Ultra Thin Zinc Die Casting Alloys

Zinc
...essential for life

THE NEW GENERATION OF ULTRA THIN ZINC DIE CASTING ALLOYS

Introduction

A new generation of ultra thin zinc die casting alloys has been developed that provides significant performance improvements compared to conventional zinc die casting alloys. Featuring a better fluidity, excellent surface quality, optimized mechanical properties and the ability to maintain close tolerances these alloys have the potential of saving material, energy and costs and creating new, innovative market opportunities.

Initial efforts of improving zinc casting alloy fluidity date back to the 1990s when Union Minière, now Nyrstar, introduced its "Superloy". Until then Alloy 7 was the zinc die casting alloy with the highest fluidity. Because of its higher aluminum and copper composition Superloy has an excellent fluidity allowing for thinner casting sections and lighter weight castings to be produced. Later, Grillo-Werke marketed this composition under the acronym of "GDSL" . [1]

More recently, with the objective of minimizing the time and excess metal needed for alloy changeover, a new ultra thin zinc die casting alloy has been developed using a composition closer to the conventional ZAMAK alloys. This new alloy, designated HF (High Fluidity) alloy has the same excellent castability of Superloy and GDSL and was developed by the International Zinc Association (IZA) in cooperation with the North American Die Casting Association (NADCA) and support from the US Department of Energy.

With their superior fluidity the Superloy, GDSL and the HF Alloy are best suited for casting parts with a section thickness of less than 0.45 mm. They can also be used for casting parts that are difficult to fill or have high surface finish requirements.

1. GDSL: Guss-Druck-Sonderlegierung

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 favorably with cast aluminum, 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 **Machining operations are reduced.**
Due to the superior net-shape casting capability of zinc alloys, machining 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. The new ultra thin zinc die casting alloys significantly improve zinc alloy fluidity to allow a reduction in casting section thickness to 0.3 mm or less.

The Ultra Thin Zinc Die Casting Alloys

The development of the ultra thin zinc die casting alloys is based on two different approaches:

The Superloy/GDSL Alloy identified a composition with higher aluminum and copper levels whereas the recently developed HF Alloy is based on the commonly used ZAMAK alloys but possesses the excellent castability of the Superloy/GDSL (Table 1). A laboratory fluidity test comparing the Superloy/GDSL and HF Alloy to Alloy 7, which is the most fluid of the conventional zinc die casting alloys, showed respectively a 42% and 40% greater fluidity of the ultra thin zinc die casting alloys. The experimental results from the fluidity testing are reported in Figure 1.

Table 1:

Composition Ranges (wt%) of the New Ultra Thin Zinc Die Casting Alloys

	Superloy/GDSL	**HF Alloy**
Aluminum	6.4 - 6.8	4.3 - 4.7
Magnesium	0.02 max	0.005 - 0.012
Copper	3.3 - 3.6	0.035 max
Iron	0.05 max	0.03 max
Lead	0.005 max	0.003 max
Cadmium	0.005 max	0.002 max
Tin	0.002 max	0.001 max
Zinc	remainder	remainder

