EZAC™ – High Strength, Creep Resistant, Zinc Die Casting Alloy

Ryan Winter, Manager Customer Engineering Services
Eastern Alloys, Inc.
Maybrook, New York

Introduction

Since zinc die casting's conception over 100 years ago, many new and improved developments have taken place to progress the industry and offer component designers a cost-effective alternative to higher priced alloys and processes.

The zinc industry has continued to develop new alloys in response to some of the challenges that face it. One such development is EZAC™, Eastern Alloys' high strength, creep resistant alloy. Now component designers can incorporate the economical advantages of zinc die casting for designs requiring higher strength, hardness and creep performance.

Early Challenges and Developments in Zinc Die Casting

The Zinc die casting industry was founded in the early 1900's after the development of a zinc die casting alloy that eventually replaced lead and tin die casting components. Zinc was considered high strength, lightweight, and low-cost compared to these alloys. It was later found that in humid conditions this early zinc alloy underwent intergranular corrosion due to lead concentrations found in the zinc.

In the 1930's, development of Special High Grade (SHG) zinc, eliminated lead, cadmium and tin contents in zinc, which solved these pressing intergranular corrosion issues. It was also found that adding magnesium helped counteract the effects of corrosion due to these elements in the zinc alloy. These developments initiated the creation of the Zamak family of zinc alloys.

Zamak 3 is still the most common zinc die casting alloy used in North America, due to its combination of strength, processing costs, castability, low attack rate on tooling, and so on.

In the 1960's the ZA alloys were developed and marketed as high strength zinc die casting alloys. In the 1980's GM developed ACuZinc 5 and 10[#1], which have higher copper concentrations resulting in even higher strength, wear performance, and creep resistance. These alloys provided solutions to component designers who were looking for lower cost alternatives for high strength applications.

Current Challenges Facing Zinc Die Casting

Some of the challenges that face zinc die casting today are more difficult to answer because they are inherent to the properties of zinc alloys. Two of the more common challenges that zinc die casting alloys continue to face are density and creep resistance.

Zinc's density challenge has generally been countered by the enhanced fluidity of zinc alloys. The ability to cast thinner walls has always been an advantage of zinc die casting. It is common to cast relatively large castings with a 0.020"-0.030" wall thickness. New alloy development (ultra thin wall zinc alloy) and processing techniques have further improved zinc die casting's ability to compete with lighter materials.

EZAC™ is Eastern Alloys' answer to the challenge of creep resistance. This new alloy has tested to be the most creep resistant hot chamber zinc die casting alloy available. In addition, it has also shown to be the strongest and hardest hot chamber alloy. The following paragraphs give a background of the development of EZAC™, as well as current testing results.

Early Research for a Creep Resistant Zinc Alloy – ZCA-9

Prior work on the development of hot chamber die casting alloys was performed by ILZRO (International Zinc Research Organization) and described in the 2003 NADCA Congress[#2]. In this report, details of research detailed one alloy that appeared to have improved creep performance compared to the commercial alloys Zamak 5 and ZA-8.

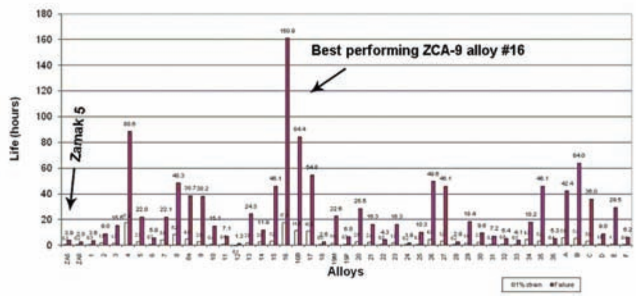

Figure 1 – ZCA-9 Results showing improved creep performance with test alloy #16.

Results of creep testing at 140° C and 31 MPa are shown in Figure 1. Alloy #16 in this program was found to have the best creep performance of all samples tested. Tables 1 & 2 give the chemistry, creep results (including time to 1% creep & rupture), and mechanical properties of alloy 16 compared to Zamak 5 and ZA-8.

