree of surface imperfection must be tolerated and more liberal allowances may be necessary, particularly regarding flatness.

If the only difference between the right and left parts of an assembly is the position of a flange or other integral member, a single die may possibly be used for both pieces. Parts could be formed into the desired shape after casting by a simple bending or machining operation to create the necessary difference.

Design's effect on all secondary operations (including machining and finishing) should be considered before freezing the design, so that the die-casting process will provide the maximum benefit.

DESIGN TIPS

Consider Parting Line Geometry

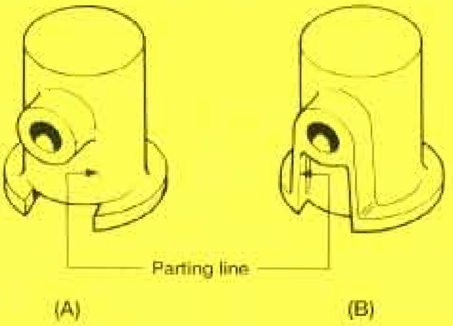
Die casting dies must be made in at least two parts, which join at the parting line. During the casting process, molten zinc can flow between the die halves causing flash. The designer should establish the position of the parting line so as to minimize the effects of flash and to facilitate its removal through trimming.

Design to avoid

(A)
A broken parting plane can leave traces of flash on the castings which are difficult to remove.

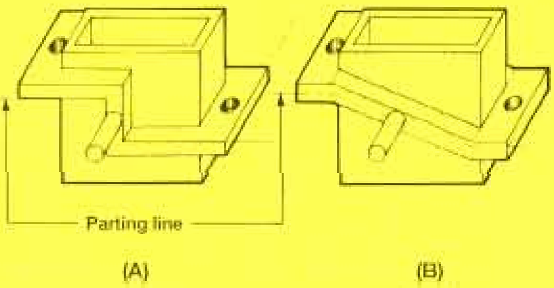
Preferred design

(B)
A simple modification greatly facilitates trimming, and improves the strength of the component.



Avoid vertical split lines wherever possible. This will give stronger die construction, less flash formation and simpler trimming.

Example (B) achieved this in a part with all the same design elements as in (A).



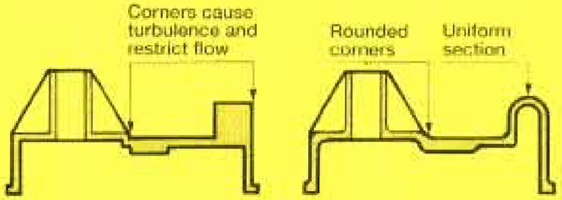
Design to Assist Die Filling

10 – 40 milliseconds are typical fill times for most die castings. Components should be designed so as to enable the molten metal to fill the die smoothly and without turbulence which can cause surface imperfections and porosity. Generally the more uniform the wall thickness the easier this is to achieve.

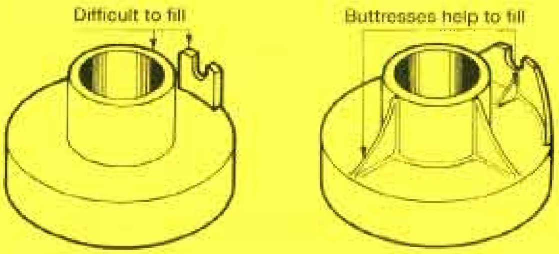
Design to avoid

Preferred design

The design must permit very fast filling without producing turbulence in the metal flow. Smooth contours and uniform sections assist this.

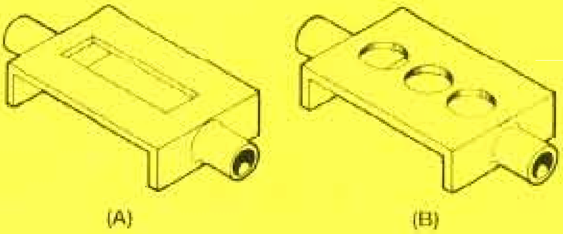


Projections and bosses can be difficult to fill. Buttresses assist flow to such features as well as strengthening the component.



(A)
A long 'window' or slot in a component may severely restrict metal flow to part of the casting.

(B)
Using a series of round holes may supply the same function while assisting metal flow.



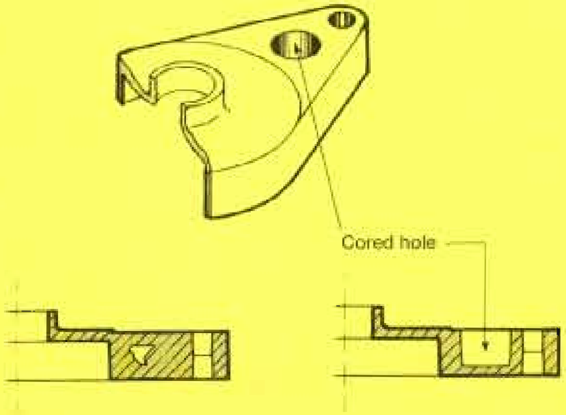
DESIGN TIPS

Design for Structural Soundness

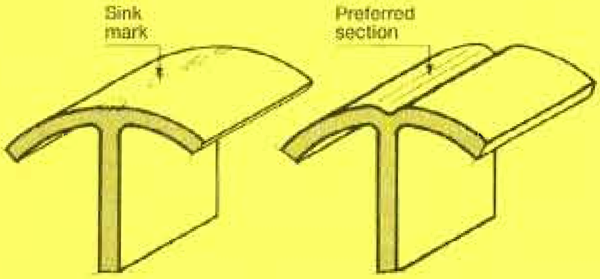
When molten metal solidifies in the die it shrinks, and so liquid metal must be available to fill the space created, or a shrinkage cavity will be left. This effect is greatly increased with thicker sections. The design should aim for uniform wall thickness throughout the component, avoiding very thick sections, rapid changes in section, and thin sections feeding thicker sections.

Design to avoid **Preferred design**

One way of reducing heavy sections is to core a hole in the thickest part. This also saves material and may speed production.



Solidification shrinkage may appear at the surface as a 'sink' mark which may be unacceptable on a highly finished component.



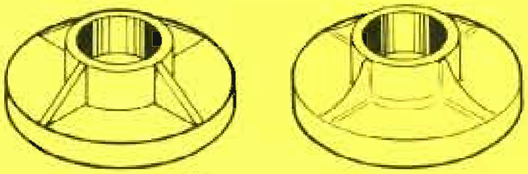
Use Ribs for Strength and Material Economy

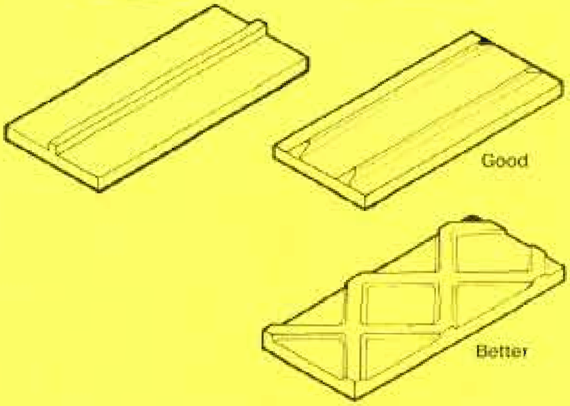
Ribs are an excellent way of strengthening a casting. They should be rounded and blended. Wherever possible arranged to join adjacent sections to provide strength and assist die filling.

Design to avoid **Preferred design**

Ribs should not be square in section.

Blended sections and curved buttresses aid die filling and give a more uniform stress distribution.





These flat plates can be strengthened and die filling assisted by adding ribs.

Shallow, rounded, well-distributed ribs are best, since they are less likely to cause distortion of the casting after ejection from the die.

DESIGN TIPS

Design Using Cored Holes

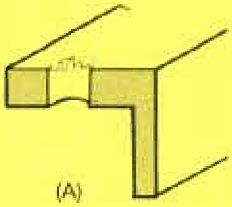
In many cases, drilling and machining can be completely eliminated by casting accurately cored holes. Techniques are available for producing small complex shaped holes without draft. However, to ensure that dies are as strong as possible and require minimum maintenance in production, some attention to detail is necessary by the component designer.

Design to avoid

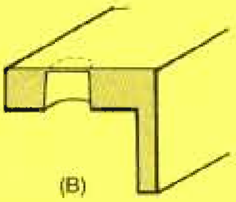
(A)
A blind hole is preferable to a through hole, since there can be problems with flash.

Preferred design

(B)
Where a through hole is required it may be preferable to cast a web at the parting line, which is then removed.

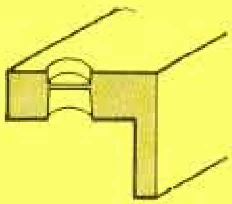


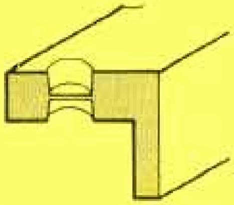
(A)



(B)

If possible, holes should be tapered to assist casting removal from the die. Where holes are tapered the position of the split line is important, since the overall tolerance will be affected by both factors.





Designing Threaded Components

Zinc die casting can produce very fine, accurate details and is capable of producing both internal and external threads on components. However, most internal threads will greatly slow down the die casting process and are therefore usually machined after castering as a separate process.

External threads

Most external threads can be cast provided that they are bisected by the parting line.

(A)
Full threads may be cast in but these require the die caster to maintain high standards of tool accuracy.