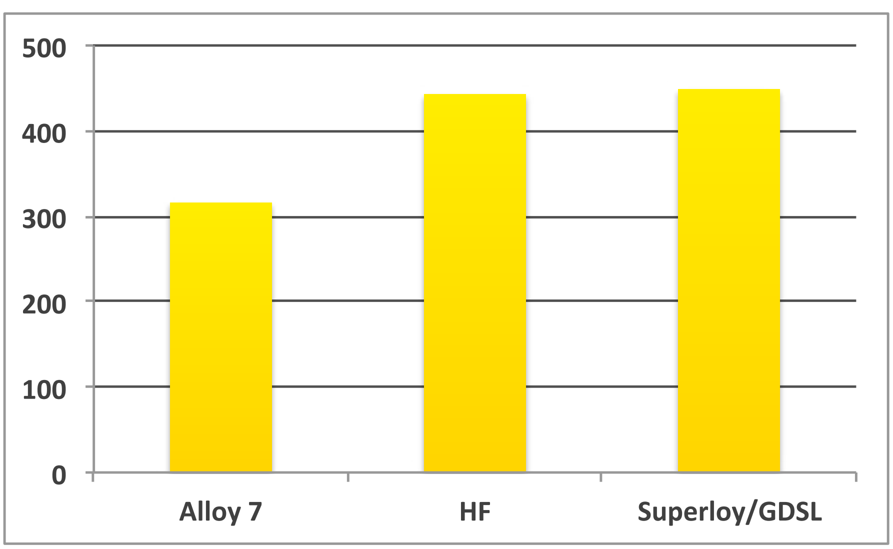

Figure 1:

Ragone fluidity distances of Alloy 7, the new HF Alloy and Superloy/GDSL, cast at 435°C (815F)

Tests with the new HF Alloy have demonstrated that the alloy has comparable physical, mechanical and corrosion properties to Alloys 3 and 7 and exceeds minimum thickness targets allowing for casting parts with a wall thickness as thin as 0.25mm.

Several industrial trials and evaluations have been carried out confirming the easy use and integration of the HF Alloy in existing die casting operations minimizing changeover time and increasing productivity.

The Superloy/GDSL Alloy provides similar manufacturing advantages to the die caster.

Thin Section Filling Ability

Superloy/GDSL's ability to make ultra-thin (0.3mm) castings in 1, 2 and 3 dimensions is shown in the photos below.

1D 0.3mm

Figure 2:
The tensile bar casting shows the ability of completely filling a 175mm long cavity.

2D 0.3mm

Figure 3:
Extended to 2 dimensions for the flat plate.

3D 0.3mm

Figure 4:
Extended to a 3-dimensional cover casting with dimensions 80x80x20mm.

The filling behavior of the HF Alloy compared to the most widely used conventional Alloy 3 with 25ms fill time is shown below in Figure 5 and Table 2.

Alloy 3 HF Alloy

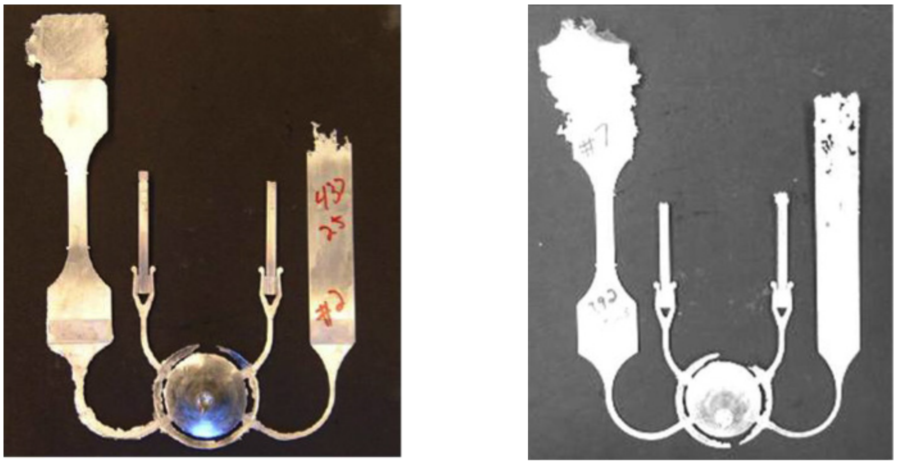

Figure 5: The more complete filling with the HF Alloy, even though a lower die temperature of 200°C (392°F) was used, in comparison with the 225°C (437°F) die temperature used for Alloy 3.