Table 1 – Chemical analysis (wt%) of test samples of ZCA-9 Research

Alloy	Al%	Cu%	Cr%	Ti%	B%
ZCA-9 (#16)	7.26	2.85	0.2	0.3	0.030
Zamak 5	3.5-4.3	0.75-1.25	-	-	-
ZA-8	8.0-8.8	0.8-1.3	-	-	-

Table 2 – Comparison of the ZCA-9 Creep Results at 140C & 31 MPa & tensile Properties

Alloy	UTS (psi)	Yield (psi)	1% Creep strain (hrs)	Creep Failure (hrs)
ZCA-9 (#16)	44,300	38,400	17.8	160.9
Zamak 5	41,400	29,700	0.3	3.9
ZA-8	42,100	29,700	0.2	2.8

At the completion of this research, it was decided that the proper casting compositional range for this new alloy was "two Euclidian distance points from the Zn-Al-Cu ternary eutectic", approximated graphically in Figure 2 as the blue oval surrounding the red dot that indicates the location of the ternary eutectic. This ternary eutectic has the lowest liquidus temperature of the system at 377° C (711° F). Because of this low temperature, small freezing range, and low attack rate on shot end components, alloys in this region can be die cast in a hot chamber die casting machine. It was also found that small amounts of Ti and B were also somewhat beneficial in creep performance, however it was suspected that the amount of aluminum and copper played a more important role.

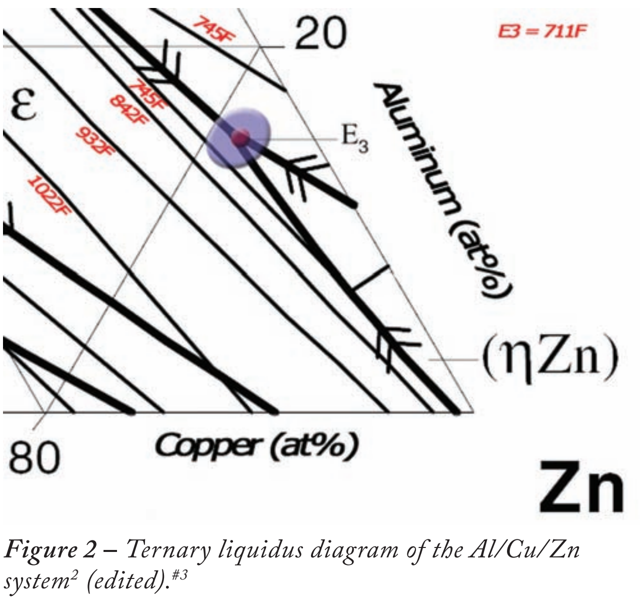

Figure 2 – Ternary liquidus diagram of the Al/Cu/Zn system[2] (edited).[#3]

After further examination, comparing this range with the ternary phase diagrams at varying temperatures, it was noticed that a portion of the ZCA-9 range (blue oval) contained alloys that developed a primary copper rich Epsilon phase (at 400° C); whereas most of the range is liquid at this temperature. At 350° C, the entire range is converted to a two phase system comprising of an Epsilon (Copper rich) phase and an Eta (Zinc rich) phase.

It was decided that more testing was needed to ensure that all areas of this alloy's composition had at least the same properties as those published in the original ZCA-9 research. Using a senior design team from Michigan Technological University (MTU) and Brillcast (Grand Rapids, MI), five alloys were chosen within the ZCA-9 range. Each alloy was die cast and tested using the same parameters as was performed in the ZCA-9 research.

Testing proved that all the alloys within the range compared in performance with the ZCA-9 research; however, an optimal compositional range was discovered which produced the best performance in creep resistance, strength and hardness.[#4]

Development of EZAC™

Continued development of an alloy within this optimal range continued until an alloy with the best combination of creep, strength and castability was determined. The final alloy was chosen and is trademarked under the name EZAC^M. The following paragraphs give the latest testing results for EZAC™ compared to other commercially known zinc alloys; however, the exact composition of the alloy has been left out for proprietary reasons.

Die casting was performed on a 150 ton FRECH hot chamber die casting machine. Tooling included cavities for two tensile specimens and one notched Charpy impact specimen, as shown in figure 3. The fourth cavity was filled, but not used for testing.

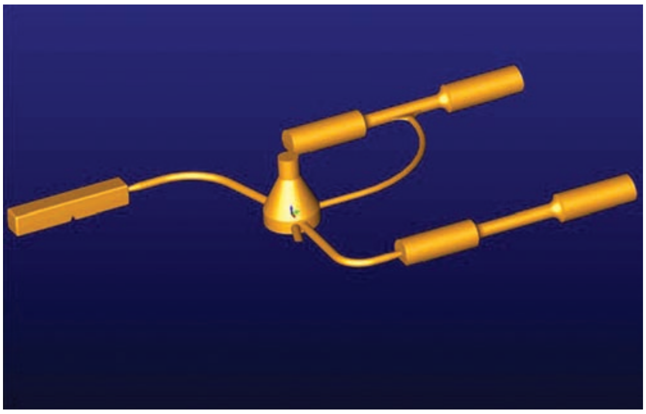

Figure 3 – Tensile and impact specimens used for testing.