(B)
Where the application permits, flats should be incorporated at the parting line so that trimming is simplified and pitch errors are accommodated.

Internal threads

It is usually cheaper to machine internal threads than to cast them in since the core is rotated to permit extraction. This slows down the casting rate (C).

Threads which are either very course or steeply pitched are an exception since they are more easily disengaged.

Internal threads consisting of a single turn can be produced without the need for rotating the core as shown in (D).

Design Tips Courtesy of Zinc Development Association.

Finishing of Zinc Alloy Castings

Zinc casting alloys can be easily finished with inexpensive coatings, producing many attractive, functional, and corrosion-resistant parts. This review of coating characteristics, part design for surface finishing, and surface-preparation techniques will assist designers in specifying the most cost-effective coating for a wide range of applications.

COATING SYSTEMS

When selecting a top coat system, the designer must fully understand the properties of the casting and coating as well as the service conditions the product will be expected to withstand. Many engineering applications do not require surface coating of zinc castings. Their excellent casting and material properties often enable them to be utilized as-cast. Coatings and finishes are specified to enhance the properties of castings in these ways:

- provide a decorative finish
- increase corrosion resistance
- improve engineering properties

The coating systems available for zinc castings offer a wide spectrum and are most often classified into three categories: chemical, metallic and organic finishes.

Chemical Finishes

These finishes are usually based on proprietary chemical solutions applied by an immersion or spray process. The chemical solution reacts with the surface of the casting to form a complex conversion coating system. No current is involved in the formation of these coatings, which are usually based on zinc chromate or zinc phosphate formation. Two of the more popular solutions for chemical blackening are based on chlorate or molybdate salts.

CHROMATE COATINGS. The primary purpose of these chemical conversion coatings is low-cost corrosion protection. In addition, with the colors now available, these finishes can be aesthetically pleasing. This coating process involves a controlled oxidation-reduction reaction.

Hexavalent chromium oxidizes the metal surface. This increases pH at the metal/liquid interface and promotes trivalent chromium to precipitate in a gelatinous form. The amount of entrapped hexavalent chromium will determine the corrosion resistance, while the trivalent chromium oxide film provides a mechanical barrier to abrasion. The ratio of hexavalent to trivalent chromium determines the coating color and, in turn, the corrosion resistance (which depends on pH, concentration, time, and temperature).

Clear chromate coatings, used primarily to prevent finger printing and the formation of white corrosion or storage stain, have the least corrosion resistance. Iridescent (yellow) chromate coatings have a greater corrosion resistance; olive drab, the highest. Figures 1 and 2 show examples of typical chromated parts.

FIGURE 1
The circuit board frame for a personal radio is finished with a clear chromate coating for added corrosion resistance.

FIGURE 2

Iridescent yellow chromate coating provides greater corrosion resistance than clear chromating.

To produce the alternative-colored chromate castings, film is dyed after the rinsing cycle before it has dried. Colors that can be obtained include green, blue, black, turquoise, gold, red, bronze, and violet in light-pastel colors and deep tones. Chromated parts should be lacquer-coated to protect the dyed finish.

PHOSPHATE COATINGS. Phosphate conversion coatings are used primarily as a precoat for organic finishes. Metal surfaces do not provide a good base for paint films, since these surfaces remain conductive. The underlying casting will corrode when the organic surface is broken or when the atmosphere diffuses through organic coatings.

Phosphate coatings impart an insoluble nonconductive film to the casting, minimizing the spread of corrosion if the paint film is broken. These coatings also improve mechanical adhesion and reduce paint blistering since the surface morphology of the conversion coat is "micro rough."

The two types of phosphate coatings in commercial use for zinc castings are amorphous phosphate/molybdate coatings and crystalline zinc phosphate coatings. Zinc phosphate conversion coatings are the most widely used for zinc castings. The gray crystalline coating that forms is a mixture of metal oxides, iron phosphate, and zinc phosphate. More recently, polycrystalline phosphate coatings offering improved corrosion resistance have become popular as a base coat on steel and zinc-based parts.

Phosphate coatings should be sealed prior to painting with a reducing chromic acid rinse, a chrome-free rinse, or a phosphate-free rinse.

These coatings can be applied by an immersion or spray process. Compared to the immersion process, the most popular spray process is characterized by higher production rates, better consistency, and lower chemical cost.

Metallic Finishes

The majority of metallic coatings on zinc castings are electrodeposited, while a small percentage are electroless deposited or vapor deposited. Metallic coatings are favored for their appearance, corrosion resistance, wear resistance, and electrical properties (Figure 3).

FIGURE 3.

Castings that are continuously exposed to harsh environments are Cu/Ni/Cr plated to maintain their original luster.

ELECTROPLATING. In the electroplating process, the metal to be plated onto the casting is introduced into solution by dissolution of a metallic salt or by metal dissolution as an anode. The zinc parts to be plated become the cathode. The most common methods of electroplating are rack electroplating for large parts and barrel electroplating for smaller parts.

Rack electroplating requires good electrical contact between the part and the rack, and the rack and the bus bar. Parts must be securely hung from the rack and positioned in such a way as to prevent excessive drag-out or air and solution entrapment.

Barrel electroplating introduces current to the parts through contact with each other as they tumble in a rotating barrel. Parts with complicated geometry may be difficult to plate, but if the designer decides barrel plating is the logical choice, dimples, grooves, or other configurations can be incorporated to prevent the parts from nesting together, optimizing the plating distribution.

Virtually all electroplating of zinc castings will first require a thin deposit or strike of copper from a copper-cyanide solution. This protects the zinc substrate from acid solutions used in subsequent plating. Usually bright-acid copper will follow the copper strike, but if heavier deposits of copper are not required. a Rochelle copper bath can be used to replace the two-stage operation.

Metals such as nickel, chromium, silver, gold, brass, and bronze can be plated over the copper layer. Zinc can be plated directly over zinc castings to provide a low-cost alternative to the Cu/Ni/Cr system. Nickel and chromium can also be plated directly from solutions formulated for that purpose.

CU/NI/CR SYSTEM. This system is used extensively in both indoor and outdoor applications, combining a decorative appearance with corrosion, wear, and tarnish resistance. Bright-acid copper over the copper strike is generally used to provide excellent leveling and brightness prior to the nickel plate. This can eliminate the need for polishing or buffing before subsequent plating.

Depending on the environment, nickel can be deposited in different thicknesses and in more than one layer (duplex nickel). Duplex nickel improves the corrosion resistance of the Cu/Ni/Cr system. Semibright, sulphur-free nickel is first deposited over the copper, followed by a bright-nickel deposit containing sulphur. This creates an electrochemical potential difference between the two layers. The outer layer corrodes preferentially, effectively providing cathodic protection to the inner nickel layer and slowing corrosion to the substrate.

In addition to providing excellent corrosion resistance, duplex-nickel coatings also produce attractive finishes. Corrosion resistance is enhanced by a thin deposit of chromium over the bright nickel layer. The recently introduced micro-discontinuous chromium (microcracked or microporous chromium) has provided especially good results.

The advantages of microcracked chromium are best realized by controlling the crack density. This ensures that any corrosion condition is distributed over a large area and not limited to a single isolated site. A typical specification for microcracked chromium would call for 64,000 active sites per square inch.

Chromium also provides a slightly blue tone to the bright finish, often found to be more acceptable than bright nickel (Figure 4, Figure 5).

TABLE 1
Plating thicknesses recommended under ASTM B-456

Service Condition	Acetic Acid salt spray Hrs.	Cu µm	Ni µm	Cr µm
SC5 – Extended Severe Service	–	5	35d	.25mc or mp
SC4 – Very Severe Service	144	5	35d	.25r
		5	30d	.25mc or mp
SC3 – Severe Service	96	5	25d	.25r
		5	20d	.20mc or mp
		5	35p	.25r
		5	25p	.25mc or mp
SC2 – Moderate Service	24	5	20b	.25r
		5	15b	.25mc or mr
SC1 – Mild Service	8	5	10b	.13r

Nickel

b – for nickel deposited in the fully bright condition
p – for dull or semi-bright nickel requiring polishing to give full brightness
d – double- or triple-layer nickel coating

Chromium

r – Regular Chromium
mc – Micro Cracked Chromium, more than 30 cracks/mm in any direction
mp – Micro Porous chromium, more than 100 pores/mm^2

Definitions:

SC1: Exposure indoors in normally warm, dry, atmospheres with coating subject to minimum wear or abrasion.

SC2: Exposure indoors in places where condensation of moisture may occur: for example, in kitchens and bathrooms.

SC3: Exposure that is likely to include occasional or frequent wetting by rain or dew or possibly strong cleaners and saline solutions; for example, conditions encountered by porch and lawn furniture; bicycles, hospital furniture and fixtures.

SC4: Service conditions that include likely damage from denting, scratching and abrasive wear in addition to exposure to corrosive environments; for example, conditions encountered by exterior components of automobiles and by boat fittings in salt water service.

SC5: Service conditions that include likely damage from denting, scratching and abrasive wear in addition to exposure to corrosive environments where long time protection of the substrate is required; for example, conditions encountered by some exterior components of automobiles.

ASTM recommends 5 plating thickness configurations, depending on the environmental exposure which the plating will be subjected to (exemplified in Figures 4 & 5).

FIGURE 4
Plating adds brilliance and brings out the detail in zinc castings.