Table 2:

Filling Results of Superloy/GDSL and the HF Alloy

1-D specimen thickness	0.5mm	0.4mm	0.3mm	0.3mm
Cavity temperature	**150°C (302°F)**	**200°C (392°F)**	**220°C (428°F)**	**260°C (500°F)**
Filling Results				
Superloy/GDSL Alloy	yes	yes	yes	yes
HF Alloy	yes	yes	yes	yes
ZL0400	yes	yes	no	yes
ZL0410	yes	yes	no	yes
ZL0430	yes	yes	no	no
ZL0810	yes	no	no	no

Mechanical Properties

Despite using less material the ultra thin alloys have excellent mechanical properties as shown in Table 3.

Table 3:

		Superloy/ GDSL	HF Alloy
Ultimate Tensile Strength (*) – ksi (MPa)	as cast:	333	40 (276)
	aged:		34 (234)
Yield Strength – ksi (MPa)	as cast:	300	35 (241)
	aged:		29 (200)
Elongation – % in 2 in. (51 mm) gauge length	as cast:	3.0	5.3
	aged:	9.9	9.9
Impact Energy (2*) – ft-lb (Joules)	as cast:	65	28 (38)
	aged:		21 (28)
Hardness, Brinell (3*) 250 kg, 5mm ball	as cast:	96	93
	aged:	71	71
Young's Modulus (4*) – psi (GPa)	as cast:	96	13.3 x 106 (91.7)
Poisson's Ratio	aged:	0.30	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 ºF (20 ºC)
Samples "aged" were kept at 203 ºF (95 ºC) 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 Figure 6.

Tolerance standards are published by the International Organization for Standardization (ISO), North American Die Casting Association (NADCA), and others (Fig. 7). 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 6: Precision capabilities of zinc die casting and other manufacturing processes

