

Final Technical Report

Energy Saving Melting and Revert Reduction Technology (“Energy SMARRT”)
Program

Task 3.5, Development of Thin Section Zinc Die Casting Technology

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List of Acronyms

HF High Fluidity

ILZRO International Lead Zinc Research Org., Inc.

NADCA North American Die Casting Assn.

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Executive Summary

A new high fluidity zinc high pressure die casting alloy, termed the HF alloy, was developed during laboratory trials and proven in industrial production. The HF alloy permits castings to be achieved with section thicknesses of 0.3 mm or less. Technology transfer activities were conducted to develop usage of the HF high fluidity alloy. These included production of a brochure and a one-hour webinar on the HF alloy. The brochure was then sent to 1,184 product designers in the Interzinc database. There was excellent reception to this mailing, and from this initial contact 5 technology transfer seminars were conducted for 81 participants from 30 companies across a wide range of business sectors. Many of the successful applications to date involve high quality surface finishes. Design and manufacturing assistance was given for development of selected applications.

Introduction

The conventional Zn-4%Al-Cu-Mg zinc alloys, termed “Zamak alloys” in the U.S., have been used to cast both small and large components with wall thicknesses of less than 1 mm, thinner than many other competitive casting materials and processes can achieve. Among the Zamak alloys, Alloy 7 has the highest fluidity [1] and has demonstrated the capability to cast parts with wall thicknesses as thin as 0.75 mm (0.030 in.) [2,3]. In an effort to develop a generally viable technology for casting parts with ultra-thin (less than 0.3 mm [0.012 in.]) section thicknesses, a new zinc die casting alloy was developed in a research program supported by the Department of Energy, the Cast Metals Coalition (CMC), and the North American Die Casting Association (NADCA). An alloy was developed that possesses higher casting fluidity than Zamak alloys and is easy to produce, maintain and recycle (reuse). The approach taken was to modify compositions of existing Zamak alloys by increasing the Al content and/or reducing the Mg content. The composition of the HF alloy, which is now included in a NADCA Product Standard and a draft ASTM Standard Specification, is shown in Table 1.

Table 1 HF Alloy composition, weight percent

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

Many die casters and their customers were interested in trying this new alloy, but had many questions about the thinnest sections this new alloy could fill, achievable surface quality, mechanical properties capabilities, surface finishing, die design, etc. Further, the new alloy required introduction to U.S. designers and specifiers to develop demand if the alloy were to move toward reaching its energy and materials saving potential.

This report describes the alloy development, initial casting trials, and technology transfer activities that have stimulated demand from industrial designers and specifiers, and triggered new investment considerations by the metalcasting industry that will allow the energy and weight savings potential of the new HF alloy to be achieved.

Background

Zinc has a specific gravity of 7.14, therefore a component made from one of the conventional Zn-4%Al-Cu-Mg (Zamak) alloys will be much heavier than the same component made from industrially available Al and Mg alloys. However on a per unit mass basis, the energy required to produce primary Zn is much less than that required for Al and Mg. Also, it only takes half the amount of energy to melt and hold a Zamak alloy before casting compared to comparable Al and Mg alloys used in similar applications. Also, the precision to which zinc alloys can be cast is much higher than Al and Mg alloys, reducing scrap and also the need for secondary operations such as machining, which not only produce scrap but consume additional energy. However, Al

and Mg castings of acceptable surface quality and soundness cannot usually be cast with section thicknesses less than 2 mm for large castings and 1.2 mm for small castings (castings with a single dimension no more than 100 mm). By contrast conventional Zamak castings can be cast with minimum section thicknesses of 1.2 mm for large castings and 0.6 mm for small castings. This comparison is shown in Table 2. Because Zamak alloys are more than twice as dense as counterpart Al and Mg alloys, this results in a weight penalty for the Zamak alloys, although savings in other operations such as machining and surface finishing may allow a lower cost per finished part to be realized in Zamak alloys. It was recognized that development of a zinc casting alloy capable of being cast with a 0.3 mm thickness, for a small casting, would allow mass parity to be achieved, if not surpassed, with many Al and Mg casting alloys. Providing mechanical property requirements could be met, the use of less metal during processing would further increase energy savings with this new alloy together with continued savings because of the higher dimension precision available with zinc alloys.

Table 2 Comparison of Typically Achievable Minimum Section Thicknesses for Commercial Casting Alloys

Alloy Family	Large Castings		Small Castings	
Al	.080"	2 mm	.050"	1.2 mm
Mg	.080"	2 mm	.050"	1.2 mm
Zn	.050"	1.2 mm	.023"	0.6 mm

Generally, castings with a single dimension over 4 inches (100mm) are termed "large castings"

Technical issues addressed related to the casting properties of the liquid zinc alloy, which was addressed through a comprehensive alloy development approach, thermal properties in the mold or die, design of the die to allow complete filling of thin section castings, and die casting machine operation parameters including die temperature control and shot speed control.

This resulted in the successful development of the HF (high fluidity) alloy. This has also been described in several technical articles [2, 3, 4, 8, 11]. Concluding activities during the final phase of the project were devoted to technology transfer that has accelerated the uptake of this new energy-saving alloy by industry.