Standard die casting techniques were used to ensure commercial quality parts. Target casting parameters included a cavity fill time below 40 ms, and a gate velocity of over 100 fps. Once the die casting machine was running at optimal conditions, 50 shots of each alloy group were cast, air cooled and collected for testing.

Testing Results – Mechanical Properties

Table 3 gives a summary of the mechanical tests performed. As shown, EZAC™ had the highest tensile strength with approximately 19% improvement in yield strength over ACuZinc 5 and a 42% improvement over Zamak 2. EZAC™ samples also had the highest hardness measurements with approximately 11% improvement over ACuZinc 5 and 19% improvement over Zamak 2. EZAC™ had the lowest elongation.

Although the Notched Charpy impact EZACTM samples did not perform as well as Zamak 2, they performed similarly to ACuZinc 5.

Table 3 – Mechanical properties

Alloy	UTS (psi)	Yield Strength (psi)	Strain (%)	Charpy Impact Strength (Ft-lbs)	Hardness (Rockwell B)
EZACTM	60,500	57,500	1	2	68
ACuZinc5	56,000	47,900	7	2	61
Zamak 2	48,000	40,400	4	3	57

Testing Results - Creep Resistance

Using the same creep parameters as was used during the ZCA-9 research (140° C & 31 MPa), additional creep testing was performed. Results are shown in Table 4. Alloys E-1 (EZAC™), E-2, E-3, and ACuZinc 5 had creep performance far superior to Zamak 2. Alloy E-1 (EZAC™) had the best creep results, reaching up to 730 hours, which is approximately 14X longer than Zamak 2 and 3X longer than ACuZinc5.[#5]

Table 4 – Final creep results at MTU

Alloy	Sample	Time to Failure (hrs)	Minimum Creep Rate (mm/hr)	Elongation at Failure (mm)
ACuZinc 5	86A	212	0.021	6.9
E-1 (EZAC™)	197A	731	0.004	6.7
E-2	312B	233	0.002	2.8
E-3	421A	218	0.030	8.4
Zamak 2	512A	52	0.152	9.0

Figure 4 shows the full creep curves for each alloy tested. Time to 1% creep was also measured, but due to the initial slippage in the creep testing apparatus, these results were considered unreliable. The secondary creep rate was also measured, with alloys E-1 (EZAC™) & E-2 having the lowest steady state creep rate.

Although the chemical compositions of alloys E-1 (EZAC™), E-2 & E-3 are relatively close, there is a fairly large variation in the long term creep results. Casting

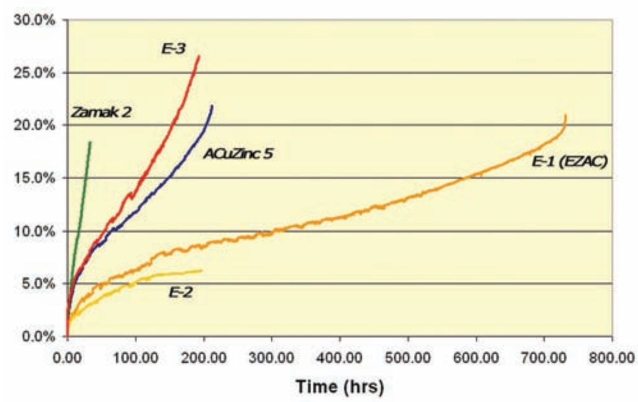

Figure 4 – Creep Curves for the alloys tested at MTU.

defects such as gas porosity and cold shuts contribute to an adverse creep performance, and may have contributed to the variation in the testing results shown here.

A cross sectional view of untested castings can be seen in Figure 5 showing the internal porosity levels. Most of the porosity in the samples occurred in the grip section, farthest from the gate; however, there was some amount of porosity within the critical gauge section, which may be affecting their creep performance. Further testing is underway to help determine the extent of the role that gas porosity plays in creep performance. The effect of aging on dimensional change during creep may also contribute to differences in the creep results.

