THE NEW HIGH FLUIDITY ZINC ALLOY

NADCA
NORTH AMERICAN DIE CASTING ASSOCIATION

U.S. DEPARTMENT OF ENERGY

Zinc ...essential for life

The New HF (High Fluidity) Zinc Alloy:
Extending zinc's alloying capabilities and improving energy efficiency

Introduction

A new high fluidity zinc alloy has been developed that provides die casters significant energy and cost savings and performance improvements compared to existing alloys. Designated the HF (High-Fluidity) Alloy, it was developed through a multi-year project coordinated by the Cast Metals Coalition, an industry consortium including the North American Die Casting Association (NADCA). The International Zinc Association (IZA) managed the project with financial support from the US Department of Energy (USDoE).

The HF alloy is based on the commonly used ZAMAK alloys but possesses up to 40% better fluidity. Industrial trials and evaluations have confirmed the excellent fluidity of the alloy as well as its easy use and adoption. Tests have shown the alloy has comparable physical, mechanical and corrosion properties as Alloy 3 and 7 and is best suited for casting parts with section thickness less than 0.45 mm. It can also be used for casting parts that are difficult to fill or have high surface finish requirements.

A Solid Foundation

Zinc alloys have many unique benefits for the die casting process; they are strong, durable and cost effective. Their mechanical properties compare favourably with cast aluminium, magnesium, bronze, plastics and cast irons. These characteristics, together with their superior finishing capabilities and choice of casting processes make zinc alloys a highly attractive option for modern die casting.

Zinc is also considered the most energy efficient of the engineering alloys by virtue of its low melting point and superior net-shape casting capability (which allows for reduced machining operations). Zinc alloys also offer the fastest production rates and longest tool life.

1 **Assembly operations are reduced.**
Entire assemblies can be cast as a single unit, eliminating the need for expensive manual assembly operations.

2 **Less material is required.**
Zinc's superior casting fluidity, strength and stiffness permits the design of thin wall sections for reduced weight and material cost savings.

3 **Maching operations are reduced.**
Due to the superior net-shape casting capability of zinc alloys, maching can be eliminated or drastically reduced.

4 **Choice of low, medium and high production.**
A variety of casting processes are available to economically manufacture any size and quantity required.

5 **Eliminate bearings and bushings.**
Zinc's excellent bearing and wear properties allow greater design flexibility and reduce secondary fabrication costs by eliminating small bushings and wear inserts.

6 **Faster production and extended tool life.**
Die casting production rates for zinc are much faster than for aluminum, or magnesium. Coupled with a tool life often exceeding 1 million parts, tooling and machine usage charges are dramatically reduced.

Less Weight = Less Energy

Weight is a major factor in reducing the energy efficiency of castings, especially since the energy savings achieved through weight reduction applies across the casting cycle life; from melting, casting, transport of finished parts, during use (e.g. vehicle applications) and end-of-life collection and recycling.

Since castings are created to specific dimensions, the only way to reduce weight is to select the lowest density casting alloy (which may come with performance trade-offs) or use less material by reducing the thickness of the casting wall. The latter approach of reducing casting wall thickness brings the added benefit of reduced material handling, melting and scrap costs.

Alloy Development

Thin section casting in all engineering alloys is limited by the casting properties of the liquid alloy, the thermal properties of the mould or die, the shape of the component to be cast and the design of the metal introduction system including gates and runners.

Zinc alloys allow a thinner wall section as compared to most other metal alloys or casting processes because of zinc's low melting point and its good fluidity during the casting process. Prior to the development of the new HF alloy, zinc castings were limited to a thickness of around 0.75 mm. The new alloy significantly improves zinc alloy fluidity to allow a reduction in casting section thickness to 0.3 mm or less.

The New HF Alloy

The HF alloy is based on the commonly used ZAMAK alloys but possesses up to 40% better fluidity than Alloy 7, which until this development was the previously most successful commercial high-fluidity zinc alloy. The composition of the HF alloy is shown in Table 1.