Results and Discussion

This project report is divided into two sections that reflect the two distinct funding periods:

Funding Period 1: 2005-2006

Task 1: Design of Phase I Test Alloys

Development of thin wall die casting technology ultimately relies on both optimum processing control and the availability of high fluidity casting alloys. In this project, the aim was to develop a high fluidity alloy that is easy to manufacture and easy to maintain and recycle (reuse). Thus, it was determined that alloy development should focus on modification of the existing commercial alloys rather than introducing new alloys that may be incompatible with existing practices. Among the alloy elements in zinc die casting alloys, aluminum and magnesium were known to have significant influence on the fluidity of the alloys [4]. In general, the fluidity of Zn-Al alloys containing aluminum close to the eutectic composition (5 wt.%) reaches a maximum. Since eutectic Zn-Al alloy has very low impact strength [5], it is recommended that aluminum content in zinc die casting alloys should not exceed 4.5 wt.% [6]. The fluidity of the Zn-Al alloy is

lowered by small additions of magnesium. On the other hand, the addition of magnesium into the zinc die casting alloys is necessary to neutralize the unavoidable presence of impurity elements, such as lead and cadmium, although magnesium negatively impacts the fluidity of the alloy. Since Alloy 7 was determined to have the highest fluidity among the commonly used zinc die casting alloys with its lower magnesium content [6], it was decided that new alloy development should be concentrated on modification of the Alloy 7 composition by increasing aluminum content or reducing magnesium content or both.

Task 2: Manufacture of Phase I Test Alloys

In total, 12 alloy compositions, including SHG zinc and commercial Alloys 3 and 7, were evaluated for comparison purposes. The designed alloy chemical compositions as well as the analyzed alloy compositions are listed in Table 3. In the preparation of the alloys, approximately 18 kg (40 lb.) of metal were melted in a SiC crucible. Other than commercial Alloys 3 and 7, all alloys were prepared using ASTM B86 Special High Grade zinc, with copper and aluminum of approximately 99.9% purity. Magnesium was added in two forms: pure magnesium metal with a purity of above 99.9% or a Zn-4.23%Mg master alloy. Typically, the melt was maintained overnight to stabilize the bath before the fluidity test. Bath assays were collected after each test to determine the chemical compositions of the alloy.

Fluidity of the selected casting alloys was investigated using a Ragone fluidity tester. The measured flow distance range and the average value for each of the alloys evaluated are detailed in Table 4. Although flow distance measured for each alloy composition could vary significantly from one test to another, the trend of alloy fluidity changing with different compositions is clearly established. Figure 1 is the graphic representation of the average flow distance of the alloys. This work showed the effect of aluminum and magnesium compositions on fluidity. Casting fluidity was found to be much more sensitive to Al composition rather than Mg, contrary to past findings. The investigators were able to increase fluidity to a level 32% higher than that of the baseline Alloy 7 alloy by only increasing Al content. Reduction of Mg content in combination with this increase in Al content gave an improvement in fluidity of 40% compared with Alloy 7. The alloy selected for further investigation had the composition of Alloy II shown in Table 4.

Table 3 Alloy compositions evaluated in fluidity tests

Alloy	Chemical compositions (wt.%) [*]							
	Al	Mg	Cu	Fe	Pb	Cd	Sn	Ni
SHG Zn	-	-	-	-	-	-	-	-
Alloy 3	4.23	0.048	0.001	0.003	0.001	0.0001	<0.001	-
Alloy 7	3.95	0.015	0.021	<0.001	0.002	<0.0001	<0.001	0.005
Alloy 7 (self-alloyed)	4.05 (4.00)	0.033 (0.030)	0.096 (0.10)	0.006 (0.006)	0.003	<0.0001	<0.001	0.005
Modified Alloy 7	4.67 (4.50)	0.014	0.021	0.001	0.002	<0.0001	<0.001	0.005
Alloy I	4.20 (4.50)	0.006 (0.005)	0.013 (0.013)	0.007 (0.007)	-	-	-	-
Alloy II	4.48 (4.50)	0.006	0.013	0.005				
Alloy III	4.61 (4.50)	0.018 (0.015)	0.018	0.006	-	-	-	-
Alloy IV**	4.54	0.015	0.017	0.006	0.003	<0.0001	<0.001	-
Alloy S	6.94 (7.00)	-	3.95 (3.80)	0.007	0.003	<0.0001	0.001	-
Alloy SI	7.44 (7.00)	-	3.49 (3.60)	0.006	0.002	0.0001	<0.001	-
Alloy SII	7.26 (7.00)	-	3.89 (3.8)	0.007	0.003	<0.0001	<0.001	-

* Numbers in brackets indicate the designed element compositions

** With 0.002% Ce (addition of mischmetal)

Table 4 Flow distances of alloys evaluated at 435°C (815°F)

Alloy	Chemical compositions (wt.%) [*]							
	Al	Mg	Cu	Fe	Pb	Cd	Sn	Ni
SHG Zn	-	-	-	-	-	-	-	-
Alloy 3	4.23	0.048	0.001	0.003	0.001	0.0001	<0.001	-
Alloy 7	3.95	0.015	0.021	<0.001	0.002	<0.0001	<0.001	0.005
Alloy 7 (self-alloyed)	4.05 (4.00)	0.033 (0.030)	0.096 (0.10)	0.006 (0.006)	0.003	<0.0001	<0.001	0.005
Modified Alloy 7	4.67 (4.50)	0.014	0.021	0.001	0.002	<0.0001	<0.001	0.005
Alloy I	4.20 (4.50)	0.006 (0.005)	0.013 (0.013)	0.007 (0.007)	-	-	-	-
Alloy II	4.48 (4.50)	0.006	0.013	0.005				
Alloy III	4.61 (4.50)	0.018 (0.015)	0.018	0.006	-	-	-	-
Alloy IV**	4.54	0.015	0.017	0.006	0.003	<0.0001	<0.001	-
Alloy S	6.94 (7.00)	-	3.95 (3.80)	0.007	0.003	<0.0001	0.001	-
Alloy SI	7.44 (7.00)	-	3.49 (3.60)	0.006	0.002	0.0001	<0.001	-
Alloy SII	7.26 (7.00)	-	3.89 (3.8)	0.007	0.003	<0.0001	<0.001	-

