Stress-Strain Curves of Die Cast Alloys

- ZA Alloys
- Aluminum Alloys
- Zamak Alloys
- Magnesium Alloys

Note: Shaded areas indicate range of properties for all the die cast alloy types.
ZINC DIE CASTING ALLOYS

This guide was created to help designers and material specifiers better understand the capabilities of zinc die casting alloys for product applications.

ADVANTAGES
Zinc casting alloys are versatile engineering materials. No other alloy system provides the combination of strength, toughness, rigidity, bearing performance and economical castability. Listers are zinc alloy attributes which can reduce component costs. Improving precision, quality and product performance are other zinc alloy design advantages discussed in this brochure.

Process Flexibility: Virtually any casting process can be used with zinc alloys to satisfy any quantity and quality requirement. Precision, high-volume die casting is the most popular casting process. Zinc alloys can also be economically gravity cast for lower volumes using sand, permanent mold, graphite mold and plaster casting technologies.

Precision Tolerances: Zinc alloys are castable to closer tolerances than other metals or molded plastics, presenting the opportunity to reduce or eliminate machining. "Net Shape" or "Zero Machining" manufacturing is a major advantage of zinc casting.

Strength & Ductility: Zinc alloys offer high strengths (up to 60,000 psi) and superior elongation for applications requiring both strength and formability for secondary process applications such as bending, drilling and riveting.

Toughness: Few materials provide the strength and toughness of zinc alloys. Impact resistance is significantly higher than cast aluminum alloys, plastics, and grey cast iron.

Rigidity: Zinc alloys have the rigidity of metals with modulus of elasticity characteristics equivalent to other die castable materials. Stiffness properties are, therefore, far superior to engineering plastics.

Anti-Sparking: Zinc alloys are non-sparking and suitable for hazardous location applications such as coal mines, tankers and refineries.

Bearing Properties: Bushing and bearing inserts in component designs can often be eliminated because of zinc's excellent bearing properties. For example, zinc alloys have outperformed bronze in heavy duty industrial applications.

Easy Finishing: Zinc castings are readily polished, plated, painted, phosphated, or chromated for decorative and/or functional service.

Thin Wall Castability: High casting fluidity, regardless of casting process, allows for thinner wall sections to be cast in zinc compared to other metal.

Machinability: Fast, trouble-free machining characteristics of zinc materials minimize tool wear and machining costs.

Low Energy Costs: Because of their low melting temperature, zinc alloys require less energy to melt and cast versus other engineering alloys.

Long Tool Life: Low casting temperatures result in less thermal shock and, therefore, extended life for die casting tools. For example, tooling life can be more than 10 times that of aluminum dies.

Clean and Recyclable: Zinc alloys are among the cleanest melting metals available. Zinc metal is non-toxic, and scrap items are a reusable resource which are efficiently recycled.

ZINC ALLOYS

There are two basic families of zinc casting alloys: ZAMAK alloys and ZA alloys. The ZAMAK alloys were devised for pressure die casting during the 1920’s and have seen widespread usage since then. It is for this reason that specifiers often relate zinc as synonymous with die casting. However, the development of the ZA (Zinc-Aluminum) Alloys during the 1970’s has radically changed zinc production design and manufacturing capabilities.

ZA Alloys were initially developed for gravity casting. Their mechanical properties compete directly with bronze, cast iron and aluminum using sand, permanent mold and plaster mold casting methods. Distinguishing features of the ZA alloys are their high aluminum content, high strength, and bearing properties.

During the 1980’s, ZA alloys evolved as valuable die casting materials. It is important to note that when considering a ZA alloy for die casting, only ZA-8 can be hot chamber die cast. Hot chamber casting (which the ZAMAK alloys employ) is highly automated and the most efficient die casting process. ZA-12 and ZA-27 require special melting procedures and must be die cast like aluminum using the less efficient cold chamber die casting process.

A brief description of each alloy is provided below:

ZAMAK 3
This alloy is usually the first choice when considering zinc for die casting. Its excellent balance of desirable physical and mechanical properties, super castability and long term dimensional stability are the reasons why over 70% of all zinc die castings are made from this alloy. It is therefore the most widely available alloy from die casting sources. ZAMAK 3 also offers excellent finishing characteristics for plating, painting and chromate treatments. It is the “standard” by which other zinc alloys are rated in terms of performance.