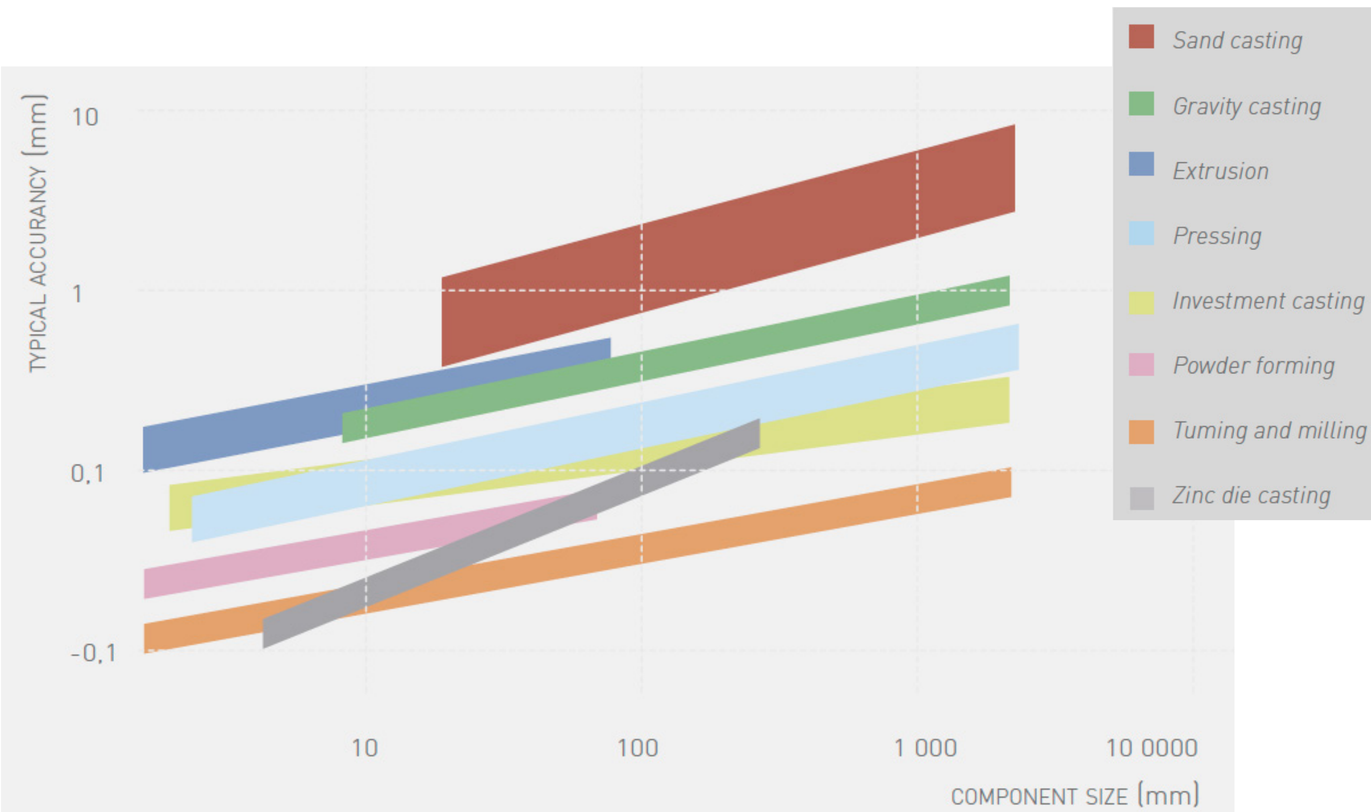

Figure 7:

Engineering & Design: Coordinate Dimensioning

NADCA

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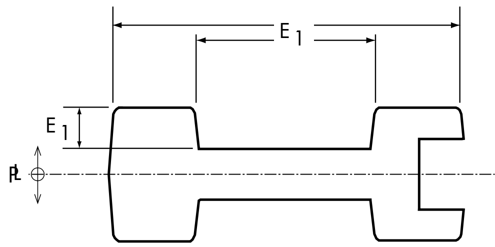
STANDARD TOLERANCES

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)

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

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 die casting. The values may vary with size, design and configuration of the component. Please consult your die caster for establishing tolerances for specific part features.*

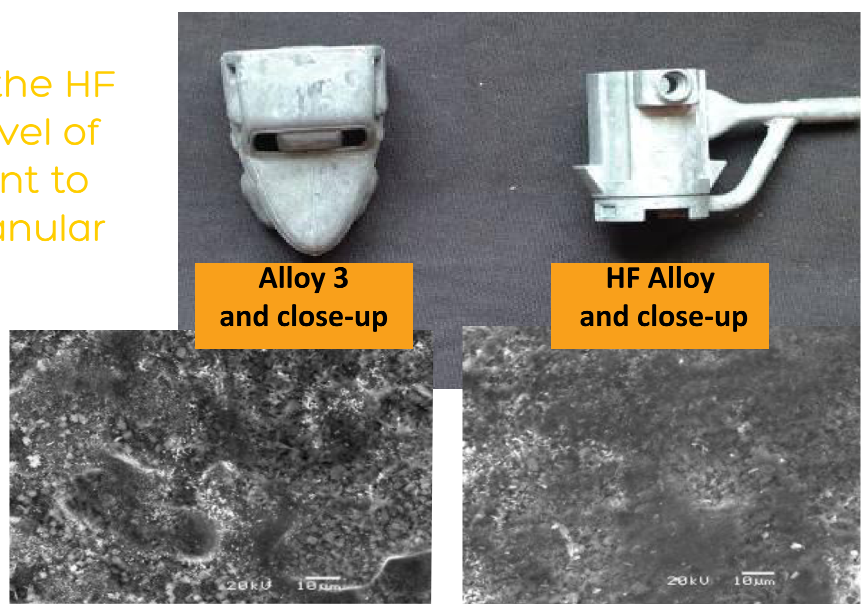
Linear Dimension	±0.0008″ up to 1″ and ±0.001 for each additional inch	±0.020mm up to 25.4mm″ and ±0.025 for each additional 25.4mm
The following values are typical for a 1.18" (30mm) component.		
Flatness	0.002"	0.05mm
Straightness	0.001"	0.03mm
Circularity	0.001" (// to parting line)	0.03mm (// to 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 was possible to lower the specified level of Mg to 0.02 in the Superloy/GDSL and to 0.01% in the HF Alloy without compromising corrosion resistance (Fig. 8).