* Numbers in brackets indicate the designed element compositions

** With 0.002% Ce (addition of mischmetal)

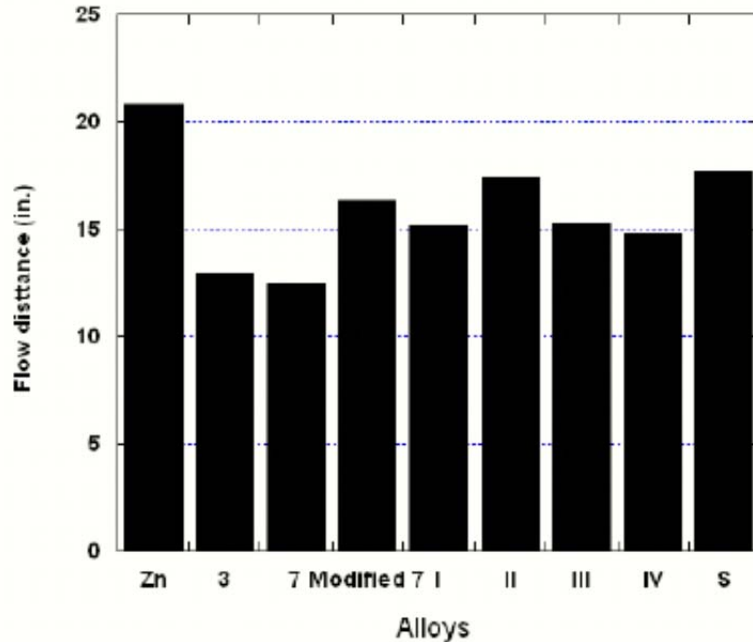


Figure 1 Average flow distance of various alloys tested at 435°C (815°F).

Task 3: Die Design-Flat Plate, Task 4: Die Modifications-Flat Plate, and Task 5: Die Casting Machine Calibration & Matching to Die

These three tasks were carried out sequentially after identification of a suitable host die for the first trials with the chosen alloy composition. The team is grateful to Brillcast, Grand Rapids, MI for all of their efforts in hosting and conducting the trial. The ILZRO die used for the trials is shown in Figure 2. This has cavities for standard tensile and impact test bars, but of special interest is the stepped fluidity cavity with successive thicknesses of 0.75, 0.5 and 0.25 mm (0.03, 0.2 and 0.1in.) as flow progresses from the entrance gate.

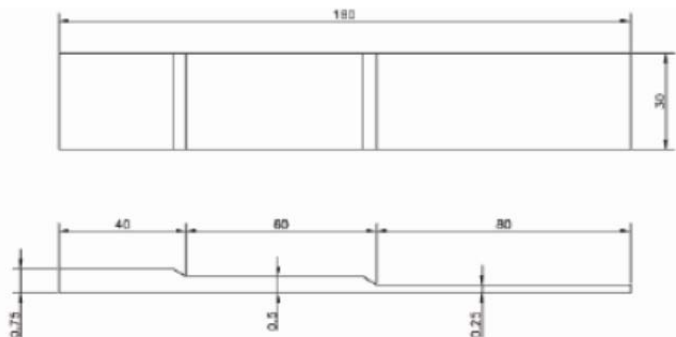


Figure 2 Photo of the ejector half of the ILZRO die (left), the stepped fluidity cavity, dimensions in mm (right)

Task 6. Die Casting Trials

During the Brillcast trial, the die was mounted with electrical cartridge heaters and thermocouples to control and monitor the die temperature. A Frech 63 (57 metric tonnes) machine was used for this trial. The die casting machine is equipped with a system that can monitor and record shot speed, gate velocity, metal pressure and fill time. Four different casting conditions, with a combination of two die temperatures of 165°C and 225°C (330°F and 437°F)

and two fill times (15 and 25 milliseconds) were selected for the trial of both Alloys 3 and 7 as listed in Table 5. These conditions represent both typical die casting operation conditions for Alloys 3 and 7 and more favorable conditions for achieving thin wall casting, hotter die temperature and shorter fill time. Typical die casting machine settings include an accumulator pressure of 5.79 MPa (840 psi), hydraulic pressure of 8.27 MPa (1200 psi), shot cylinder diameter of 95.0 mm (3.74 in.), plunger diameter of 60 mm (2.36 in.), and dry shot speed of 2540 mm/s (100 ips). It was decided that 70 castings would be made at each condition and both the tensile and fluidity specimens would be collected for examination.

Table 5 Brillcast trial test matrix

Test Condition	Die Temperature (°C)	Fill Time (milliseconds)
1	177 (350°F)	25
2	177 (350°F)	15
3	200 (392°F)	25
4	200 (392°F)	15

The die was mounted onto the Frech 63 machine after bench testing and was heated up to the desired die temperature. The die temperature was monitored in four different locations which represented the operator cover die side, the operator ejector die side, the helper ejector die side, and the helper cover die side. Before actual sampling, 20 to 30 die casting shots were made to stabilize the die temperature and to fine-tune the casting conditions. The next 70 shots were then collected for each of the casting conditions listed in Table 5.