Tests have shown the alloy has comparable physical, mechanical and corrosion properties to Alloy 3 and 7 and is best suited for casting parts with section thickness less than 0.45 mm. It can also be used for casting parts that are difficult to fill or have high surface finish requirements.

The new alloy exceeded minimum thickness targets and allows for casting parts with a wall thickness as thin as 0.25 mm (Fig. 1). Industrial trials and evaluations have confirmed the excellent fluidity of the alloy as well as its ease of use and integration in existing die casting operations.

Table 1:

HF Alloy Composition (wt%)

Aluminum	4.3 - 4.7
Magnesium	0.005 - 0.012
Copper	0.035 max
Iron	0.03 max
Lead	0.003 max
Cadmium	0.002 max
Tin	0.001 max
Zinc	remainder

Alloy 7 HF Alloy

Figure 1:
Die filling behavior into a 0.25mm thickness section for the most fluid conventional alloy, Alloy 7, and the new HF Alloy

The new alloy exceeded minimum thickness targets and allows for casting parts with a wall thickness as thin as 0.25mm.

Thin Section Filling Ability

A comparison of the filling capability of the new HF Alloy versus Alloy 7 for a stepped cavity die from an industrial trial with one die caster (Fig. 2) showed a 15% improvement, with the greatest increase observed under the most favorable filling conditions (Table 2).

Figure 2:

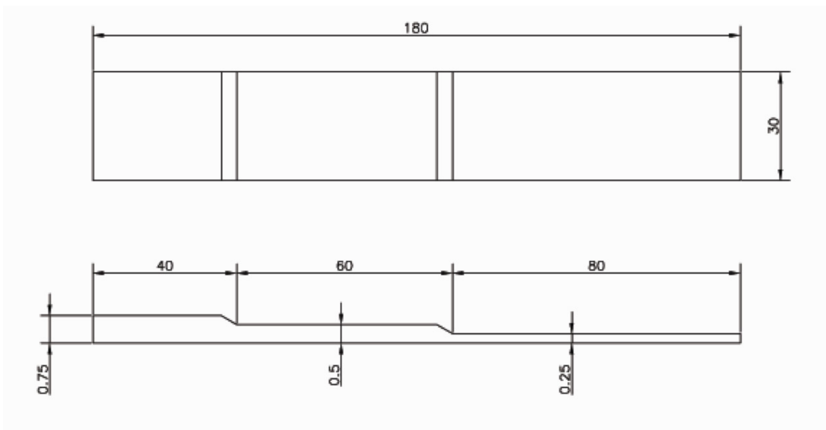


Table 2:

Alloys	Die Temperature (C)	Fill time (milliseconds	Average weight (g)	Average Flow Distance (mm)
Alloy 7	200	15	28.19	180.0
	200	25	18.21	125.4
	177	15	27.51	180.0
	177	25	16.87	117.8
HF Alloy	200	15	32.53	180.0
	200	25	18.88	125.5
	177	15	29.42	180.0
	177	25	18.52	118.8

Mechanical Properties

Despite using less material, the HF Alloy has excellent mechanical properties as shown in Table 3.

Table 3:

Ultimate Tensile Strength (*) – ksi (MPa)	as cast:	40 (276)
	aged:	34 (234)
Yield Strength – ksi (MPa)	as cast:	35 (241)
	aged:	29 (200)
Elongation – % in 2 in. (51 mm) gauge length	as cast:	5.3
	aged:	9.9
Impact Energy (2*) – ft-lb (Joules)	as cast:	28 (38)
	aged:	21 (28)
Hardness, Brinell (3*) 250 kg, 5mm ball	as cast:	93
	aged:	71
Young's Modulus (4*) – psi (GPa)	as cast:	13.3 x 106 (91.7)
Poisson's Ratio	aged:	0.30

(*) -- Sample cross-section dimensions 0.040 x 0.500 in; tensile strength increased to 54 ksi when sample cross-section was reduced to 0.020 x 0.300 in.
(2*) – Sample dimensions 0.25 x 0.25 x 3 in.
(3*) – Tested under 250kg weight with 5mm ball
(4*) -- Calculated using stress-strain curve

Samples "as cast" were tested at 68 °F (20 °C)

Samples "aged" were kept at 203 °F (95 °C) for 10 days.

