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PLASTICS INSIGHTS NEWSLETTER

Thixomolding® Design Overview

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Thixomolding is an environmentally friendly, high-speed, net-shape, semi-solid, magnesium injection molding process. In a single step, the process transforms room-temperature magnesium chips, heated to a semi-solid slurry inside a barrel and screw, into precision-molded components. No sintering or debinding steps are required as in the MIM (metal injection molding) process to complete the densification process.

Thixomolded® components, after cooling in air, are ready for trimming and assembly or secondary operations. They typically exhibit as molded densities in the range of 98% to 99%. This low porosity level makes them good candidates for coating or plating without blistering or outgassing.

Structured Design Process

A structured design process is suggested when considering the use of Thixomolded magnesium components in your assembly, including:

1. Define the functional requirements of each component, as follows:
    - At an operating temperature of +250°F (+121°C), creep should be considered.
    - Establish the magnitude, type and duration of stresses.
    - Is fatigue a factor in this design?
    - Define the cosmetic requirements (critical, moderate, hidden).
    - What type of fastening system (if any) will be used?
    - Consider the compatibility of adjoining materials.
    - Will the part function in a corrosive atmosphere?
    - Will a decorative finish be required?

CareerMentor

2. Do not be limited by the existing design. Use a "blank sheet of paper" approach, as existing designs may have limitations in the design because of former materials or process used.

3. Seek multiple benefits to offset higher material costs, including:
   - parts consolidation; for example, "design to combine";
   - weight savings; and
   - performance improvements.

4. Direct material substitution does not always yield competitive applications. Significant benefits of Thixomolded magnesium components include:
   - light weight;
   - thin walls, 0.020 in. (0.05 cm) minimum;
   - castability and stiffness;
   - EMI—RFI shielding;
   - high-strength-to-weight ratio;
   - high dimensional stability and tight tolerances;
   - low porosity, 50% lower than die cast;
   - dent resistance and good machinability;
   - heat transfer capability;
   - sound and vibration damping;
   - no surface sinks at wall junctions;
   - wide variety of surface finishes available;
   - low draft (zero draft possible, 0.5° to 2° typical);
   - recyclability and low warpage; and
   - environmentally friendly process.

Tolerances

The high dimensional stability and tight tolerances that the Thixomolding process produces are a direct result of laminar flow of the semi-solid magnesium into the mold cavity as well as the high mold-filling pressures and rapid solidification process.

Typical tolerances are classified as follows:

- Linear tolerances: ±.001 in. (0.003 cm) for each inch of dimension.
- Across parting line and moving die components: The appropriate linear tolerance plus an allowance of an additional +.002 to +.010 depending on projected area of the component from 10 to 100 sq. in. (19 sq cm), respectively.
- Flatness tolerances: .003 to 3 in. (0.008 to 8 cm) dimension with an additional .001 in. (0.003 cm) flatness allowance for each additional inch. The largest dimension of the flat surface should be used.
- Machine stock allowance of .010 in. (0.03 cm) max is recommended if machining is required to hold extremely tight dimensions.

Thixomat licensees have reported dimensional results on production magnesium components, reinforcing the abovementioned guidelines. A total range of .0008 in. (0.00203 cm) was reported on a 1.024 in. (3 cm) molded bore, measured over a 10-day run of parts. While on another Thixomolded component, flatness across parting line and linear dimension results measured over a four-day run were:

.0009 flatness on a 3.000 in. (8 cm) dimension
.001 total range across parting line on a .326 dimension and projected area under 3 sq in. (19 sq cm)
.0018 on a linear dimension of 2.158 in. (6 cm)

Thixomolding Tooling and New Development, Hot Runners

Tooling for the Thixomolding process is similar in construction and cost to plastic injection or die-cast tooling. Lifters, slides and other actions are easily designed into the tooling. A consistent pattern shrink of .005 in. (0.013 cm) per inch of dimension is used by most Thixomolders for die construction. Clamping forces from 5 to 7 tons/sq in. of component projected area should be used to determine machine size.