Task 7. Assessment of Phase I Castings

Figure 3 shows two full shots of the HF alloy castings at using two die fill times.. It can be seen that the flow samples were not completely filled at a die temperature of 200°C and a fill time of 25 milliseconds for both alloys. The HF alloy, however, showed improved cavity fill capability compared with Alloy 7, which as evidenced in Figure 4. With a shorter fill time of 15 milliseconds, flow samples of both alloys were fully filled although the new alloy generated more flash.

Measurement of the actual thickness in the thinnest section of the flow sample turned out to be about 0.41 mm (0.016 in.) rather than the designed 0.25 mm, probably due to die wear or distortion.

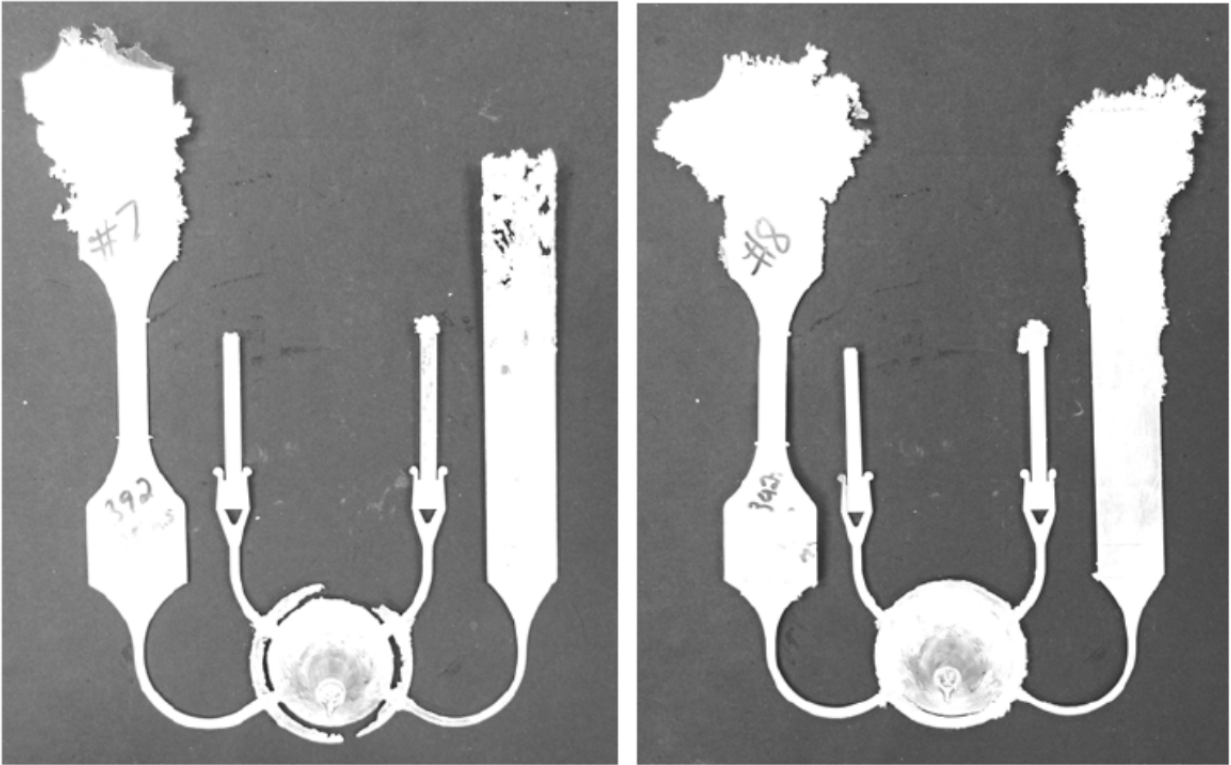


Figure 3 Full shots of HF alloy cast at a) a die temperature of 200°C (392°F) and a fill time of 25 milliseconds and b) a die temperature of 200°C and a fill time of 15 milliseconds.

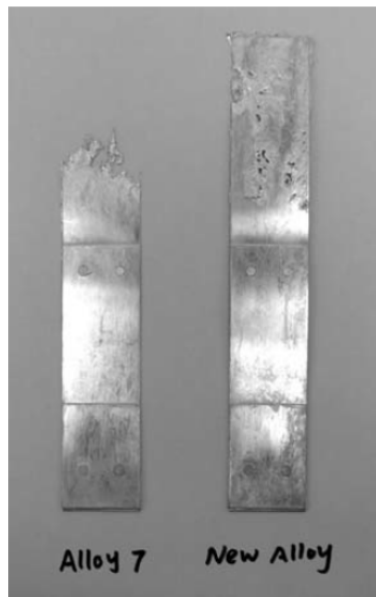


Figure 4 Cross-sectional views of flow samples cast at a die temperature of 200°C and a fill time of 15 milliseconds: Alloy 7 (left), and the HF alloy (right)

The flow distance and weight of the flow samples cast at different conditions were measured and the average values are listed in Table 6. At similar conditions, the new alloy achieved better fill of the flow cavity, demonstrated by heavier and longer flow samples as shown in Figure 5. For the fully-filled samples, the complete fill of the overflow and more prominent flash of the new alloy samples make them much heavier than the corresponding fully-filled Alloy 7 samples. Both

die temperature and fill time affect the cavity fill of the alloys, however, fill time has much more profound impact on the flow distance than the die temperature. The variation of the flow distance among flow samples cast at the same conditions can also be attributed to the variation of the fill time as shown in Table 6. Longer flow distance is typically associated with a shorter fill time. The flow sample was completely filled by casting at a shorter fill time (15 milliseconds) at both die temperatures for Alloys 7 and the HF alloy.