Linear Dimension Tolerances

Die casting is a high precision components manufacturing process. A comparison of typical linear dimension tolerance capabilities of zinc die casting and other manufacturing processes is shown in Fig. 3.

Tolerance standards are published by the International Organization for Standardization (ISO), North American Die Casting Association (NADCA), and others (Fig. 4). These are minimum standards that in many cases can be improved upon by the die caster, greatly reducing post-casting operations such as machining to true up holes and critical dimensions. Many zinc die castings are produced in so-called "four slide" machines to even greater tolerances (Table 4).

Figure 3: Precision capabilities of zinc die casting and other manufacturing processes

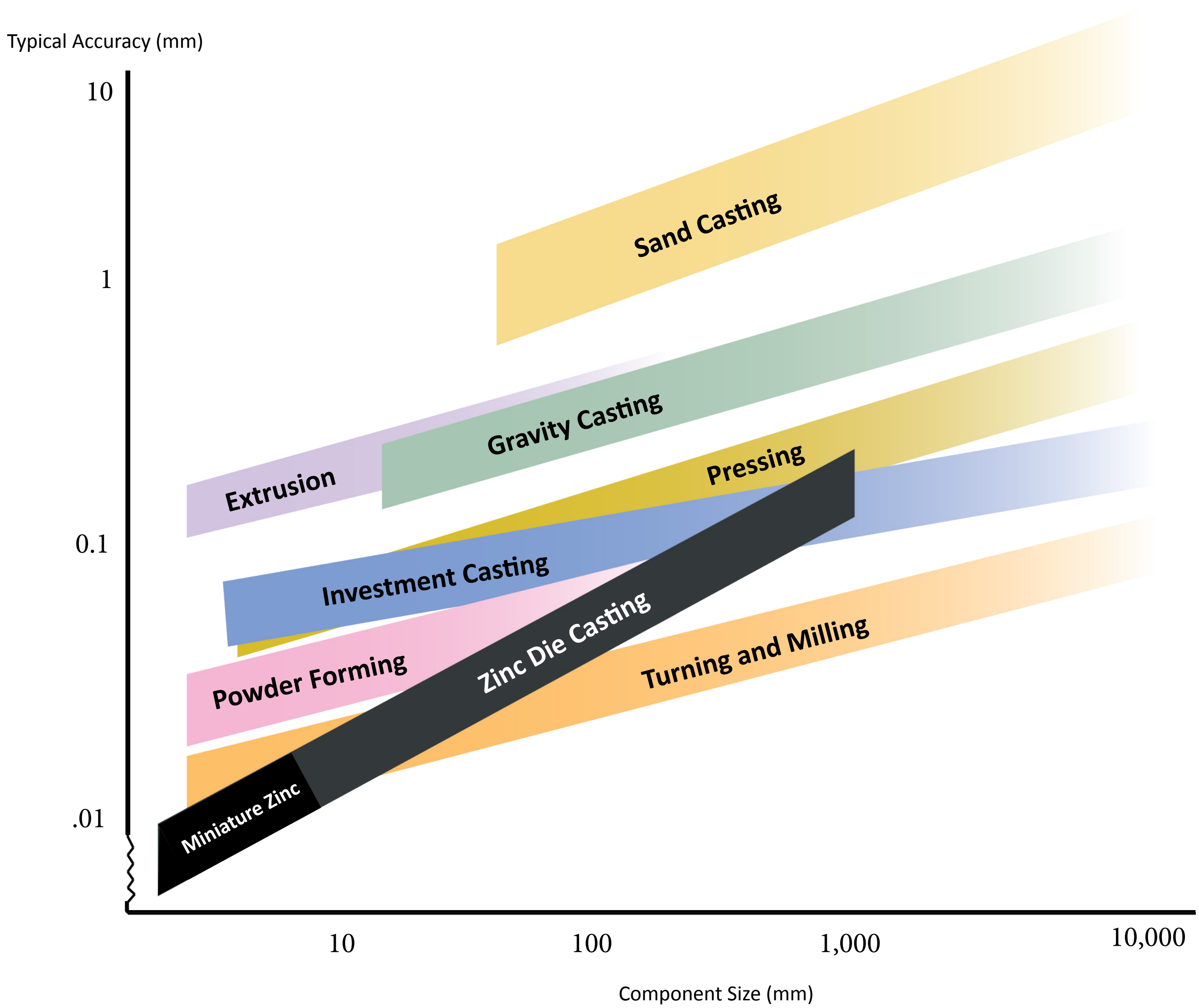


Figure 4:

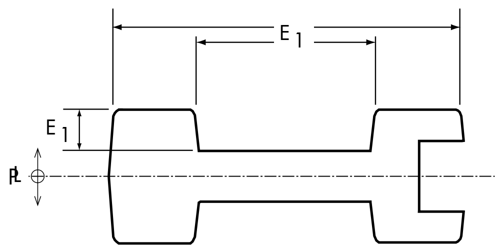
Engineering & Design: Coordinate Dimensioning

6 Linear Dimensions: Standard Tolerances

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

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

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



Example: An aluminum casting with a 5.00 in. (127 mm) specification in any dimension shown on the drawing as “E_1”, can have a Standard Tolerance of ±0.010 inch (±0.25 mm) for the first inch (25.4 mm) plus ±0.001 for each additional inch (plus ±0.025 mm for each additional 25.4 mm). In this example that is ±0.010 for the first inch plus ±0.001 multiplied by the 4 additional inches to yield a total tolerance of ±0.014. In metric terms, ±0.25 for the first 25.4 mm increments plus ±0.025 multiplied by the 4 additional 25.4 mm to yield a total tolerance of ±0.35 mm for the 127 mm design feature specified as “E_1” on the drawing. Linear dimension tolerance only applies to linear dimensions formed in the same die half with no moving components.

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

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

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

Significant numbers indicate the degree of accuracy in calculating precision. The more significant numbers in a specified tolerance, the greater the accuracy. Significant number is the first non-zero number to the right of the decimal and all numbers to the right of that number. For example, 0.014. The degree of accuracy is specified by the three significant numbers 140. This is not to be confused with tolerance precision. A tolerance limit of 0.007 has a higher degree of precision because it is closer to zero tolerance. Zero tolerance indicates that the part meets design specifications exactly.

Linear Standard and Linear Precision tolerances are expressed in thousandths of an inch (.001) or hundredths of a millimeter (.01).

Notes:

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

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

Table 4: Minimum Tolerance Standards for Four Slide Machines (NADCA, 2012)

Note: *Tolerances given below have been achieved and are strictly applied to multiple slide, miniature diecasting. The values may vary with size, desgin and configuration of the component. Please consult your diecaster for establishing tolerances for specific part features.*