Figure 8: Surface appearance of test castings after 10 days in 95°C saturated humidity test

Side-by-side corrosion testing of Alloy 3 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 ultra thin zinc die casting alloys, 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. 9). A similar stability was seen in earlier tests carried out with the Superloy/GDSL Alloy.

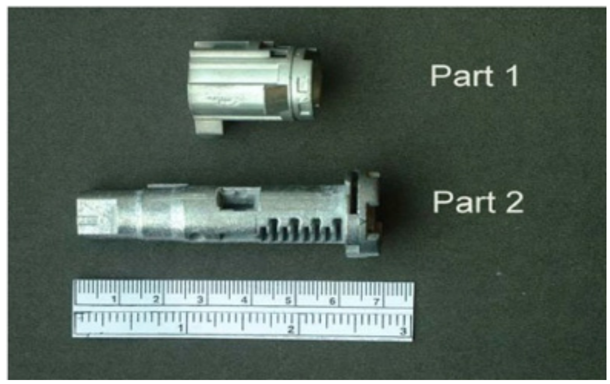


Figure 9: This automobile door lock is difficult to consistently fill with conventional Alloy 5. The HF alloy provided consistent casting weights, allowing for zero-draft precision casting.

	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

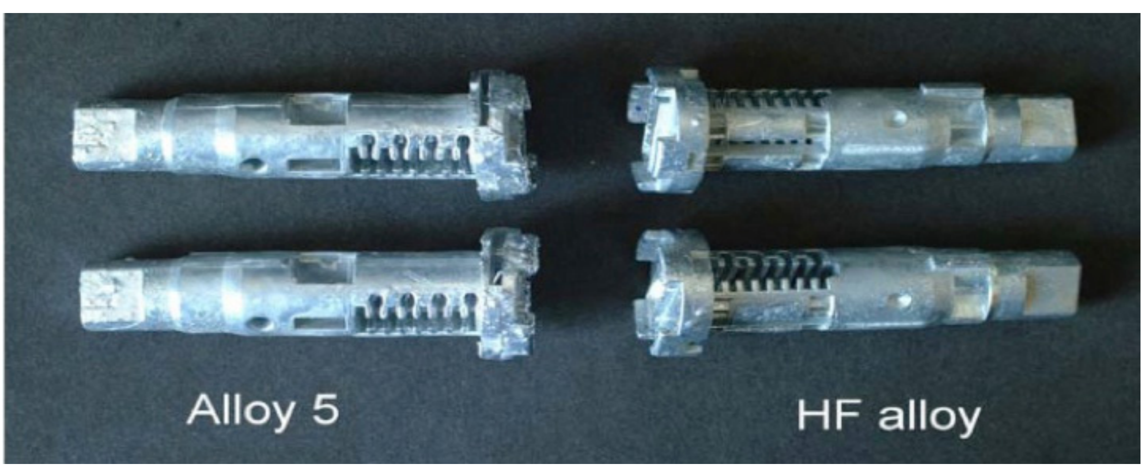


Figure 10: Casting appearance after blister testing, 310°C, 90 minutes

Surface Finishes

The ultra thin zinc die casting alloys, like all zinc die castings, accept a wide assortment of surface finishes, including traditional solvent-based painting, electroplating and hexavalent chromium conversion coatings which have been providing reliable performance for decades as well as new electrophoretic surface finishes using best practice green technology. These new green finishes are free of cadmium or lead and do without chromium plating topcoats while providing high corrosion protection and appealing aesthetics.

Almost any desired aesthetic characteristic can be achieved making the ultra thin zinc die casting alloys 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. The new green finishes offer an environmentally friendly alternative to the end-user and parts manufacturer.

The charts below show the relative performance for the various types of traditional and green finishes in terms of corrosion protection and retention of aesthetics (Figs. 11 and 12). The finishes with the best overall performances are in the upper-right portion of the chart.