Table 6 Average Flow Distances and Weights of the Flow Samples Cast at Different Conditions

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
New 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

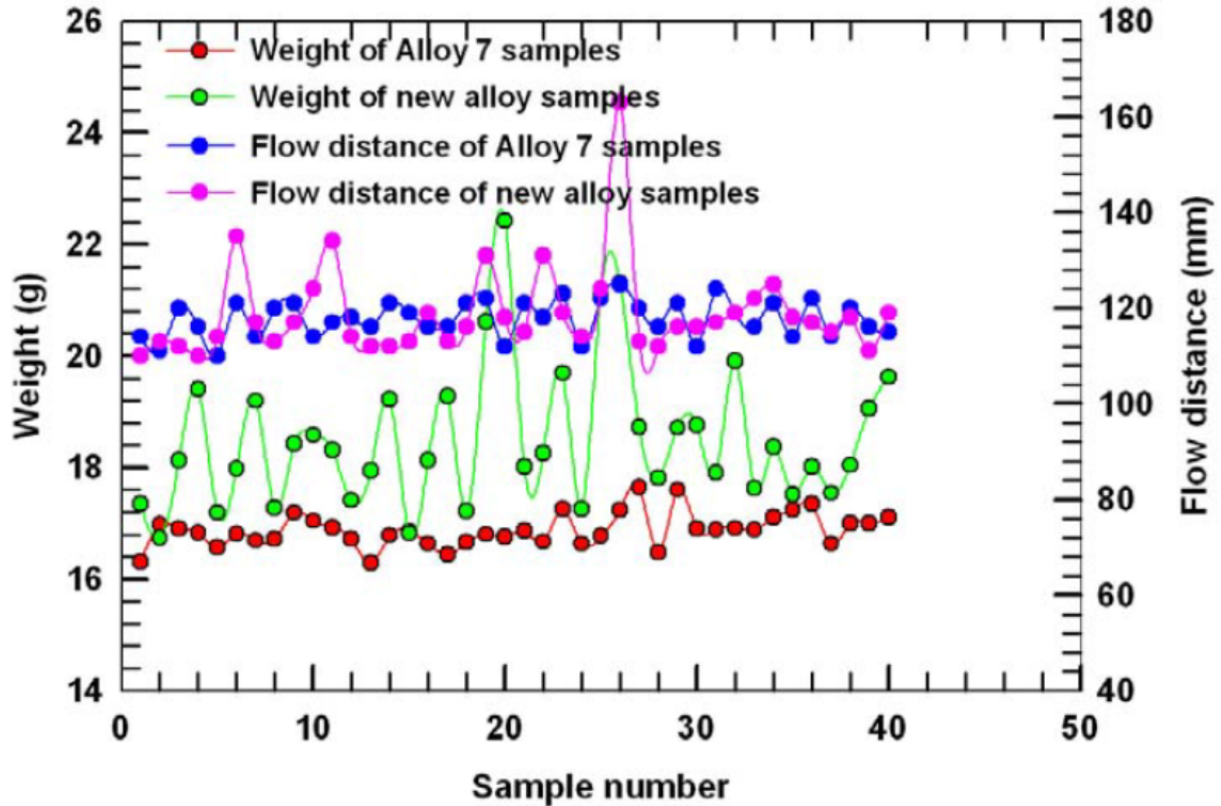


Figure 5 Comparison of weight and flow distance of Alloy 7 and HF alloy samples cast at a die temperature of 177°C (350°F) and a fill time of 25 milliseconds.

Mechanical Properties Measurements, Brillcast Trial

Tensile and impact samples were collected during the Brillcast trials for evaluating mechanical properties of the HF alloy and Alloy 7. Selected tensile samples were aged at 95°C (203 °F) for 10 days to evaluate the aging effect. Tensile samples of both Alloy 7 and the HF alloy were machined from the thinnest sections of the fully-filled flow samples using a rotary cutter.

Uniaxial tensile tests were carried out at room temperatures using a Schenck Universal Machine while impact tests were conducted using a Riehle Impact Testing Machine.

Results of the mechanical tests of as-cast samples are listed in Table 7. Typically, three tests were repeated for samples cast at a specifically condition. The values in the table represent the average of the repeated tests. At similar conditions, Alloy 7 reported higher tensile strength than the HF alloy. Favorable cavity fill conditions, hotter die temperature or shorter fill time, resulted in higher values of tensile strength, elongation and impact energy for both alloys. Figure 6 graphically depicts the tensile test results of samples from each trial. Results of tensile strength were very much repeatable for samples cast at same conditions while elongation values show more fluctuations.

Table 7 Mechanical Properties of As-Cast Tensile Samples. Trial Number conditions are repeated in the order shown in Table 5 for each alloy.