FIGURE 5
This Cu/Ni/Cr plated faucet satisfies consumer demand for a high-quality bright finish.

An alternative to bright-chromium plate is a black chromium. Many industries now use this electroplate, nonreflective, durable and corrosion-resistance surface.

Minimum thickness requirements for the Cu/Ni/Cr system vary according to the specification. In North America, ASTM B-456 defines five service conditions and minimum thickness required for the various plating methods. For example, a mild service condition is defined as exposure indoors in a normally warm, dry atmosphere with the coating subject to minimum wear or abrasion. This might include toasters, oven doors, interior auto hardware, hair dryers, and luggage racks.

The minimum recommended coating thicknesses using single-layer bright nickel is 0.13 micrometers Cr over 10 micrometers Ni over 5 micrometers Cu. This compares to 0.25 micrometers Cr, 35 micrometers duplex Ni, and 5 micrometers Cu, which is recommended for severe conditions.

Alternative Electroplated Systems.

Numerous other coatings can be plated on top of a Cu/Ni system, effectively replacing chromium. These include gold, silver, copper, bronze, brass, and tin/nickel. Many of these can also be directly plated over copper for a lower-cost alternative.

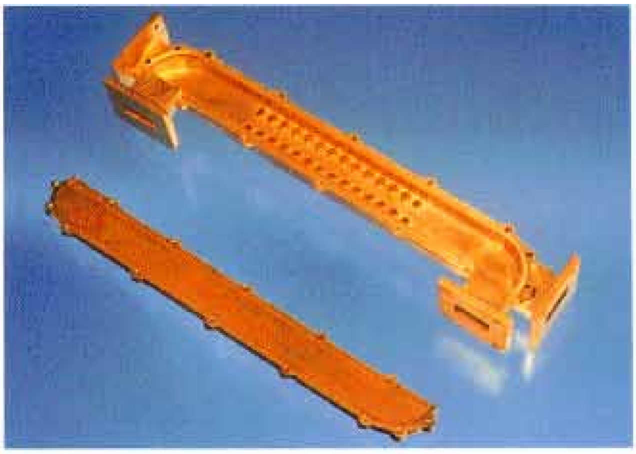


FIGURE 6
This die-cast microwave coupler and cover utilize a thin gold plating on top of a copper/nickel substrate. This provides maximum conductivity and tarnish resistance.

Brass coating can vary considerably in tint from red to yellow to white, depending on the ratio of copper to zinc in the brass. Normally, a 60/40 or 70/30 Cu/Zn ratio is utilized, producing a familiar rich yellow color. Bronze coatings can be buffed or bright plated to an attractive appearance, which is richer and more golden in color than brass.

FIGURE 7
This collage of fittings illustrates various lacquer-coated parts.

Plated copper and its alloys are often used to produce antique finishes. The copper electroplate is usually oxidized by a chemical treatment producing a darker brownish color, depending on the copper content and treatment used. Parts can then be scratch-brushed or relieved to provide the desired antique finish. Clear and tinted lacquers can be used after electroplating to protect copper and brass electrodeposits in either the bright or oxidated condition. Lacquers may be applied by brushing, spraying, or dipping (Figure 7).

Satin finishes on Cu/Ni/Cr electrofinished parts are generally obtained by wire brushing the nickel deposit prior to Cr plating. This provides a more durable finish than brushing the chromium topcoat.

Some proprietary baths can produce satin colors, but they do not have the same reflectance as wirebrush finishes. Textured dies are also used to produce a satin finish and other desired surface textures (Figures 8 and 9).

FIGURE 8
These parts were produced in textured dies to obtain the desired Cu/Ni/Cr finish.

FIGURE 9
This security lock illustrates a satin finish obtained by wire brushing.

Zinc plating of zinc castings has been used for many years to produce more uniform coating appearance. Zinc deposited from cyanide (and, more recently, noncyanide solutions) provides a good bright appearance at a low cost. Subsequently chromating and clear-lacquering parts increase service life.

In addition to metallic coatings, some applications use a combination electroplate/organic coat. Parts that have been electroplated can be masked and painted to highlight certain areas. Highlighting a Cu/Ni/Cr electroplate with paint is very effective (Figure 10).

FIGURE 10

A combination of electroplating and painting can be used for highlights, as illustrated by the Cadillac hood and trunk ornaments.

The traditional Zamak alloys are widely recognized as excellent substrates for plating. ZA-8 and ZA-12 are the preferred ZA alloys for plated applications. ZA-27, having a higher aluminum content (25.5-28.0%), is not normally plated.

ELECTROLESS DEPOSITION. Metallic coatings can also be applied with an electroless deposition process. Compared to electroplating, this process improves coating hardness, wear resistance, corrosion resistance, and dimensional tolerances. Disadvantages include higher chemical costs, lower deposition rates, and less ductile deposits.

This method is used extensively to apply a conducting layer to plastic prior to electroplating. On zinc castings, electroless plating is used to plate parts containing many low current-density areas such as recesses and holes. Gears and sprockets can be given a uniform coat using the electroless process.

From a commercial standpoint, the most widely used metals for electroless deposition are nickel and copper. New procedures allow electroless plating of nickel directly on zinc castings, eliminating the need for a cyanide copper strike.

VAPOR DEPOSITION. Vapor deposition or vacuum metallizing is a method used to deposit thin metallic films on high-volume, low value-added parts. The main objective of this process is to improve the finished part's appearance.

Organic Finishes

Organic finishing systems usually dissolve the resin (the film-forming media) and the pigment (for color and hiding power) in organic solvents or water-based solutions. Water or organic solvents allow the property-forming media to be dispersed over the zinc casting. The solvent is evaporated by air drying or force drying, or aided by baking to leave a dried barrier film on the casting.

Many types of organic finishes are available today. Some of the more popular resins include acrylics, alkyds, epoxies, polyesters, vinyls, and other polymers including polyurethanes. The choice depends on service environment, application method, appearance requirements, environment, health concerns and cost.

COATING RESINS. *Acrylic resins* are used primarily in top coat paint systems over a primer, avoiding adhesion problems between the zinc substrate and the acrylic coating. A durable primer such as epoxy should be used in combination with acrylic resins. Acrylics have good outdoor durability and resist chemical and heat damage very well.

Alkyd resins are good, low-cost top coats characterized by high gloss and good durability, although they will yellow over time. Alkyds are slightly acidic and will react with the casting, causing adhesion problems. They should be used in combination with a suitable primer.

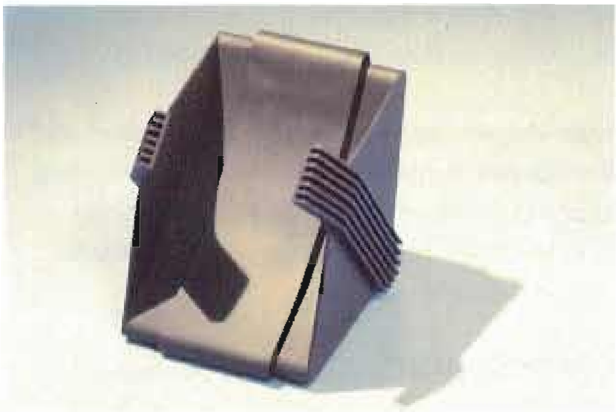


FIGURE 11
A spray-painted ash tray nomenclature. Spray painting is still one of the most widely-used methods of applying paint.

FIGURE 12
Dip-painted belt buckles. As the name implies, parts are dipped in an organic coating and withdrawn.

Epoxy resins are widely used to coat zinc castings. They can be used as prime coats or top coats offering good water resistance, excellent adhesion, and excellent corrosion resistance when in contact with petrochemical derivatives.

Epoxy resins can be formulated to improve gloss, hardness, and impact resistance. They tend to chalk and lose color when exposed to sunlight for prolonged periods; therefore, they are not recommended as a top coat for outdoor application. Epoxies can be applied in thick deposits (1-20 mils), making them suitable for a single coat.

Polyester resins produce high-gloss enamels that offer good weatherability and retain good appearance when exposed to sunlight. Hardness and impact resistance are as good as epoxy coatings, but impact resistance is slightly better. They can also be applied in thicknesses up to 20 mils for good one-coat coverage.

Polyurethanes are also popular coating resins. These coatings produce smooth, even films at low film thickness. Most types resist weathering and ultraviolet exposure well.

Chemical and abrasion resistance is good, permitting high color retention. Polyurethane coatings are not recommended where heavy film buildup is required, since mechanical properties decline when cured film thickness exceeds 3.0 mils.

CHARACTERISTICS OF ORGANIC RESINS.

This section is only a general overview of resin characteristics and application methods. Once the product characteristics are determined, the designer/specifier should consult the coating shop and/or the coating supplier to ensure the most cost-effective coating is specified.

Comparing the cost of coating resins is difficult, but polyester resins are generally the most expensive, followed by acrylic, epoxy, polyurethane, and alkyds.

In addition to the basic resin groups, some hybrid coatings are available that combine the properties of two or more groups to form a coating.

Most resins are now available as both organic solvent and water-based paints. Increased government regulations, particularly in the United States, have generated a lot of interest in water-based paints, high solids loading, powder coats, electrocoats, and spray painting with improved transfer efficiencies.

Even though organic solvent-based paints still occupy a large percentage of the market, designers and specifiers should be familiar with the current, more environmentally acceptable application methods, using such features as reduced organic solvents, nonorganic solvents, or water-based solvents.