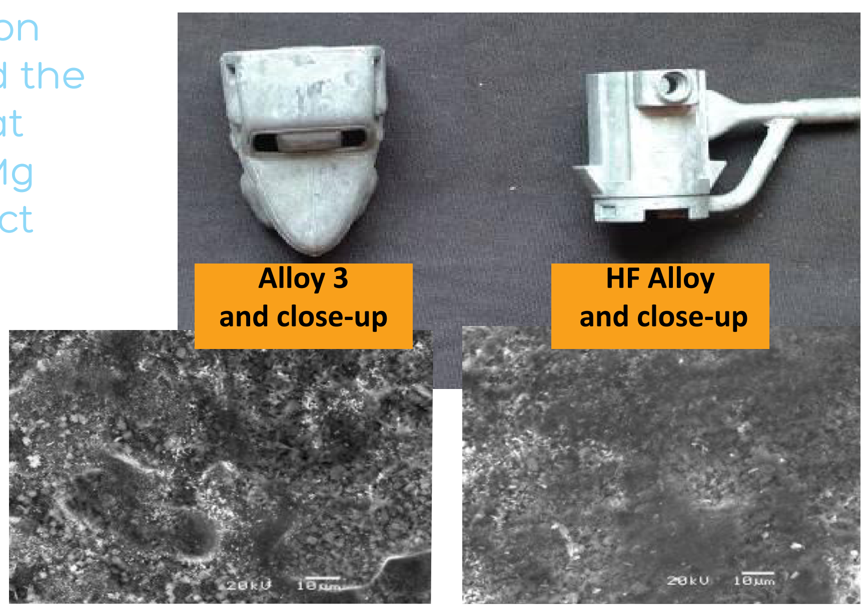
Linear Dimension	±0.0008" up to 1" and ±0.001 for each additional inch	±0.020mm up to 25.4mm" and ±0.025 for each additional 25.4mm
The following values are typical for a 1.18" (30mm) component.		
Flatness	0.002"	0.05mm
Straightness	0.001"	0.03mm
Circularity	0.001" (// to parting line)	0.03mm (// to parting line)
Angularity	0.001 in/in	0.001 mm/mm
Concentricity	0.002" (// to parting line)	0.05mm (//to parting line)
Minimum Wall Thickness	0.020"	0.50mm
Surface Finish	to 32 to 64 microinches	0.8-1.6 microns
Gears	AGMA 6 - AGMA 8	
Threads-Extermal As-Cast	2A	6g

Linear Dimension Tolerances

Historically, zinc die casting alloys have been made with Magnesium (Mg) levels between 0.02-0.05%. These recommended levels ensured that harmful effects of lead (Pb), tin (Sn) and cadmium (Cd) impurities on corrosion resistance were effectively counteracted. Since then, the purity of refined primary zinc has improved considerably making it essentially free of the impurities. Consequently, it is possible to lower the specified level of Mg in the HF Alloy to 0.01% without compromising corrosion resistance (Fig. 5).

Figure 5: Surface appearance of test castings after 10 days in 95°C saturated humidity test

Side-by-side corrosion testing of Alloy3 and the HF alloy showed that a level of 0.008% of Mg is sufficient to protect it from intergranular corrosion.



Draft Behavior

Draft, or taper, is created on die casting surfaces perpendicular to the parting line for proper ejection from the die. Recommended draft is a function of depth or length of the feature from the parting line. In many cases the HF alloy, as with other zinc die casting alloys, can be cast with zero draft if die temperature is carefully controlled to prevent die soldering.

Process Stability

Comparisons were made of 30 samples of door lock parts cast in both Alloy 5 and the HF Alloy. Results showed that the HF castings weighed less on average due to their slightly higher aluminum (Al) content while also showing greater consistency due to their more uniform die filling behavior (Fig. 6).

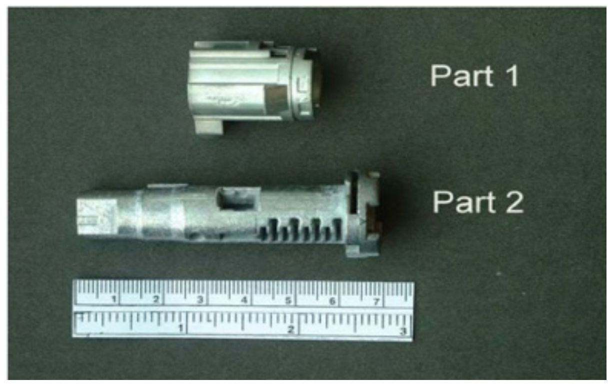


Figure 6: This automobile door lock is difficult to consistently fill with conventional Alloy 5. The HF alloy provided consistent casting weights, allowing for zero-draft precision casting.