Alloys	Trial No.	Tensile Strength (MPa)	Elongation (%)	Impact Energy (Joules)
Alloy 7	1	321.9	3.77	
Alloy 7	2	312.4	4.35	27.8
Alloy 7	3	312.4	3.50	61.4
Alloy 7	4	326.0	9.26	38.8
New Alloy	5	305.5	3.32	55.4
New Alloy	6	310.1	12.60	
New Alloy	7	288.5	3.07	
New Alloy	8	308.0	8.23	30.3

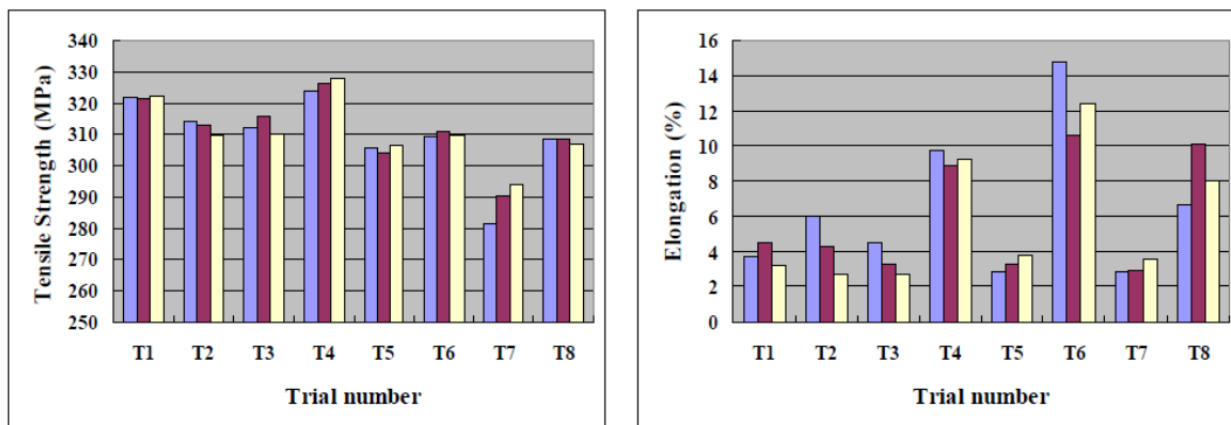


Figure 6 Tensile strength and elongation of as-cast samples. Alloy 7 samples: T1 to T4; the new HF samples: T5 to T8. Trial Number conditions are repeated in the order shown in Table 5 for each alloy.

Task 8. Phase I Analysis & Reporting

Analysis and reporting was provided in in the quarterly reports transmitted during this period.

Funding Period 2: 2012-2013

Task 1: Brochure development and production

A 16-page brochure was developed and produced that describes the development of the alloy through a multi-year project coordinated by NADCA and the Cast Metals Coalition (CMC) industry consortium. It details the 40% improvement in fluidity over conventional Zamak alloys,

and lists the physical, mechanical and corrosion properties shown to be comparable with existing Zamak #3 and #7 alloys. The excellent fluidity is shown to be beneficial for casting thin sections below 0.45mm, but also for casting parts that are difficult to fill or that have high surface finish requirements.

This brochure has been completed. NADCA has produced a quantity of paper copies for disseminating at seminars. An electronic copy of the final version has been uploaded to the ESMARRT reporting website.

Task 2: Consultant analysis and recommendations

An experienced zinc die casting consultant with expertise in both technology and market development was retained for this task. His conclusions are:

1. The transfer of technology to end users needed to fully exploit the advantages of the new HF alloy has begun. A cursory evaluation of the properties indicate that the new HF alloy is appropriate for thin wall applications or the casting of complex parts, and some initial test castings have included a thin walled cell phone case and smart phone cover, and a heavy and difficult to cast nozzle cover plate [5]. Subsequent castings in the HF alloy included another phone cover, a high intensity light fixture, a jewelry locket, and a shot glass [8].
2. Zinc alloys already compete with other metal casting alloys and plastics, across a broad spectrum of manufacturing techniques, notably sheet metal forming, stampings, weldments, machining, powder metallurgy, and castings in a wide range of market sectors. Past surveys have identified shortcomings and opportunities:

- a. A 1995 market survey conducted for the International Lead Zinc Research Organization by PERA Consulting identified seven important markets for zinc die castings, namely Automotive, Builders Hardware, Electronics, Home Appliances, Industrial, Leisure and Toys [9]. The survey revealed the many positive benefits of zinc die casting alloys, while highlighting only one major drawback. In the automotive sector respondents noted zinc alloys for having high strength, net shape casting capabilities, close tolerances and ease of assembly, but disliked the weight or density of the alloys. In the home appliances sector, respondents approved of the close tolerances, net shape casting, excellent surface finish, and good stiffness benefits that zinc casting allows, but disapproved of the weight penalty of the alloys. In the Industrial sector, respondents liked the high strength, close tolerances, stiffness, and net shape casting of zinc alloys, but again disapproved of the weight of the alloys compared to aluminum casting alloys or plastics.

With only weight as the perceived obstacle to further market penetration, the new high fluidity zinc die casting alloy provides a ready solution. Featuring a better fluidity, excellent surface quality, optimized mechanical properties and the ability to maintain close tolerances, the new HF alloy has the potential of saving material, energy and costs, thereby maintaining or regaining market share, and creating new market opportunities.

- b. A more current 2011 market survey commissioned by the North American Die Casting Association and Interzinc revealed a similar range of important markets

for zinc die castings with the top seven reported as; Automotive, Appliances, Plumbing fixtures, Computer/business machines, Instruments, Motors (non-auto), and Hardware [10]. Moreover, enclosures for handheld electronic devices, for example, are not currently made from zinc die casting alloys. The ultra thin wall casting capability of the new HF alloy, along with its high strength, net shape casting capability and excellent surface finishing potential could be very beneficial for this market segment. Another opportunity lies with complex shapes, and not necessarily thin walled castings. The convoluted flow lines needed to fill complex parts with tight tolerances will benefit from enhanced flow of the HF alloy allowing more complete filling of the die and more dense parts, ensuring primarily that the full strength of the part is achieved.