ZAMAK 5
This alloy is marginally stronger and harder than ZAMAK 3. However, these improvements are tempered with a reduction in ductility which can affect formability during secondary bending, riveting, swaging or crimping operations. ZAMAK 5 has approximately 1% copper which accounts for these property changes.

Because of ZAMAK 3’s wide availability, designers often strengthen components through design modifications, instead of changing alloys. However, when extra performance is necessary, ZAMAK 5 alloys can be a viable alternative.

ZAMAK 7
This alloy is a modification of ZAMAK 3 in which lower magnesium content is specified to improve fluidity. To avoid problems with intergranular corrosion, lower levels of impurities are called for and a small quantity of nickel is specified. ZAMAK 7 also has slightly better ductility than ZAMAK 3, with other properties remaining relatively equal.

ZAMAK 8
This is the only hot chamber zinc die casting alloy in the ZA family. It has improved tensile strength, creep performance and hard properties compared to the ZAMAK alloys (except for ZAMAK 2, which is similar in performance). ZA-8 can be plated and finished using the same standard techniques as the ZAMAK alloys. ZA-8 offers an excellent alternative to ZAMAK alloys when greater properties are required.

ZAMAK 12
Although more readily recognized as a gravity casting alloy, this alloy can also be die cast when a higher strength is required. It has the best combination of strength (yield strength is 46 ksi) and castability of all the ZA alloys. The cold chamber die casting process is required for this alloy due to the higher attack rate on the shot end components.

ZAMAK 27
This alloy is the strongest of all the ZAMAK and ZA alloys with a reported yield strength of 55 ksi. It also is the lightest alloy available, and has excellent bearing and wear performance. Additional care is needed when casting this alloy to ensure a sound casting. It may also need a stabilization heat treatment if tight dimensional tolerances are required. ZA-27 is not recommended for plating. When brute strength or wear resistant properties are needed, ZA-27 has demonstrated extraordinary performance.

ACUZINC™ 5
This alloy was developed by GM, and has improved tensile strength, hardness and creep performance compared to the ZAMAK alloys. ACUZINC™ 5’s strength and hardness properties are comparable to ZA-12. Testing has also shown ACUZINC™ 5 to have excellent wear characteristics.

Although this alloy is a hot chamber die casting alloy, it is known to be much more difficult to die cast with a higher wear rate of the shot end components in the die casting machine.

EZAC™
This is the most recent development in commercially available zinc die casting alloys. Research has shown EZAC™ to be the most creep resistant of all the zinc die casting alloys with over an order of magnitude improvement over ZAMAK 5 and ZA-8. This is also a very strong alloy with a yield strength (57 ksi) and hardness (102-134 Brinell) comparable to ZA-27.

Due to its low melting temperature, EZAC™ can be cast in a hot chamber die casting machine, and does not exhibit the same wear and tear as shown with ACUZINC™ 5.
### Zinc Die Casting Alloy Properties and Comparison Guide