Organic finishes can be applied by spray painting (Figure 11), dip painting (Figure 12), flow coating, powder coating, and electrocoating.

SPRAY PAINTING. Spray painting is still one of the most widely-used methods of applying paint. Traditional spray painting mixes a solvent and binder together, and air pressure then forces the mixture through an orifice, causing atomization of the liquid. The deposited film is either air dried, force evaporated, or baked.

Conventional air-atomized spray guns have poor transfer efficiency and are being replaced by methods such as air-assisted spray, electrostatic air spray, and high-volume, low-pressure spray (HVLP). Table 1 illustrates some of the characteristics of these newer systems.

DIP PAINTING. As the name implies, parts are dipped in an organic coating and then withdrawn at a steady, even rate to be air dried or baked. Complicated large parts can be effectively coated in quantity. Dipped parts will typically have coating variations around holes and corners and from top-to-bottom because of coating run-off.

Parts must be withdrawn from the bath at a consistent rate to prevent sag or ring marks. Parts may also be dipped to obtain complete coverage and then spray coated for appearance.

FLOW COATING. This method applies the paint as a heavy coating that flows over the parts. Parts are usually placed on a conveyor that will travel through a flow coating section, drain section, and bake cycle.

Intricate shapes can be coated by this method, and paint utilization is usually better than with dipping. Coating will be more consistent than with a dip method but it will have a wedge-shape thickness, due to the draining methods.

ELECTROCOATING. Electrocoat or electrophoretic paints are always applied from a dip tank, with the part acting as either the cathode or anode, depending on the resin used. The resin and pigments are then electrolytically deposited onto the part. Subsequently, parts are baked to form the final film (Figure 13).

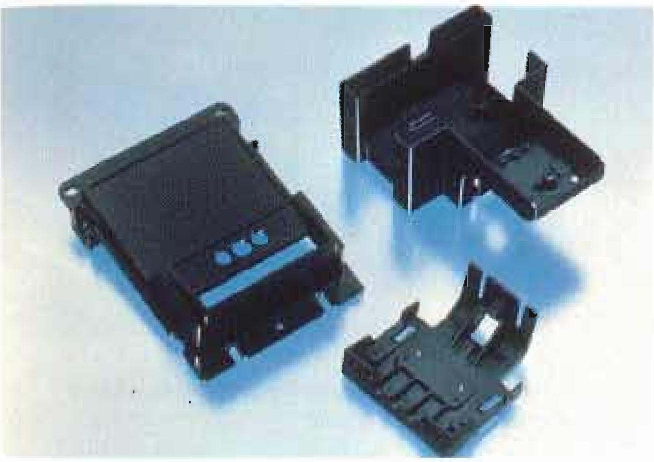


FIGURE 13

The face plate (left) of a dollar bill changer is finished with an electrocoat while two internal components are black dichromate plated.

Electrocoats are widely used in the auto industry. They provide uniform coatings with reduced emissions.

POWDER COATING. This method involves electrostatically spraying a premixed granulated powder onto a workpiece and then curing to obtain final coating properties. Powder coating has many advantages, including the absence of organic solvents, a wide choice of coating materials for many service conditions, minimal material waste, and easy handling.

Disadvantages include high capital investment, process limitations (the process is suited for long production runs with one color), and part-geometry limitations due to the Faraday cage effect.

FIGURE 14
This kitchen mixer is powder coated for a smooth, rich look.

Surface Preparation

All the top coating systems mentioned, regardless of application method, share the need for proper surface cleaning prior to the application of the finishing system.

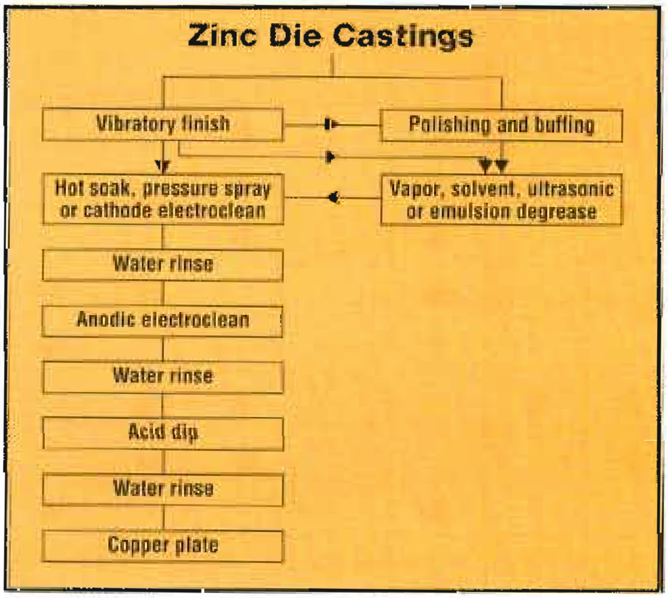


TABLE 1
Typical surface preparation sequence for zinc die castings, prior to electroplating. Sequence may vary.

Table 1 illustrates a typical cleaning sequence for zinc die castings prior to electroplating. This sequence varies, depending on the type of contamination present and the finishing system to be applied. Improper cleaning may cause top coat failure due to substrate adhesion failure and/or blistering.

Coating System Summary

Table 2 summarizes the comparison of the coating systems discussed. It outlines the three criteria that distinguish a coating system: appearance, corrosion resistance, and engineering properties.

This comparison is very general and many individual exceptions exist. Metallic finishes have various degrees of corrosion resistance and different engineering properties, depending on the makeup of the total plated system. Organic finishes also exhibit varying degrees of corrosion protection and abrasion and impact resistance, based on the type of resins used.

SURFACE FINISHING DESIGN

To effectively finish zinc casting alloys the designer needs to understand the required finish at the earliest stages of design. Several proven techniques can be employed minimizing secondary finishing and preventing substandard coating quality.

Most castings can pass directly from the trim press through many of the top coat processes without secondary operations. If required, inexpensive bulk finishing in automated vibratory machines can improve the "as produced" surface finish.

Exceptionally smooth finishes can be obtained by lightly buffing the castings prior to finishing or by proprietary chemical polishing. If a textured finish is specified, the die surface can be tooled accordingly to produce a "cast in" textured surface.

The choice of finish can have a marked effect on part design. A sharp corner tends to develop a thick electrodeposited coating, while void of finish with an immersion-type coating. Involving the finishing shop early in part design eliminates unnecessary part modification, added finishing costs, or in-service quality concerns.

DESIGN CONSIDERATIONS

When a coating is specified for a part, the coating quality specification usually applies only to certain surfaces. Optimizing the coating on significant

TABLE 2 – Service Properties

	Appearance			Corrosion Resistance			Wear and Abrasion Resistance			
Finish	Excel.	Good	Fair	Excel.	Good	Fair	Excel.	Good	Fair	Poor
Chemical Finishes										
Chromates										
A. Clear	●					●				●
B. Yellow		●			●					●
C. Gold	●			●					●	
D. Olive Drab			●	●					●	
Phosphates										
A. Iron Phosphate			●			●				●
B. Zinc Phosphate			●		●				●	
Metallic Coatings										
Electroplating										
A. Copper/Nickel/Chromium	●			●	●	●		●		
B. Black Chromium		●			●	●		●		
C. Direct Chromium on Zinc			●			●		●		
D. Trivalent Chromium			●			●			●	●
E. Zinc Electroplate	●					●				●
F. Silver	●			●	●			●	●	
G. Gold	●			●				●	●	
H. Copper		●				●				●
Vacuum Metallizing										
A. Aluminum Vaporizer	●					●				●
Organic Finishes										
All types and methods of application	●	●		●	●				●	●

surfaces, while working under constraints of the coating process, can provide a formidable task for the design engineer.

Significant material savings, time, and part quality can be achieved by design. The door handles in Figures 15 and 16 are good examples of material optimization on exposed critical surfaces. The Cu/Ni/Cr system is applied to the outer surface for appearance, durability, and corrosion resistance. The handle's underside does not require the same degree of finishing.

FIGURE 15
The outer surface of these 1992 Buick Park Avenue car door handles has a mirror-like chrome finish through a copper, duplex nickel and chrome plating process.

FIGURE 16
The level of plating is reduced on the backside of handles where the only requirement is corrosion resistance.

When designing parts that will be electroplated or electropainted, coating uniformity depends on the part's current distribution. Sharp corners, protrusions, and areas near the part anode will receive a larger percentage of the current, resulting in thicker deposition. Deep recesses tend to be starved of current, resulting in thinner deposits (Figure 17).

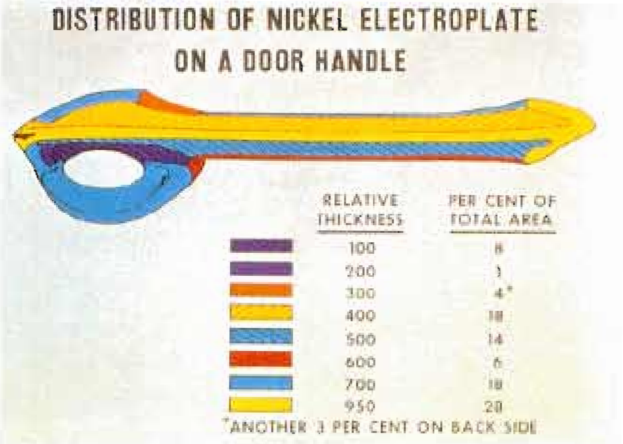


FIGURE 17
Plating distribution on 1970s style door handle

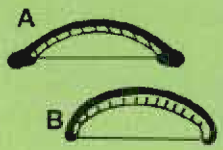
Some subtle design changes (Table 3) can be applied, reducing the effects of current distribution on thickness requirements. For example, a flat surface can be improved by slightly crowning the part. A crown of only 0.005 inches per inch will improve current distribution.