	Alloy 5		HF Alloy	
Part No.	1	2	1	2
Average Weight (g)	19.9796	54.2745	19.6982	53.6358
Std. Dev.	0.076	0.046	0.034	0.036

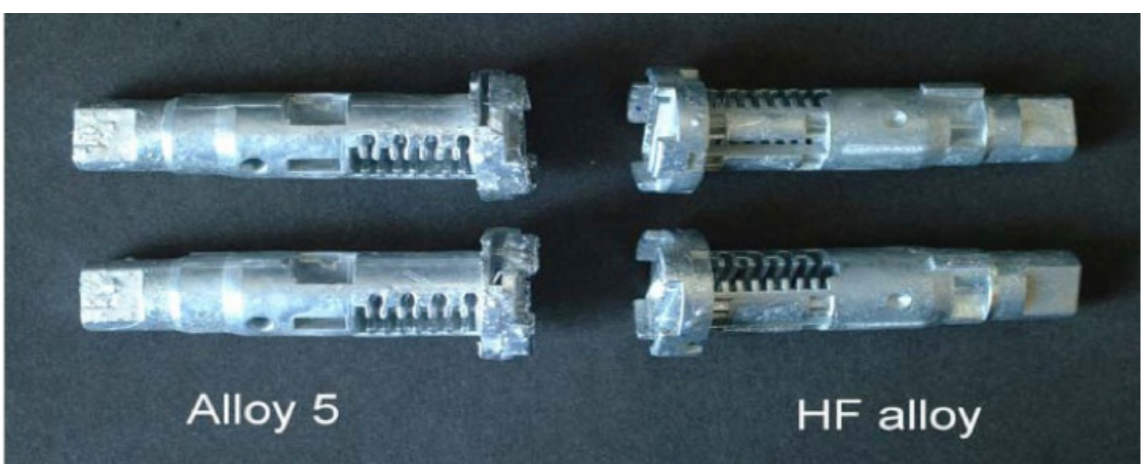
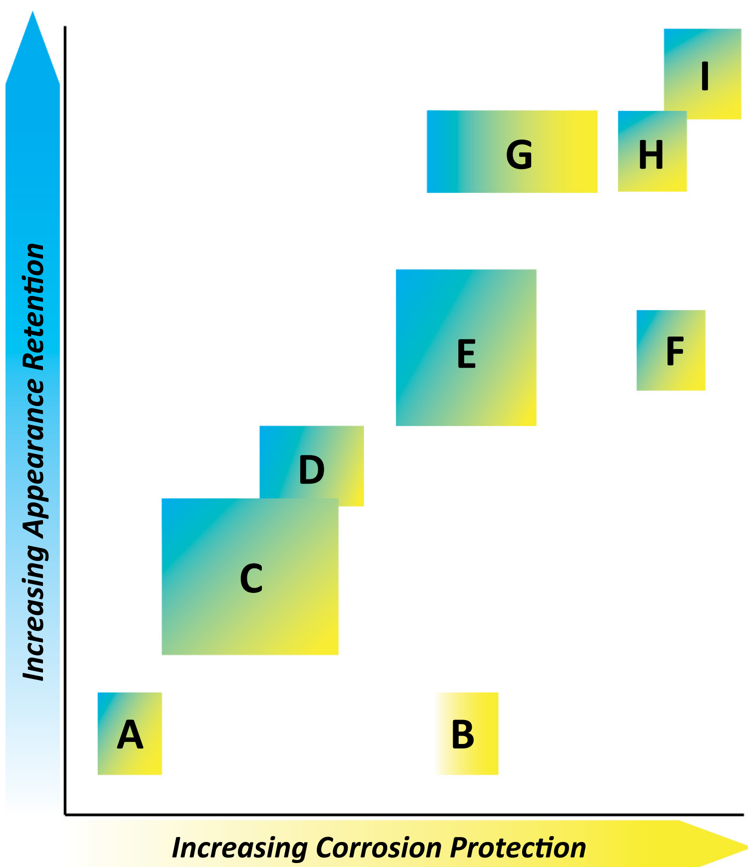