#### Alloy Properties

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Zamak 3</th>
<th>Zamak 5</th>
<th>Zamak 7</th>
<th>Zamak 2</th>
<th>ZA-8</th>
<th>ZA-12</th>
<th>ZA-27</th>
<th>EZAC&lt;sup&gt;TM&lt;/sup&gt;</th>
<th>Al 380&lt;sup&gt;10&lt;/sup&gt;</th>
<th>AZ91D&lt;sup&gt;10&lt;/sup&gt;</th>
<th>FC-0208-R&lt;sup&gt;11&lt;/sup&gt;</th>
<th>Brasse&lt;sup&gt;12&lt;/sup&gt;</th>
<th>Nylon&lt;sup&gt;13&lt;/sup&gt;</th>
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<tbody>
<tr>
<td><strong>Mechanical Properties</strong></td>
<td></td>
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</tr>
<tr>
<td>Ultimate Tensile Strength, ksi (MPa)</td>
<td>41 (283)</td>
<td>48 (332)</td>
<td>41 (283)</td>
<td>52 (359)</td>
<td>58 (400)</td>
<td>61 (421)</td>
<td>60 (416)</td>
<td>47 (324)</td>
<td>34 (244)</td>
<td>60 (415)</td>
<td>52 (360)</td>
<td>11.5 (79.3)</td>
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</tr>
<tr>
<td>Yield Strength, 0.2% Offset, ksi (MPa)</td>
<td>32 (221)</td>
<td>39 (270)</td>
<td>32 (221)</td>
<td>41 (283)</td>
<td>46 (317)</td>
<td>55 (379)</td>
<td>57 (396)</td>
<td>43 (296)</td>
<td>23 (160)</td>
<td>48 (330)</td>
<td>20 (140)</td>
<td>NYA</td>
<td></td>
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<tr>
<td>Elongation, % in 2”</td>
<td>10</td>
<td>9</td>
<td>13</td>
<td>6-10</td>
<td>7</td>
<td>4-7</td>
<td>1</td>
<td>15</td>
<td>3</td>
<td>1</td>
<td>45</td>
<td>10 (69)</td>
<td></td>
</tr>
<tr>
<td>Shear Strength, ksi (MPa)</td>
<td>31 (214)</td>
<td>38 (262)</td>
<td>31 (214)</td>
<td>46 (317)</td>
<td>30 (205)</td>
<td>15 (102)</td>
<td>12 (82)</td>
<td>10 (70)</td>
<td>8 (55)</td>
<td>10 (69)</td>
<td>85 H0M</td>
<td>125 (86)</td>
<td></td>
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<tr>
<td>Hardness, Brinell</td>
<td>82</td>
<td>91</td>
<td>80</td>
<td>100</td>
<td>95-110</td>
<td>105-125</td>
<td>120</td>
<td>80</td>
<td>63</td>
<td>110</td>
<td>78 HRF</td>
<td>125 (86)</td>
<td></td>
</tr>
<tr>
<td>Impact Strength, ft-lb/in (J)</td>
<td>49 (358)</td>
<td>48 (358)</td>
<td>49 (358)</td>
<td>50 (375)</td>
<td>50 (375)</td>
<td>50 (375)</td>
<td>50 (375)</td>
<td>37 (282)</td>
<td>32 (245)</td>
<td>44 (325)</td>
<td>44 (325)</td>
<td>1.25 (4.0)</td>
<td></td>
</tr>
<tr>
<td>Tension Fatigue-Spec Yield, ksi (MPa)</td>
<td>6.5 (44)</td>
<td>8.2 (57)</td>
<td>6.8 (47)</td>
<td>8.5 (58)</td>
<td>15 (102)</td>
<td>20 (140)</td>
<td>20 (140)</td>
<td>14 (97)</td>
<td>14 (97)</td>
<td>14 (97)</td>
<td>14 (97)</td>
<td>125 (86)</td>
<td></td>
</tr>
<tr>
<td>Tension Fatigue-Hardness Offset, ksi (MPa)</td>
<td>60 (414)</td>
<td>69 (494)</td>
<td>69 (494)</td>
<td>73 (514)</td>
<td>79 (549)</td>
<td>20 (140)</td>
<td>20 (140)</td>
<td>14 (97)</td>
<td>14 (97)</td>
<td>14 (97)</td>
<td>14 (97)</td>
<td>125 (86)</td>
<td></td>
</tr>
<tr>
<td>Modulus of Elasticity, psi x 10&lt;sup&gt;6&lt;/sup&gt; (MPa x 10&lt;sup&gt;6&lt;/sup&gt;)</td>
<td>12.4 (85.5)</td>
<td>12.4 (85.5)</td>
<td>12.4 (85.5)</td>
<td>12.4 (85.5)</td>
<td>12.4 (85.5)</td>
<td>12.4 (85.5)</td>
<td>12.4 (85.5)</td>
<td>16.2 (112)</td>
<td>13.9 (92)</td>
<td>6.5 (44)</td>
<td>1.5 (10)</td>
<td>0.3 (2.0)</td>
<td></td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.30</td>
<td>0.30</td>
<td>0.33</td>
<td>0.35</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

#### Physical Properties

- **Density, lb/ft<sup>3</sup> (g/cm<sup>3</sup>):** 0.24 (6.5)
- **Melting Range, °F (°C):** 718-728/386-397
- **Electrical Conductivity: NACS:** 27
- **Thermal Conductivity, Btu/h-ft°F (W/m-K):** 65.3 (113.0)
- **Coefficient of Thermal Expansion:** 15.2 (27.4)
- **Specific Heat, Btu/lb°F (J/kg°C):** 0.10 (4.19)
- **Permittivity or Die Sinking Rate:** 0.007
- **Chemical Specifications (Per ASTM) (Yo weight):**
  - Al - 3.2-3.7
  - Mg - 0.8-0.9
  - Cu - 0.2-0.28
  - Fe - 0.40-0.55
  - Ca - 0.004-0.006
  - Mn - 0.003-0.004
  - Zn - -