Contemporary designs that often call for a square look incorporating right-angled corners and edges can be modified slightly to benefit current distribution. Rounding corners will save time and material. Slots, blind holes, and through holes are all usually starved for current. Premature corrosion will often propagate from inside these areas, and when close tolerances are required, the heavy buildup around the edges will change the effective diameter.

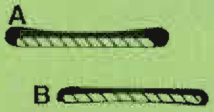
Rounding corners is important. In general, diameters less than 1/32 of an inch are difficult to coat. Blind holes should be less than half as deep as they are wide for effective coating.

Grooves, whether flat-bottomed or V-shaped, will

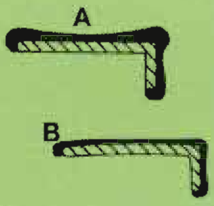
TABLE 3
Design Features that Influence the Electroplatability of Zinc Die Castings



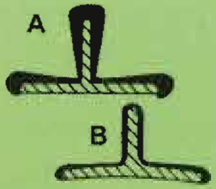
Convex Surfaces
Ideal shape. Easy to plate uniformly, especially where edges are round.



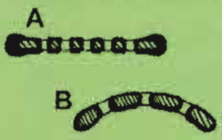
Flat Surfaces
Not as desirable as crowned surfaces. Use a 0.015-inch/inch crown to hide undulations caused by uneven buffing.



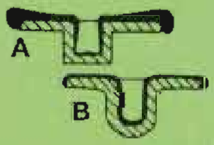
Sharply Angled
Edges undesirable. Reduces thickness at center areas and requires increased plating time for depositing a minimum thickness of durable electroplate. All edges should be rounded. (Edges that will contact painted surfaces should have a minimum radius of 1/32 inch.)



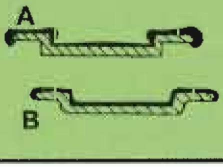
Flanges
Large flanges with sharp inside angles should be avoided to minimize plating costs. Use a generous radius on inside angles and taper the abutment if an unsupported, narrow flange like this is necessary.



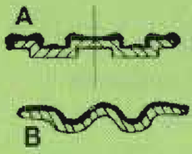
Slots
Narrow, closely-spaced slots and holes reduce electroplatability and cannot be properly plated with corrosion-protective nickel and chromium unless corners are rounded.



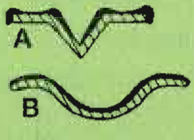
Blind Holes
Blind holes must usually be exempted from minimum thickness requirements.



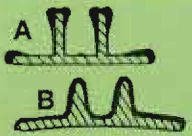
Sharply Angled Indentations
Sharp angles increase plating time and costs for a specified minimum thickness and reduce the durability of the plated part.



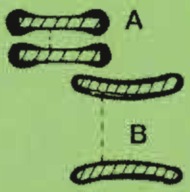
Flat-Bottom Grooves
Inside and outside angles should be rounded generously to minimize plating costs. Plating thickness distribution will tend to restore the crisp design concept that is usually desired for styling grooves.



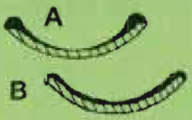
V-shaped Grooves
Deep, V-shaped grooves cannot be satisfactorily plated with corrosion-protective nickel and chromium and should be avoided. Shallow, rounded grooves are better.



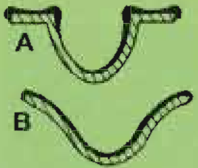
Fins
Fins increase plating time and costs for a specified minimum thickness and reduce the durability of the plated part.



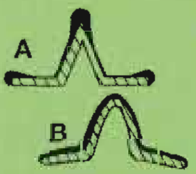
Ribs
Narrow ribs with sharp angles usually reduce elec-troplatability; wide ribs with rounded edges impose no problem. Taper each rib from its center to both sides and round off edges. Increase spacing if possible.



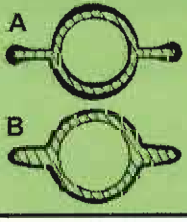
Concave Recesses
Electroplatability is dependent upon dimensions.



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



Spearlike Juts
Buildup of 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 center line, sloping towards both sides.

A = Design Feature **B = Improved Design** *The distribution of electroplate is indicated in an exaggerated fashion by heavy inking* distribute current more evenly if they are rounded and shallow. When fins and ribs are required design elements, rounding, tapering, and wide spacing will improve current distribution and decrease coating time.

While these considerations apply to electrodeposited coatings, the opposite situation usually exists for immersion coatings and non-electrodeposited spray coatings. These coatings tend to be thinnest at corners, cover flat plates more uniformly then cornered plates, and accumulate in deep recesses.

Of course, other process concerns should be of interest to the design engineer. Parts designed with proper coatings will result in smoother transitions from prototype to production part.

Finished casting quality can be drastically affected by how a part is positioned on a coating rack or by how it is held. If parts cannot be secured to a rack in a spray process, a change in design and/or coating process will be required.

Redesigning parts for drainage and effective wetting by rinse water and cleaning and coating solutions will ensure proper surface activities and minimize drag out in continuous immersion-type operations.

Similarly, shapes that entrap air upon entry into processing tanks can block the access of solution to critical areas and prevent proper surface activation. Considering these and other process-related parameters will lead to a smoother transition.

SUMMARY

When proper design is combined with effective part processing, zinc castings will accept a wide variety of surface finishes. Quality finishes that enhance corrosion protection, aesthetic appeal, and engineering properties have been applied to zinc castings for decades.

Zinc Casting Applications

This section describes numerous industrial applications for zinc casting alloys. The applications included represent the broad range of zinc alloys and their casting process capabilities, as described in the other sections of this manual.

Zinc alloys and casting should be considered in component manufacturing for two excellent reasons:

- Zinc alloys offer desirable mechanical and physical properties. These properties challenge those of traditional metals, including steel, bronze, aluminum, and cast iron, and exceed the properties of most engineered plastics.
- Zinc alloys suit a wide range of casting processes that will satisfy most quality and quantity requirements. For example, sand casting and precision-plaster or ceramic-mold casting are ideal for prototyping and short runs of a few to several hundred castings. Permanent-mold and near-net-shape graphite-mold casting fill the gap for production of 1,000-10,000 pieces. Pressure-die casting and miniature-die casting provide the ultimate cast-to-size technology for precision high-volume production. This versatility provides unlimited opportunities for designers to consider zinc alloys for virtually any shape, size, and quantity.

Die casting is probably the most important process, and major technical advances over the last few years have made it even more competitive. Casting machine variables can now be monitored and controlled better. New high-efficiency die design techniques have also been developed. As a result, smaller, more efficient casting machines can produce thinner castings at higher production rates. The new technology permits extremely predictable production performance of new die-cast parts. As a result, zinc die castings are being made that just a few years ago would have been considered difficult or impossible. Today's castings are lighter, have closer tolerances, and cost less to manufacture.

The following applications have been grouped by casting process to assist designers in selecting the process and zinc alloy that best meet their needs.

SAND CASTINGS

Angle Valve

The sand-cast fuel-dispensing angle valve shown was switched from bronze to ZA-12 to lower the material cost (Figure 1). The cost of zinc alloy was only one-third that of bronze. In addition, ZA-12 proved to be more pressure-tight, eliminating a leakage problem. Porosity in bronze had accounted for up to 10% of production losses. Direct substitution with ZA-12 was possible using existing casting patterns. Machining cost was the same as with the original red brass (85-5-5-5) valve (Figure 1).

FIGURE 1
Angle valve

Blender Base

Castings form the base for a commercial food processor and are unique because the sand-cast wall sections are only 0.10 inches thick (Figure 2). This demonstrates the excellent thin-wall sand castability of ZA-12. A smooth finish was also important to minimize surface preparation for painting. Aluminum sand casting would have required walls two to three times thicker to fill properly (Figure 2).

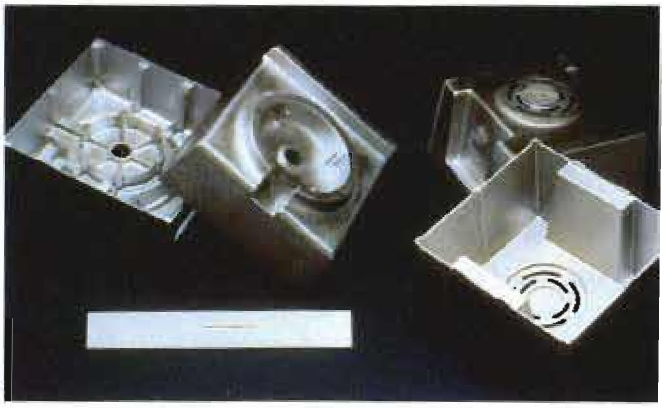


FIGURE 2
Blender base.

Hand-Held Air Hammer

A hand-held air hammer operating at pressures ranging from 50 to 125 p.s.i. now utilizes a ZA-12 alloy hammer cap. The cap was converted from cast iron early in the production stage because machining exposed porosity and weakened the air grill vents.