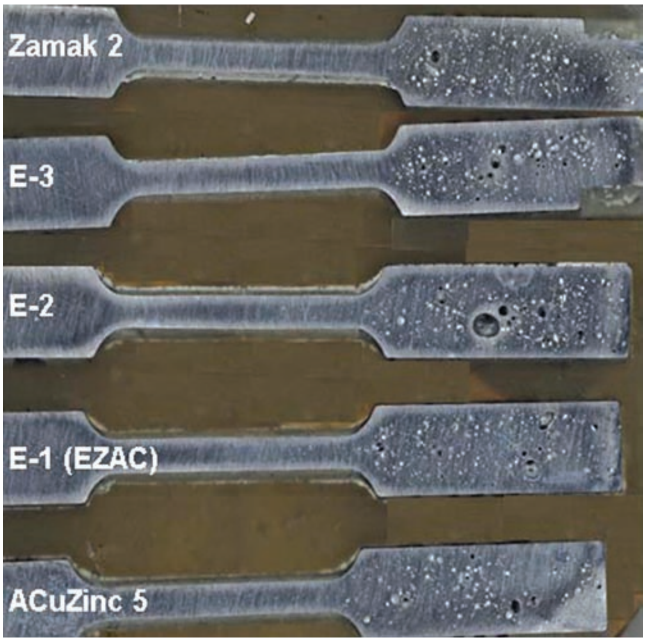

Figure 5 – Cross sectional view of the samples with resulting porosity content.

Summary/Conclusions

EZAC™ is the result of continued alloy development following the initial success of the CMC-sponsored research program, "Improved Creep Resistant Zinc Alloys" conceived and managed by ILZRO and conducted at CSIR, South Africa. Two rounds of subsequent alloy development and testing showed continued significant improvements in mechanical properties and creep performance over conventional hot chamber zinc alloys. Although all test alloys exhibited improved performance, test alloy E-1 showed to have the best combination of mechanical properties, and was chosen for commercial development under the trademark EZAC™.

Due to EZAC's™ proximity to the ternary eutectic point, it has a very low melting temperature and can be die cast in a hot chamber machine. Casting trials have shown EZAC™ to have excellent castability without accelerated wear on shot end components associated with other zinc based die casting alloys such as ACuZinc5. Future testing is warranted to improve the understanding of EZAC™, including additional creep testing, high temperature tensile testing, effect of aging, thermal conductivity, electrical conductivity, fatigue, wear rate, etc. An investigation of what role porosity plays in creep results is also of interest due to the variance in the results collected thus far.

Zinc alloys have often been overlooked in many applications due to their performance at higher temperatures and stresses compared to other materials. The improved properties of EZAC™ combined with the design advantages offered by the die casting process offers component designers and engineers a more cost effective approach when designing and converting components from other higher cost materials and processes.

About the Author

Ryan Winter is the manager of customer engineering services for Eastern Alloys. His responsibilities include offering technical assistance to Eastern's die castings customers including defect analysis, energy audits, training seminars, etc. Winter is also very active in market development for the zinc die casting industry and gives marketing seminars to designers and end users of components, as well as developing markets for new and existing zinc alloys. He can be contacted at rwinter@eazall.com for any zinc die casting related questions.

References

1. *M.D. Hanna and M.S. Rashid, "ACuZinc: Improved Zinc Alloys for Die Casting Applications", SAE Paper 930788, presented at SAE International Congress and Exposition, Detroit, MI, March 1-5, 1993, SAE, Warrendale, PA.*
2. *Hope, D., Benson, J.M., Stander, C.M., Goodwin, F.E., "Assessment of Experimental Hot Chamber Die Casting Zinc Alloys," NADCA Transactions 2003*
3. *MSIT (author), Thermodynamic Properties – Ternary Alloy Systems: Phase Diagrams, Crystoallographic and Thermodynamic Data – Light Metal Systems – Part 2, pgs182-205*
4. *Eric Vincent, Jeffery Allen, Kiera Kampe, "Improved Creep Resistant Zinc Alloys", Final Report 2007*
5. *Katherine Becker, Brett Helzer, Andrew Hodges, Daniel Hoffman, & Grethen Lange, "Creep Resistant Zn-Al-Cu Alloy Development", Final Report 2009*
6. *ASTM E139-06 Standard Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Test for Metallic Materials.*
7. *ASTM E8 / E8M - 09 Standard Test Methods for Tension Testing of Metallic Materials*