Figure 7: Casting appearance after blister testing, 310°C, 90 minutes

Surface Finishes

The cast HF Alloy, like all zinc die castings accepts a wide assortment of surface finishes, including chemical conversion treatments; electroplating and sprayed and baked polymers, among others. Almost any desired aesthetic characteristic can be achieved making the HF casting look like solid gold, weathered brass, stainless steel and even leather. The majority of zinc die cast applications are not exposed to corrosive environments and it is appearance requirements that define which finish, if any, will be used (Fig. 8).

Figure 8:



A Zinc Black
B Cu-Sn-Zn Electroplate
C Clear Chromate and Triavalent Chromium
D Sprayed & Baked Liquid Coatings
E Hexavalent Chromium Conversion
F Mechanical Plating
G Cu-Ni-Cr Electroplating
H Epoxy & Polyester Powder Coatings
I Urethane Resin E-Coats

Originally made of an assembly of brass stampings with low rigidity this decorative "legacy locket" was converted into an HF Alloy assembly with greatly expanded surface finishing possibilities at a low cost.

Cost-Savings and Market Impact

The new HF Alloy offers the potential of saving material, energy and costs relative to other engineering alloys. Its unique technical properties are being recognized by some designers and users and will impact the market.

One such example is a religious communion wafer dispenser originally designed in the Al A360 alloy. The requirement for a high quality gold surface finish made the casting excessively expensive. Casting in the new HF Alloy allowed for a decrease in section thickness from 2.54 to 1.27 and significant reduced the cost. The resulting zinc casting had nearly the same weight as its aluminium predecessor and, as shown in figure 12, improved cast-in interior features. It also met a key requirement, which was to survive without damage a drop of 1 meter (3.2 ft) onto a stone floor (Fig. 9).

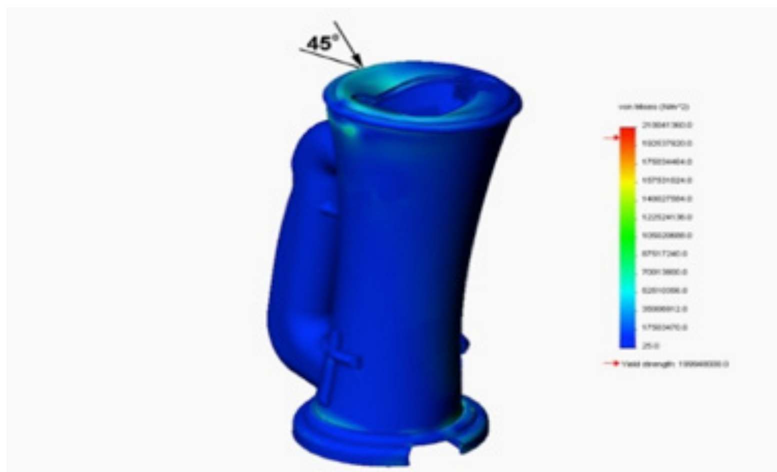
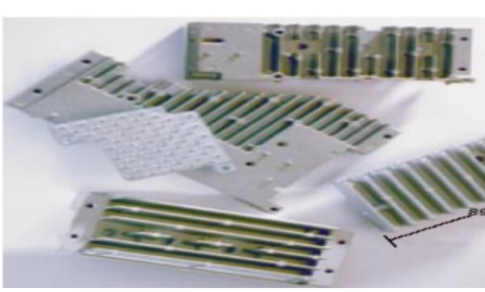


Fig 9: Magnified strains during simulated drop test

The new HF alloy also shows promise in the design of more effective heat sinks. The performance of heat sinks depends more on the available fin area for convective heat transfer than the fin thickness conducting the heat. The HF Alloy allows for producing 0.25mm thick fins making possible high performance, low cost heat sinks in custom shapes. Cost savings of 75% compared to heat sinks made of machined aluminium machined have been realized.