The ZA-12 sand casting has greater tensile strength than cast iron and is free of porosity. ZA-12 alloy machines faster and with less tool wear than cast iron. Moreover, surface finish is improved and zinc's dampening characteristics reduce vibration and user fatigue (Figures 3 and 4).

FIGURE 3
ZA-12 sand cast hammer cap.

FIGURE 4
Hand-held air hammer.

Scoop Tram Bearings

Underground mining scoop trams now use zinc bearings instead of SAE660 bronze. Figure 5 compares a ZA-12 bearing (on right) and a bronze bushing after one year of rugged service. The bearings were installed side-by-side in the oscillating rear axle of a front-end loader. The maintenance department rated the zinc bearing suitable for another year of service while the bronze bearing required replacement. In addition, zinc bearings cost 30% less.

The recent availability of continuously cast ZA-12 hollow stock gives designers and end-users an even more cost-effective product for sleeve bearing applications (Figures 5 and 6).

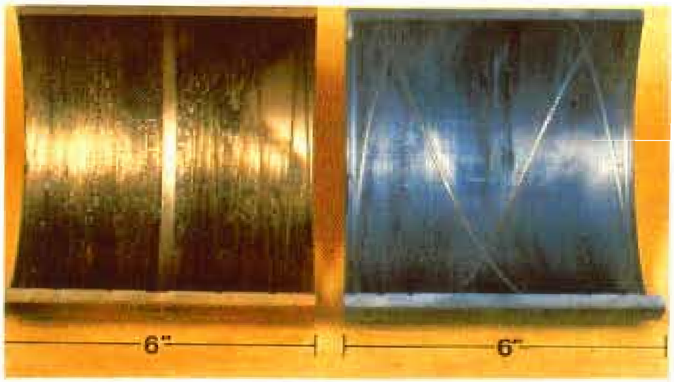


FIGURE 5
Bronze and ZA-12 alloy scoop tram bearing.

FIGURE 6
Scoop tram

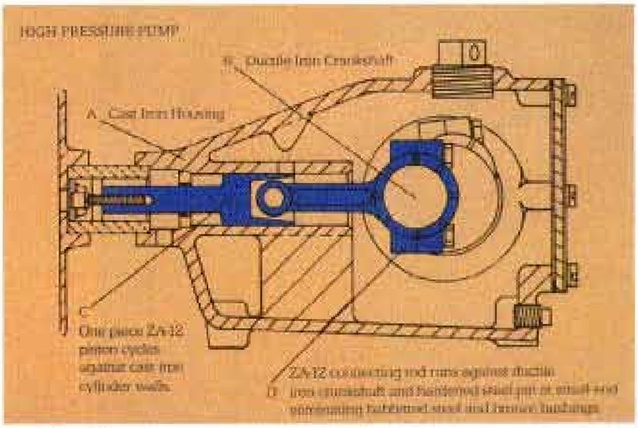


FIGURE 7
Piston pump diagram with ZA-12.

PERMANENT MOLD CASTINGS

Piston Pump

A heavy-duty piston pump used in car washes and industrial spray-cleaning equipment features ZA-12 metal permanent-mold castings for two critical high-wear/bearing components. The connecting rod and piston cross head, shown in Figure 7, cycle at 775 RPM and 1200 psi and surpassed 12,000 hours of around-the-clock testing.

Connecting rods were previously specified in aluminum or cast iron with babbitt-coated steel-bearing inserts at the large end and a bronze wrist pin bushing in the small end. The piston cross head was made as a chrome-plated steel fabrication.

ZA-12 parts, without bushings or plating, showed minimal wear and were rated superior to the old designs. The cost of both ZA-12 parts was less than half that of the original parts. Some secondary machining and assembly operations were also eliminated for additional savings (Figures 7 and 8).

FIGURE 8
Heavy-duty piston pump.

Parabolic TV Antenna Parts

At the focus of this parabolic TV antenna is an electric feed horn assembly that uses six ZA-12 castings made by the graphite-mold process. The parts had to be dimensionally stable and leak-proof under all weather conditions. ZA-12 castings proved to be strong and durable and had good machinability and the necessary RF shielding qualities.

The graphite-mold process, with its low tooling cost, was ideal for the production quantities required, while epoxy coating gave the assembly an aesthetic, durable finish (Figures 9 and 10).

FIGURE 9
Parabolic T. V. antenna cast components.

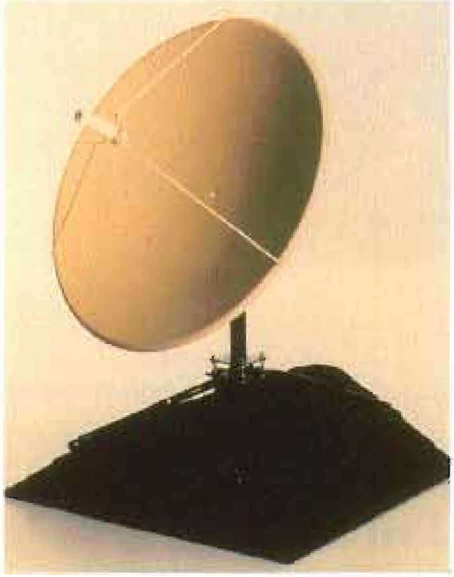


FIGURE 10
Parabolic T. V. antenna.

Blood Analyzer Centrifuge

Not all designs need thin walls. The blood analyzer centrifuge casting, shown in Figure 11, required high mass and high strength. A ZA-12 permanent-mold casting was selected because of its soundness for heavy-walled designs. Several coats of paint protect the casting from aggressive chemicals used in equipment cleaning (Figure 11).

FIGURE 11
Blood analyzer centrifuge.

GRAPHITE PERMANENT MOLD CASTINGS

Collage of Castings

Figure 12 shows an assortment of ZA-12 graphite permanent-mold instrument brackets, levers, and machine components. These components dramatically illustrate the quality of the as-cast finish and design detail possible with this relatively new casting process; particularly, cast holes with diameters down to 0.030 inches. The process can readily satisfy quality and precision requirements (similar to investment casting tolerances) at reasonable tooling costs for production volumes from several hundred to several thousand pieces (Figure 12).

FIGURE 12
Graphite permanent mold castings.

Tucker Vise (Wood Worker's Vise)

This award-winning vise is a complex, professional-quality tool intended for pattern makers, cabinet makers, and serious hobbyists. The patented design contains many features including three types of jaws, integral swivel "dogs" and a quick-release mechanism (Figures 13 and 14).

The vise uses eight graphite mold-cast ZA-12 components that were chosen over cast iron, for the following reasons:

- ZA-12 has higher strength (48,000 psi UTS vs. 31,000 psi UTS for cast iron).
- Thin-wall complex shapes were made without machining or fabricating.
- Close tolerances and good surfaces eliminated most of the machining and finishing.
- Tooling cost was 25-30% less.

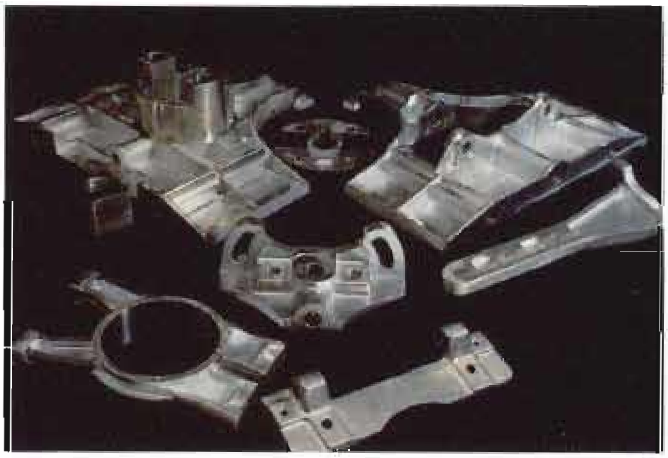


FIGURE 13
Wood working vise components.

FIGURE 14
Tucker vise.

Card Racks for IBM AS400 Computer

Two grids are used (top & bottom) in the IBM AS400 computer to support the electronic "cards". The grids are 10-1/4 by 16-3/4 inches, and have a critical flatness tolerance of 0.020 inches.

Final production quantities will eventually be high enough to warrant investing in die-cast tools, but as an interim measure, initial production uses graphite mold-cast ZA-12 components. This was considerably less expensive than the alternative of machining from solid aluminum, while still permitting design changes to be carried out quickly and inexpensively.

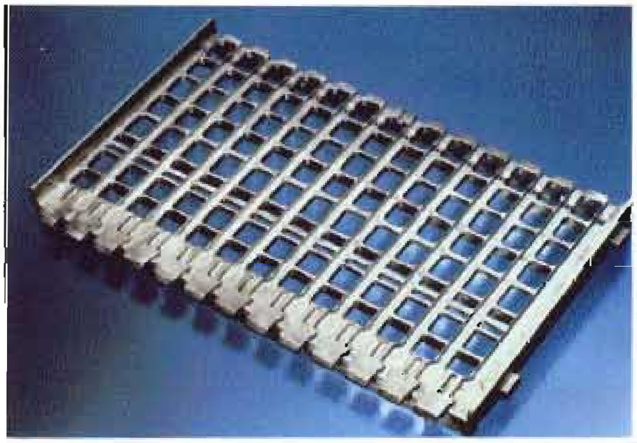


FIGURE 15
Computer card deck.

The castings met all dimensional and surface-finish requirements and proved strong enough to pass a severe drop test with flying colors (Figures 15 and 16).