Task 3: Consultant Contacts with Strategic Potential Applications

To unlock the potential of the new HF alloy, the consultant then conducted a national email campaign, distributing the HF alloy brochure to potential users across a wide range of companies covering many diverse market segments throughout the United States. The brochure was sent by email to 1,184 product designers across the United States identified by Interzinc as having a serious interest in zinc. The contacts have either attended a zinc die casting seminar or requested technical or design assistance with a zinc die casting. The distribution of the brochure by geographic region in the United States is shown in Table 8.

Table 8 Distribution of the HF Alloy brochure by region in the United States

Region	North East	Mid Atlantic	South East	Great Lakes	Midwest	Texas	California	Total
Contacts	203	116	173	145	240	75	232	1,184

There was excellent reception to the news of the HF Alloy. Five seminars were arranged and completed before during September 2013 for 81 employees from 30 companies in the Automotive, Appliances, Plumbing, Computer/Electronics, Instruments and Hardware market sectors. Both general group and individual company seminars were held. The 30 companies came from across a range of business sectors:

- Automotive
 - Autoliv ASP Inc., Daedong America Corp., Eaton Corporation, General Motors, Gunslinger Auto Inc., Hendrickson International Corporation, Key Safety Systems Inc.
- Appliances
 - Evenflo Company Inc., Invacare Corporation, The Kirby Company, MSA, Norcold Inc., Transmotion Medical Inc.
- Plumbing
 - GOJO Industries, Norweco Company Inc.
- Computer/Electronic
 - BlackBerry Inc, PMI industries
- Instruments
 - Automated Packaging Systems Inc., Flextronics Medical, GE Inspection Technologies, GE MCS, Harman International, Pepperl+Fuchs Inc., Valeo Radar Systems Inc.
- Hardware

- Atlas Bolt and Screw Company LLC, Cable Manufacturing and Assembly Co., Forms+Surfaces, Protista, Qinetiq North America, Structural Plastics Corporation

Each of the seminar participants then sent one or two examples of HF castings to further cultivate their interest: the business card case and/or the cast “shot glass” shown in Figure 7. Reactions from the recipients ranged from disbelief that these very light and detailed castings were actually made in a zinc casting alloy to great excitement. Other companies showing significant interest, who have received samples but have not yet attended a seminar before the project conclusion date, included Kohler [plumbing segment], Siemens Healthcare Diagnostics [instruments] and Mattel [toys].



Figure 7 Business card case, thickness 0.3mm cast by Ka Shui, Shenzhen, China (l) and Cast “shot glass”, thickness 0.3mm cast by Havelleandischer Zinkdruckguss, Premnitz, Germany

Interest in the alloy was generated across many different business sectors, roughly in line with the results of the 2011 NADCA-Interzinc market survey described above. Detailed questioning of seminar attendees about design and product opportunities failed to reveal a unique or specific group of product types suitable for the HF Alloy. All participants felt the alloy had broad application potential based on the ability to remove mass from a product and reduce material costs.

A webinar on the HF alloy was prepared and presented on May 29, 2013. This was produced by NADCA and is now stored for access on the NADCA website.

Task 4: Applications Design Assistance

1. A “legacy locket”, formerly made from stamped brass, was converted to the new high fluidity alloy developed in this program. Three-dimensional modeling by R&S Design, Roselle, IL resulted in delivery of STEP and IGES files to the customer and the die caster, Joyners’s Die Casting, St. Paul, MN. Zinc cast prototypes were then made by Prototype Castings, Denver. Substantial design assistance to develop the shape, hinge and

clasp functions and 0.75mm (0.030") wall thickness was provided. The part is shown in Figure 8. Joyner's received a purchase order and proceeded to production during September 2013.



Figure 8 Legacy Locket converted from brass stamping to lightweight HF alloy casting assembly.

2. Components of a smartphone case were designed for zinc die casting for HTC, a major supplier to this market. This included casting shape development, die design and flow simulation work, and selection of surface finishes. HTC has ordered 6 die casting dies, at a cost of about \$100,000 each to proceed further with high volume production. Average casting thickness will be about 0.4mm (0.15"). The default method of manufacturing smartphone cases is to machine them from forged aluminum performs. Very significant improvements in cost, energy reduction and strength can be realized by producing smartphone cases in thin section zinc die castings.
3. Three other parts were proposed by Joyner's: Swing handle garnish plate, ID Garnish ring, ID Garnish ring with 1x11 inch slot. It was shown that wall thicknesses of 0.75mm (0.030") could be achieved with these components.
4. Table bezel for Joyner's. This was shown to have a weight of 2.73 oz (77g) for a wall thickness of 0.060" (1.5mm) and 1.37 oz (39 g) for a wall thickness of 0.030" (0.76mm).
5. Design assistance was provided to a leading manufacturer of LED lighting fixtures. LED lights have significant heat dissipation requirements, and the service temperature of a LED light chip has a significant effect on its lifetime. For example, doubling the junction

temperature from 75 to 150°C can shorten the life of a LED light by 70 percent. Also, elevated temperatures reduce the light output per unit of power input, and therefore efficiency. Therefore, management of heat dissipation of LED lights is a key point in improving the attractiveness of LED lights versus less efficient lighting sources such as incandescent and fluorescent lights. At present the base of most LED lights that are designed to screw into existing incandescent sockets are made of extruded aluminum. These are finned to improve heat transfer; however minimum fin thickness is limited to about 3 mm. It is well known that the performance of heat transfer fins is limited by their surface area in contact with air rather than fin thickness. The use of the HF alloy should reduce fin thickness to less than 1 mm, greatly improving fin surface area while reducing weight.