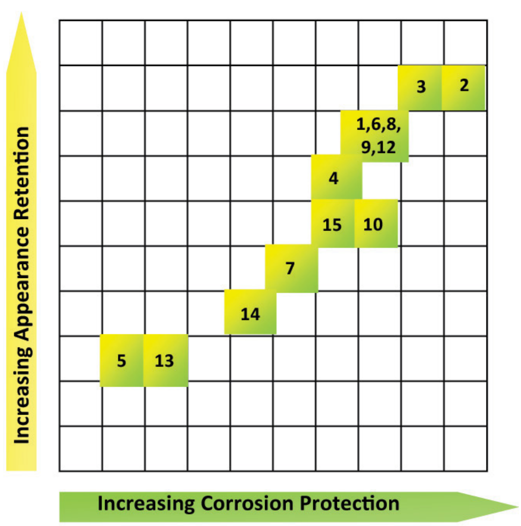


Figure 11. Green Finishes

1. Tin-nickel alloy plating
2. Electroless nickel plating
3. Black nickel plating
4. Black electrophoretic coating (sample A)
5. Black electrophoretic coating (sample B)
6. Clear electrophoretic coating, stainless steel effect post dye
7. Clear electrophoretic coating with gold post day
8. Clear electrophoretic coating with brass effect post dye
9. Clear electrophoretic coating with bronze effect post dye
10. Antique bronze electrophoretic coating
11. Oil-rubbed bronze eletrophoretic coating
12. Oil-rubbed bronze electrophoretic, polyurethane topcoating
13. White electrophoretic coating
14. Blue electrophoretic coating
15. Blue electrophoretic coating plus polyurethane top-coating

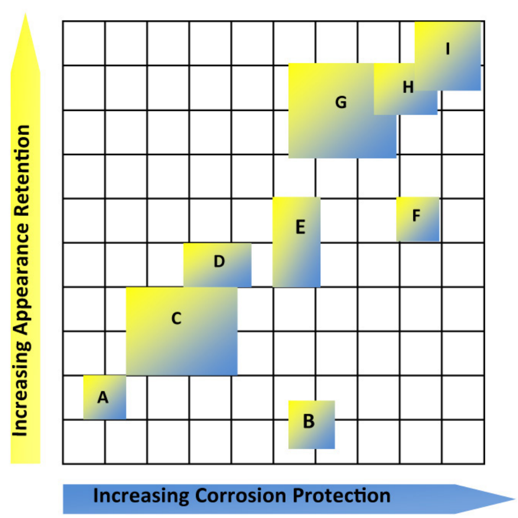


Figure 12. Traditional Finishes

A. Zinc Black
B. Cu-Sn-Zn Electroplate
C. Clear Chromate and Trivalent 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

Saving Weight, Costs, & Resources

The ultra thin zinc die casting alloys offer the potential of saving material, weight, time, energy and costs relative to other engineering alloys. Their unique technical properties are being recognized by some designers and users and will impact the market.

The GDSL alloy has demonstrated its exceptional castability in the manufacturing of a bevel gear used in fully retractable arm awnings that provide shade to balconies and terraces (Fig. 13). This fine gear part resides in the awning's case and serves to extend and retract the awning. Due to its mechanical properties the copper-rich GDSL is ideal for the thin section filling of this complex-shaped bevel gear (Fig. 14).

Figure 13: photo courtesy of Geiger/Jeners

Figure 14: photo courtesy of Geiger/Jeners

Another 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 aluminum predecessor and, as shown in Figure 15, 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.