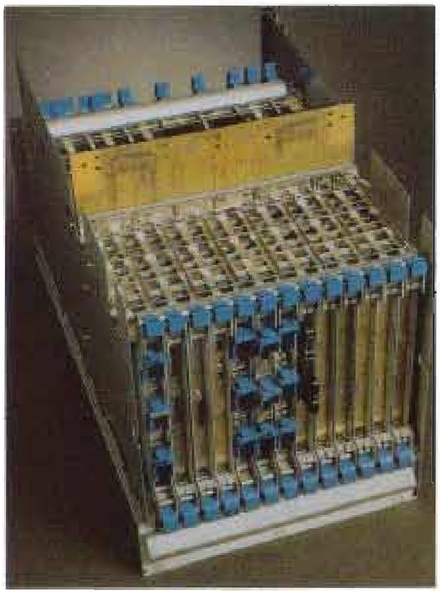


FIGURE 16
IBM AS400 computer.

PRESSURE-DIE CASTING

Tower Model Mini Computer

NCR's Tower Model minicomputer features two sets of No. 3 alloy zinc die castings. The first are long, thin, bulkhead castings (Figure 17), which support computer logic cards loaded with microchips and electronics (Figure 18). The second are rectangular logic module frames (Figure 19), which separate and position banks of logic cards. The outer edges of the frames can be seen in Figure 18 above and below the logic cards.

FIGURE 17
Bulk head castings.

Four bulkhead castings were developed from a single tool, using die inserts to cast variations of tabs, slots, and openings that would accommodate different I/O connectors. The 19-inch-long castings have a nominal thickness of 0.075 inches. Part complexity, thinness, and tolerances were beyond the capability of steel stampings, which were found to be expensive and inadequate.

Wire form weldments were tried for the logic module frames, but this design proved too heavy and tolerances too loose. Innovative application of die inserts permitted three styles to be die-cast from a single master tool. Wall sections were lightened to 0.060 inches using an oval channel cross-section for strength. Zinc die castings reduced cost by one third and weight by 35%. In fact, die-cast tooling costs were recouped within eight months. The parts are given a bronze chromate finish, machined, and inspected by the die caster for JIT delivery to NCR's assembly plant.

FIGURE 18
NCR Tower Model minicomputer.

Using the latest casting and design technology, the die caster achieved "predictable" castability with the demanding wall frames. First shot success resulted in immediate customer approval and product introduction (Figures 17 – 19).

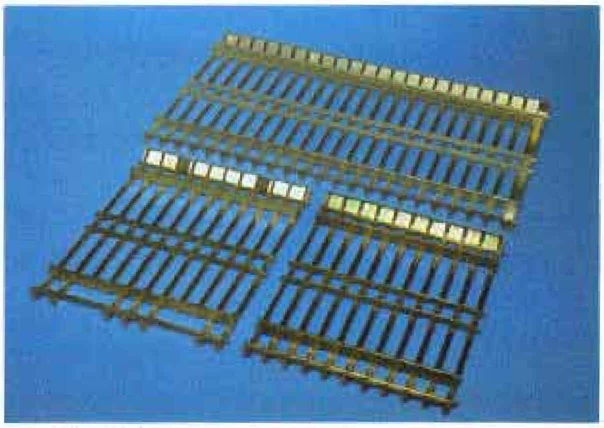


FIGURE 19
Logic module frames.

High-Frequency Radio RF Deck

Another dramatic example of zinc die-cast engineering excellence is the high-frequency radio RF deck shown in Figure 20. The casting is made with 98 cored holes, slots, and grooves. Secondary machining is limited to tapping of selected holes.

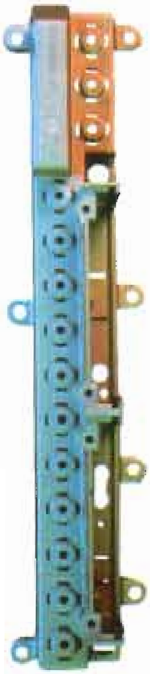


FIGURE 20
High-frequency radio RF deck – front.

FIGURE 21
RF deck with 0.019-in. ribs, seen from backside.

The alternate view, Figure 21, shows the casting is divided into 14 individual cells by a network of 0.019-inch ribs running perpendicular to the length of the casting providing the necessary RF shielding.

Costs were astronomical when investigated as a light-gauge metal stamping assembly. A design using a Zamak 3 zinc alloy die casting was the only economical choice (Figures 20 and 21).

Truck Winch

High strength is the main requirement for the two ZA-27 die castings shown in Figure 22. They are major structural components in a line of recreational winches used on trucks, jeeps and off-road vehicles. The casting functions as a rotation and stationary ring gears that must transmit the entire load during winching. The original design used aluminum die-cast ring gears. However, the aluminum casting limited loading to 1500 pounds.

FIGURE 22
ZA-27 alloy winch components.

The manufacturer cast ZA-27 parts using the original dies and found ZA-27 gears significantly stronger and harder. Subsequently, the company designed two higher-load winches of 2500- and 3500-pound capacity using ZA-27 castings. Today, this manufacturer casts both aluminum and ZA-27 with the same dies. As a result, new tooling costs were minimized and product design and market introduction for the new designs shortened by nearly one year (Figures 22 and 23).

FIGURE 23
Heavy-duty recreational winch.

Axle Tube Extension and Valve

The axle tube extension is another high-strength application. The 9-pound ZA-27 casting is used on pickup trucks. It is shown with a smaller ZA-8 die-cast valve part. The ZA-27 die casting is a key component of the fixed front drive axle/differential in a General Motors four-wheel drive system.

FIGURE 24
Axle tube extension and valve.

The die-cast tubes are a radical departure from a steel fabrication. As a result, ZA-27 went through years of exhaustive testing, using literally thousands of castings on prototype vehicles at GM's Milford, MI, and Mesa, AZ, proving grounds. In torque-to-failure tests, ZA-27 tubes withstood 40,000 inch pounds, while a fabricated steel alternative failed at 11,000 inch pounds. Both ZA items have been in production since 1987 (Figures 24 and 25).

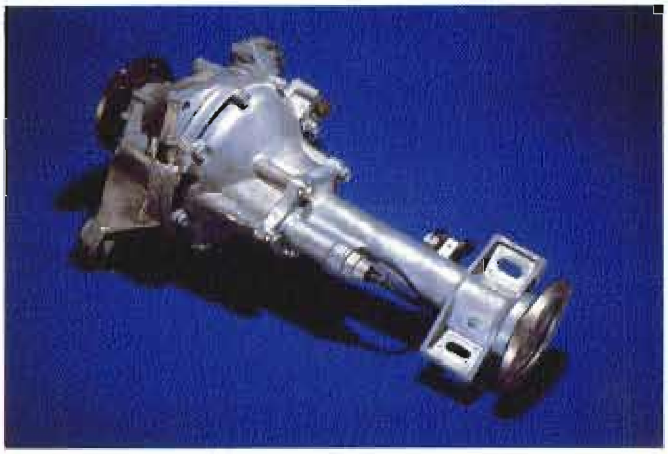


FIGURE 25
Axle tube extension assembly.

Subminiature Die Castings

Imagine die castings so small that a pound of zinc produces 170,000 finished parts. One instrument manufacturer was able to accomplish this. Two separate castings, one 0.0155 by 0.019 by 0.100 inches and the other 0.020 by 0.031 by 0.100 inches, are produced for use in scientific instruments. Both castings have detailed features that require tolerances of ±0.00025 inches.

Using miniature zinc die castings saved the instrument manufacturer $590,000 annually (Figures 26 and 27).

FIGURE 26
Subminiature die castings, 170,000 parts per pound.

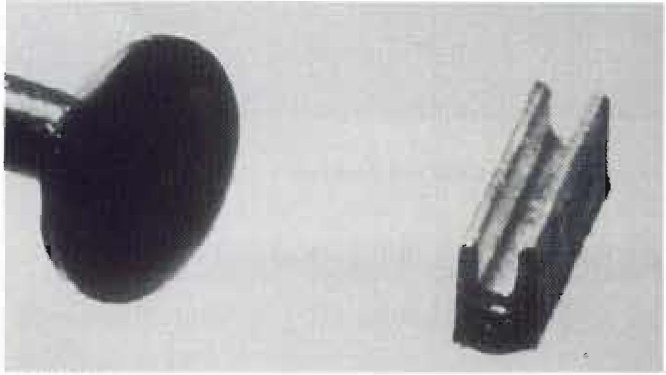


FIGURE 27
Zinc die casting next to a standard straight pin.

Automatic Transmission Selector Tube

This component was originally designed as a steel tube with die-cast magnesium ends. By converting it to ZA-8 die casting, the designer combined high-strength material and one-piece construction. He was also able to incorporate the indicator arm and brake cancel cam, thus reducing assembly costs. Total savings was calculated at $1.50 per assembly times a production rate of 55,000 per week (Figures 28 – 30).

FIGURE 28
ZA-8 alloy transmission selector tube.

FIGURE 29
Replaced steel tube and magnesium casting assembly.