#### Industry Standards

- **ASTM:**
  - 2040 (B86)
  - 2041 (B86)
  - A506 (A506)
  - A506 (A506)
  - 3648 (3648)
  - 3648 (3648)
  - 903 (903)
  - 23325 (23325)
  - 23325 (23325)

- **SAE:**
  - 23350 (23350)
  - 23351 (23351)
  - 23352 (23352)

- **UNS:**
  - 23350 (23350)
  - 23351 (23351)

Contact us to discuss your die casting questions and other available services:
- Die casting consultation to OEM and designers
- Technical services, including defect analysis to customers
- Reducing risk in metal purchasing
- Library of technical information
- Prototyping using zinc bar stock

Notes:
1. 1/4” square specimen unnotched.
2. 10 mm square specimen unnotched.
3. 10 mm square specimen machined from a 20 mm con-cast bar
4. Compressive Strength
5. Estimated values to be confirmed by research
6. Values for permanent mold condition which should be similar for the die casting process
7. For all notes pertaining to chemical specifications, please refer to ASTM b240 (ingot) and ASTM b86 (casting).
8. Data collected from research. Some research showed that Zamak 2 had a Modulus of 111 GPa & ACUZinc 5 had a modulus of 117 GPa for comparison purposes.
9. The hardness value reported for EZAC was performed on die casting samples using a Rockwell B scale (converted to Brinell), along the outer surface of the cross sectional area (not on the casting skin).
10. EZAC is expected to have a surface hardness value similar to 2A-27.

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PROTOTYPING ZINC DIE CASTINGS

Prototyping is an essential step when developing a component’s design, helping prove out the ability of the material to withstand the necessary stress requirements. Modifications to the design of the component are much less costly during the prototyping stage compared to when modifications are made to the die steel after the tool is designed and built.

There are many ways to prototype Zinc die casting alloys. One of the quickest and easiest approaches to prototyping Zinc components is using Zinc “Con-Cast” (continuous cast) bar stock. This material is free from shrinkage and gas porosity voids that are generally present in standard ingot bars used for the die casting process. Eastern Alloys keeps a large inventory of Con-Cast bar stock consisting of many sizes, shapes and alloys. This material is also easily machined, using similar techniques when machining Bronze and Aluminum alloys.

The mechanical properties of Zinc Con-Cast bar stock are very similar to Zinc Die Castings, which makes it a perfect prototyping material. The following table compares the aged and “as-cast” properties of Con-Cast bar stock and Zinc die castings:

<table>
<thead>
<tr>
<th></th>
<th>Zamak 3</th>
<th>Zamak 5</th>
<th>ZA-8</th>
<th>ZA-12</th>
<th>ZA-27</th>
<th>ACuZinc 5</th>
<th>EZAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTS (ksi)</td>
<td>45.6</td>
<td>32.2</td>
<td>41.0</td>
<td>46.7</td>
<td>36.6</td>
<td>48.0</td>
<td>64.0</td>
</tr>
<tr>
<td>Yield (ksi)</td>
<td>38.1</td>
<td>25.0</td>
<td>32.0</td>
<td>40.7</td>
<td>31.4</td>
<td>39.0</td>
<td>50.7</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>1.6</td>
<td>3.2</td>
<td>10.0</td>
<td>1.7</td>
<td>1.8</td>
<td>7.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Brinell hardness</td>
<td>101.0</td>
<td>76.0</td>
<td>82.0</td>
<td>109.0</td>
<td>86.0</td>
<td>91.0</td>
<td>126.0</td>
</tr>
</tbody>
</table>

Table notes: 1.) Data for the Zamak and ZA alloys extracted from Paper No. G-789-091 (15th International Die Casting Congress & Exposition). 2.) Data for ACuZinc® extracted from the “ACuZinc Reference Manual”. 3.) Data for EZAC collected through internal research and testing. 4.) Properties are an average value of 1” and 4” diameter bars. (except for ACuZinc5, which values are an average of 3/4” and 4” dia bars).

For the majority of applications, using the same Con-Cast alloy to test die casting is sufficient. However, there are some properties where the con-cast bar stock may not replicate die castings, such as creep resistance, or forming techniques. In these cases, please call us for other solutions to your prototyping needs.