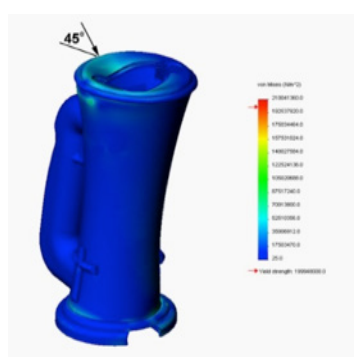
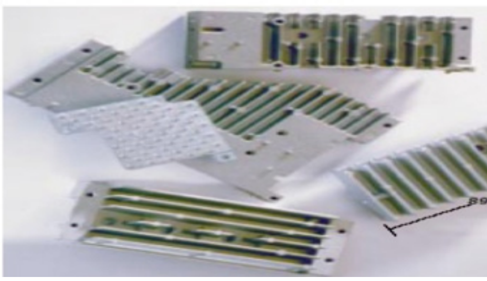
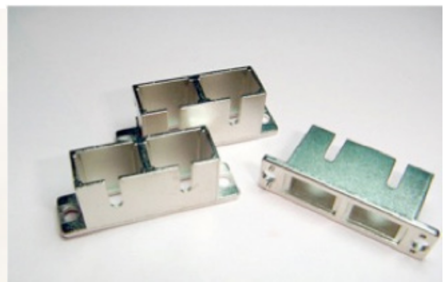


Figure 15

Ultra thin alloys also show 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 aluminum have been realized.

The ultra thin alloys also share 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.





A case study comparing the HF Alloy (Fig. 16) to aluminum in the production of a cell phone case showed enormous savings when using the HF Alloy. It takes 20 minutes to machine the aluminum forged blanks versus 2 minutes to machine the zinc die castings. Based on a production level of 1 million cell phones per month the cost saving for machining alone is USD 60 million per month. The energy savings for machining, coupled with the difference in melting aluminum for forging stock versus melting zinc for die casting is estimated to 1.083 MWh (3.7 billion BTU) per month.

Other advantages over aluminum are zinc's higher yield strength and ultimate strength compared to the aluminum alloy. The HF Alloy also allowed for casting to the desired 0.4mm wall thickness. Production was done on a four-slide zinc die casting machine accommodating undercuts and other details not achievable with current aluminum or magnesium die casting alloys.

Figure 16

Environmental Sustainability

Humans need zinc for a multitude of critical functions. It positively affects the immune system, growth and development, fertility, eyesight, learning and wound healing. In some areas of the world zinc deficiency is a major health problem.

Pollution and greenhouse gases are minimized with zinc die casting:

> Negligible emissions to air, land and water.
> Much smaller energy consumption than comparable alternative mass manufacturing processes.
> No environmentally harmful blanket gases required in processing.
> Any 'scrap' product from processing can be recycled.

Zinc alloys, as defined by international chemical composition standards, easily conform to the requirements of the End of Life Vehicle (ELV), Restriction of Hazardous Substances (RoHS) and Waste Electrical and Electronic Equipment (WEEE) legislation.

Zinc die castings are premium quality low cost products that are highly resilient to many hostile conditions. They display considerable corrosion and wear resistance resulting in very long and reliable service, frequently measured in decades, and saving resources by not needing to be frequently replaced.

- A recycling infrastructure is actively in place to treat today's zinc processing scraps and tomorrow's end of life cast zinc alloy products. Zinc castings can be marked with the Zinc Logo and the ISO recycling mark as featured in EN 12844 for easy alloy recognition and future recycling.

- Zinc is an inherent part of the Earth's crust and one of nature's most abundant elements. Over 13 million tons of zinc are produced annually. Zinc has a broad range of applications, including galvanizing, brass, chemicals and diecasting. Approximately 15% of zinc metal goes into the production of zinc alloys for die casting. Zinc die casting has a long tradition dating back to the development of Zn-Al casting alloys in the 1930's.

Zinc ...essential for life

References

1. The New High Fluidity Zinc Alloy, International Zinc Association; North American Die Casting Association; US Department of Energy, 2013
2. A Performance Evaluation of Traditional and Green Surface Finishes for Zinc Die Castings, International Zinc Association, 2013
3. Zinc ... A Sustainable Material, International Zinc Association, 2010