The HF Alloy also shares zinc's capabilities of providing electromagnetic shielding in connectors and housings. Even in 10GB Ethernet connectors, a 0.2mm zinc section thickness provides complete shielding avoiding signal coupling and crosstalk. Another advantage is the production of a near-net shape part.



Success Story

Problem/Opportunity: A multinational cell phone manufacturer was seeking to decrease machining time and manufacturing costs for a popular cell phone case. The two-piece case (front and back) was being machined from forged 6000 series aluminum blanks with a total production time of 20 minutes. The dimensional capability of the HF alloy allowed them to die cast the case and reduce production time to just two minutes, providing a huge incentive to convert to die casting the case using the HF zinc alloy.

Solution/Implementation Strategy: The front and back components of the case were designed as die castings utilizing the HF zinc alloy. This alloy has higher yield strength and ultimate strength than the 6000 series forged aluminum alloy as well as the ability to be cast to the desired wall thickness of 0.4 mm (slightly less than 0.016 inch). Dies for the two castings were designed for a 4-slide zinc die casting machine to accommodate undercuts and other details of the configurations not achievable with current aluminum and magnesium die casting alloys. Based on computer simulation which showed acceptable flow and fill analysis, die sets were fabricated.

Result: Converting the cell phone case front and back to die cast HF zinc alloy from machined aluminum forgings provides large cost and energy savings. Based on a production level of one million cell phones per month, the cost savings for machining alone is $60 million per month. The energy savings for machining, coupled with the difference in melting aluminum for forging stock versus melting of zinc for die casting is estimated to be 3.7 billion BTU per month.

Energy Savings Estimate

It takes about 450 BTUs to melt a pound of aluminum alloy as a theoretical minimum, and about 113 BTUs to melt a pound of zinc alloy -- a 4-fold difference.

Each phone case weighs 100 grams. The zinc is thinner than the aluminium but the higher density of zinc makes it come out to about the same weight. Over 50% of the aluminum forging is machined away so it starts at about 200 grams. The zinc shot weight is about 200 grams. There is less loss in reprocessing the zinc scrap but this will not be taken into account.

Production is about 1,000,000 phone cases per month or 200,000,000 grams of metal needed (431,034 pounds). Melting energy for Al would be 194 million BTU per month. Melting energy for Zn would be 48 million BTU per month. The difference is 146 BTU per month based on theoretical minimum melting. Considering inefficiencies, it is not uncommon for the actual required energy to be at least 2-3 time the theoretical. Therefore, the difference can easily be 300 million BTU per month, not considering forging or casting processing.

A centroid machining cell is rated at 34 kW of power. It is assumed that on average, about 10% of this power is used for machining. Based on 20 minutes to machine the Al case it then would take 1.1 kWh for one and 1,100,000 kWh for 1,000,000 cases per month. 100 kWh = 341,200 BTU, therefore, 3.75 billion BTU per month. If two minutes are required to machine the zinc case, the energy savings in machining is 3.4 billion BTU per month.

Total energy savings (melting and machining) for 1 million cases per month would be 3.7 billion BTU per month.

Cost Savings Estimate

It takes 20 minutes to machine the Al forged blanks and 2 minutes to machine the Zn die casting. At a machining cell rate of $200/hr the cost savings per case is $66.66 minus $6.66, or $60. For a million cases per month this is a savings of $60 million per month. If the cost of energy is $0.03/kwh, the energy savings defined above would be an additional $32,000 per month.

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