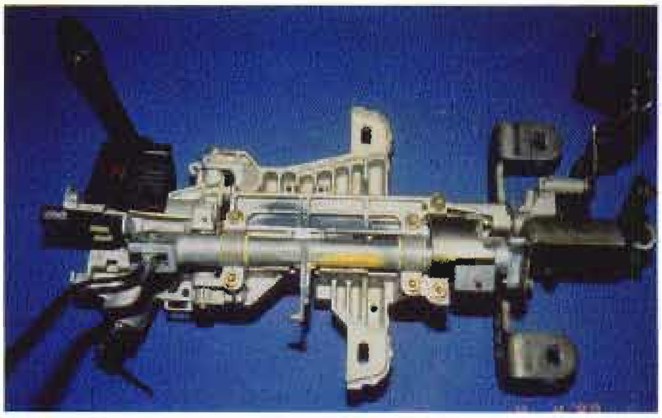


FIGURE 30
Automatic transmission selector assembly.

Computer Heat Sinks

The 1-1/2-inch-diameter ZA-8 die castings shown are used to cool a powerful tower-type computer. The threaded ends are screwed directly into the PC cards to give a very efficient heat path. The 0.020-inch-thick radial fins provide an exceptionally large surface area and efficient radial flow direction to the air, which is ducted into the center of each die casting via a plenum chamber (Figures 31 and 32).

FIGURE 31
1-1/2-in.-diameter radial-fin heat sink.

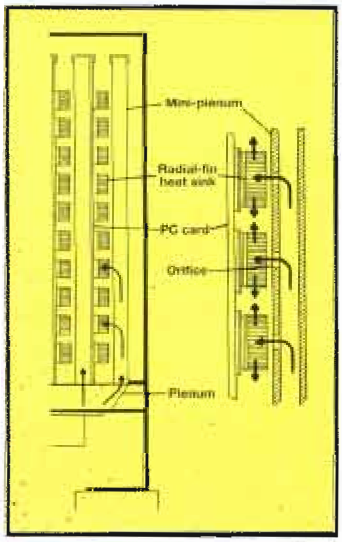


FIGURE 32
Cooling air flow diagram for mainframe computers.

Air Compressor Manifold & Check Valve

In this example, a single Zamak 3 die casting replaced an assembly of machined parts in a pressure-tight application. This change cut manufacturing costs by 85 percent. The casting weighs 13 oz. and measures 5.75 by 4 by 1.25 inches. It has seven male threads and nine cored holes, all cast in (Figure 33).

FIGURE 33
Air compressor manifold and check valve.

Miniature Electronics Jack

This miniature electronics jack, used in professional digital video systems, originally was a six-piece brass assembly that was soldered together. Changing to a Zamak 3 die casting reduced the cost and improved tolerances and durability. The jack is electroless nickel plated to give low electrical contact resistance and corrosion protection, without build-up on projecting portions (Figure 34).

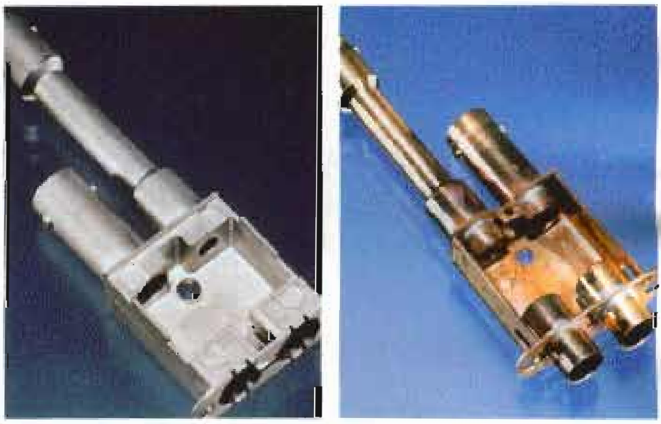


FIGURE 34
Die-cast miniature electronics jack and replaced welded brass assembly.

High Security Lock

This drop-bolt jimmy-proof lock was designed to be strong and rugged, but inexpensive. The designer chose to use Zamak 3, which has a good combination of strength, toughness, and ductility. The surfaces are textured to aid die filling and to give the required finish. The housing is copper/nickel/brass plated to protect against corrosion and retain the aesthetic appeal of brass (Figure 35).

FIGURE 35
High-security lock.

Air-Drive Ratchet Wrench

This high-quality 1/4-inch pneumatic ratchet wrench was completely redesigned to reduce cost and improve looks and performance. Die-cast ZA-8 was used for the internal air manifold, reducing the number of parts and simplifying assembly.

Die-cast ZA-27 was used for the body because of the high stresses and abusive conditions the wrench undergoes in garage use. The thin-wall, two-part assembly requires virtually no machining and it is finished by polishing and epoxy coating, giving the look and feel of stainless steel. A design bonus is the sound-dampening characteristics of zinc, which reduce the wrench's operating noise (Figure 36).

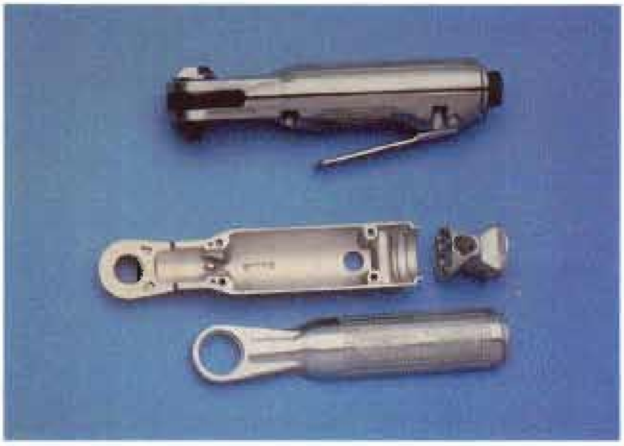


FIGURE 36
Air-drive ratchet wrench and die cast components.

Radio Circuit Board Frame

A professional-quality personal radio utilizes three different zinc die castings which all provide thin-wall design, strength, EMI and RFI shielding. The castings include the circuit board frame or chassis, the chassis shield and the synthesizer housing.

The most intricate casting is the circuit board frame which compartmentalizes and isolates the various electronic components of the transmitter. The frame provides protection for the electronics by stiffening the circuit board and dampening damaging vibrations.

The frame is cast with 0.032-in. maximum wall thickness at the parting line and 0.024 in. at the taper in addition to zero-draft for tight assembly requirement (Figures 37 and 38).

FIGURE 37
Professional-quality personal radio.

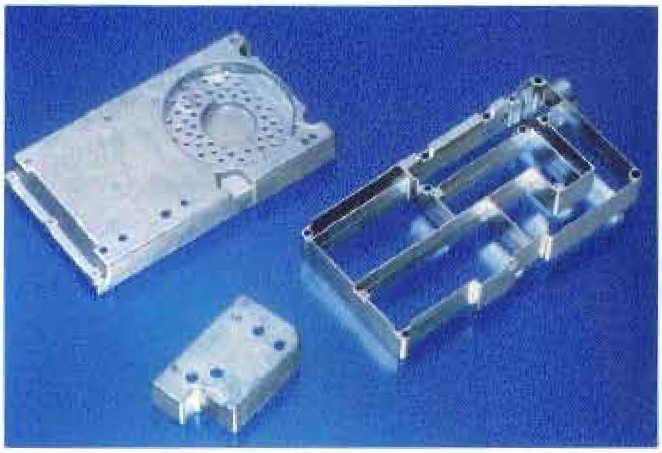


FIGURE 38
These three zinc die castings are incorporated in the personal radio.

Power Seat Adjuster Gearbox

This gearbox is 11 inches long and has two 1.75-inch diameter internal ring gears. The 27 gear teeth are cast with zero draft and held to 0.003 in. T.I.R. Die-cast zinc alloy permitted zero clearance between the teeth and the wall as well as incorporation of the worn gear mountings and reversing mechanism. The extensive use of fins and buttresses reduced weight and cost while giving great rigidity and strength to the part (Figures 39 and 40).

FIGURE 39
Cast 27-tooth, 1-3/4 in.-diameter ring gear.

FIGURE 40
11 in. long power seat adjuster gear case.

Grinding Disk Arbor

This critical safety item had to retain and support a high-speed grinding disk used under extreme conditions.

The die casting process was used to achieve close dimensional tolerances and good balance. Zamak 3 alloy is specified for its good balance of strength and toughness, coupled with its ability to be "spin" riveted providing a tight, safe joint between the abrasive disk and the arbor (Figure 41).

FIGURE 41
Grinding disk and center arbor.

SUMMARY

Zinc castings have application across a broad range of products and industries, ranging from high-volume automotive components to one-of-a-kind prototypes, and from nonprecision wear bearings to precise subminiature components.

In fact, zinc castings have such wide application that 500 million pounds of zinc alloys are cast in North America annually by over 500 casters.

INTERZINC

INTERZINC is a market development and technology transfer group, dedicated to increasing awareness of zinc casting alloys among engineers, designers and specifiers. It aims to accomplish this mission through technology transfer, technical services and designer education programs.

Zinc casting technology is not a process frozen in time. Rather, it continues to undergo advancements benefiting those who specify and select engineering materials. INTERZINC assists designers to take maximum advantage of this technology.

Since its formation in 1986, INTERZINC has participated in national and international exhibitions; presented technical sessions at these exhibitions and conducted its own technical seminars. Through these activities INTERZINC has provided potential end-users of zinc castings with the following services:

- Technical literature.
- Alloy and process selection help.
- Casting design and prototyping assistance.
- Product feasibility studies.

For information and assistance contact INTERZINC:
1-800-247-6265 or (313) 794-3940
P.O. Box 455, Algonac, MI 48001-0455

Printed in U.S.A.

11/92