6. Assistance was given to a New Jersey die caster in developing a high security electronic enclosure for a U.S. government agency. The objective was to design an enclosure that would sufficiently destroy the enclosed electronics, if the enclosure was forced open, so that no useful content could be retrieved. No other details are available.
7. Further development work was done with HTC on their HF alloy case for smartphones. A prototype case, 0.5mm (0.02") thick was cast by Brillcast and castings sent to New Brunswick Plating and Saporito Finishing to develop surface finishes thought to be of interest to HTC for their desired "natural metal look". During a working visit to New Brunswick, a glass bead blasted preparation as used with their proprietary chemical etching and other preparation techniques to produce samples for HTC. The appearance of this surface is shown in Figure 9. Further work on die texturing with Brillcast together with production of thinner prototype parts is planned.
8. Detailed casting production analysis, including PQ squared shot analyses have been completed for Mattel to optimize gate and runner design in order to minimize recurring porosity in several products. There is significant interest in the HF alloy at Mattel following telephone discussions and their review of the HF alloy brochure and the cast business card holder and shot glass samples. A production trial is being planned with the new HF alloy.



Figure 9 Surface appearance of prototype smartphone case, glass bead shot peened and surface treated to give “natural metal look”

Benefits Assessment

Along with an attractive combination of mechanical properties as summarized in Table 9, it is well known that zinc alloys allow casting of a thinner wall section with the high pressure die casting process as compared to other metal alloys because of zinc’s low melting point and its excellent fluidity. The development of the new High Fluidity [HF] zinc die casting alloy significantly improves zinc alloy fluidity to allow an ultra-thin wall casting section thickness of 0.3mm or less.

The high fluidity alloy can significantly improve upon the energy and cost savings already inherent in zinc alloys, including fast production rates and net shape casting that eliminates the need for subsequent machining operations. The low melting temperature (385°C) alloy reduces energy requirements for metal melting and holding, and increases die life, while the weight reduction achieved through ultra thin wall casting capability reduces energy use throughout the life of the cast part from melting and casting, transportation of finished parts, during use and final collection for end of life recycling. All are important benefits for the zinc alloy die caster and end user of zinc die castings.

Table 9 Mechanical Properties of the HF Alloy

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 10 ⁶ (91.7)
Poisson's Ratio	aged:	0.30

Commercialization

Commercialization leadership has been taken by Joyner's Die Casting in Minneapolis, MN and Brillcast in Grand Rapids, MI. These companies have been proactive in seeking new jobs that could be manufactured to advantage in the HF alloy, including conversions from brass and steel stampings where parts consolidation, such as the hinges on the legacy locket, lead to savings in materials, processing, cost and energy. The stimulation of demand by the Tasks 2 and 3 consultant has resulted in many inquiries to these and other U.S. die casters.

Accomplishments

1. A new high fluidity zinc casting alloy has been developed that is compatible with existing production equipment. The alloy is 40% more fluid than existing alloys and has the capability of filling sections of 0.3 mm (0.011 in.) thickness.
2. The mechanical properties of the HF alloy are in the same range as existing zinc casting alloys.
3. A brochure describing the HF alloy, its advantages and potential applications has been produced. It has been printed by NADCA for distribution and is also available electronically at the www.zinc.org and www.diecasting.org websites.
4. An analysis of the full spectrum of applications where the HF alloy could best be utilized has been performed, leading to recommendations for focus in technology transfer activities.
5. Five "live" seminars were performed that further increase the interest of 81 designers and specifiers. A webinar was also performed that was joined by 13 participants. The webinar is now stored for distribution on the NADCA website www.diecasting.org
6. Technical assistance was provided to diecasters and their customers on conversion of parts to the CF alloy. One of these has entered industrial production; others are expected to follow.

Conclusions

1. The new zinc die casting alloy capable of producing castings with thinner sections than achievable before, termed the high fluidity (HF) alloy, was successfully developed in a DoE CMC program. Development of mechanical properties data and casting trials carried out during this prior project resulted in an alloy ready for commercial development.
2. A study of potential applications that could use the HF alloy to advantage was conducted. Electronic enclosures such as smartphone cases, which do not have high mechanical property requirements but very high cosmetic (surface finish) requirements, together with very light weight, were seen as very attractive for development. Other applications such as toys that also have minimal mechanical property requirements together with high demands for surface finish are attractive; it is noted that several toy manufacturers seek to reduce their “carbon footprint” and are receptive to conversion of plastic toys to ultra-thin zinc castings. Intricate castings that are difficult to fill, including lock hardware, have been filled more reliably with the HF alloy [8].
3. Technology transfer activities conducted during the present project have been met with enthusiasm from U.S. designers and specifiers. The webinar and five seminars conducted for this audience were well received, in some cases with disbelief that the exhibited castings produced in the prior project were actually zinc die castings.
4. Technical assistance given during applications development has allowed for successful development of castings converted from other materials that have the potential of reducing metal and energy usage. One of these has proceeded to industrial production; others will certainly follow.

Recommendations

1. Success stories and other documentation encouraging the increased usage of the HF alloy should be developed. Industry organizations serving the zinc and die casting industries are expected to continue technology transfer and market development activities, and should be encouraged to participate in Department of Energy activities that further the usage of the HF alloy, together with participation of interested die casters and their customers.

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