Hot runner systems similar to those used in plastics are now being used in a number of Thixomolding applications. Benefits of the hot runner systems are: significant improvements in cycle times, increased yield and simplified gating, improved component quality, and reduction of machine size required.

Mechanical Properties (nominal)	AZ-91-D	AM-50	AM-60
Tensile Strength Ksi (MPa)	34 (230)	32 (220)	32 (220)
Yield Strength Ksi (MPa)	23 (160)	18 (120)	19 (130)
Elongation %	6	13	9
Young's Modulus psi x 10^6 (Gpa)	6.5 (45)	6.5 (45)	6.5 (45)
Fatigue Strength* Ksi (MPa)	14 (97)		10-13 (68-89)
Impact Strength** Ft-lb (J)	6.6 (9)		6.2 (8.4)
Shear Strength Ksi (MPa)	20 (140)		
Hardness BHN (500 kg, 10 mm)	63		65
Compressive Yield (0.1% offset) Ksi (MPa)	26 (180)	20 (138)	19 (130)
*Rotary bend 5 x 108 cycles **10 mm unnotched charpy			

Table 1. *Typical mechanical design properties.*

Corrosion Issues

Atmospheric corrosion occurs when unprotected magnesium surfaces are exposed to the atmosphere. A thin layer of alkaline hydroxide-carbonate forms on the surface as a result of oxidation.

With today's high-purity magnesium alloys, loss of material to oxidation is very slow, as can be seen in *Figure 1*.

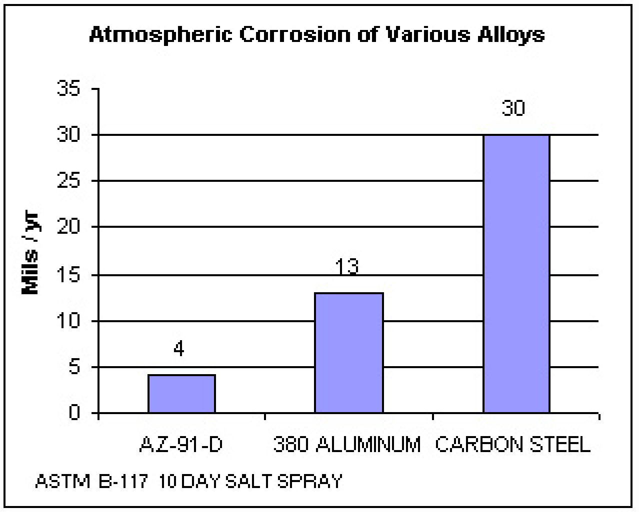

Figure 1. *Today's high-purity magnesium alloys have very slow loss of material to oxidation.*

This chart shows the results of accelerated corrosion testing on various materials. Testing shows that the high-purity magnesium alloy AZ-91-D demonstrates less corrosion than 380 die-cast aluminum by a factor of three and is more than seven time better than carbon steel. In general use, Thixomolded components need not be coated unless they are going to be used in cosmetic applications.

Galvanic corrosion occurs when a magnesium component in an assembly is in direct contact with a dissimilar metal and an electrolyte is present. A galvanic reaction produces an electric current, and the magnesium component is corroded. This reaction will only occur if an electrolyte is present. Eliminate the electrolyte source or insulate the two metals from each other with a gasket or coating, and the reaction is stopped.

Creep Issues

Creep causes a magnesium component to deform or creep under load at elevated temperatures over extended periods of time even if the stress applied is below the yield stress of the alloy.

If a design component will operate consistently above 250°F (121°C), the issue of creep must be taken into account. Conventional AZ and AM alloy groups show minimal creep below 250°F (121°C), but for applications above this temperature, the creep-resisting alloys must be considered. These alloys will typically extend the operating temperature range to as high as 425°F (218°C). Values for creep under load for various common magnesium alloys are shown in *Figure 2*.

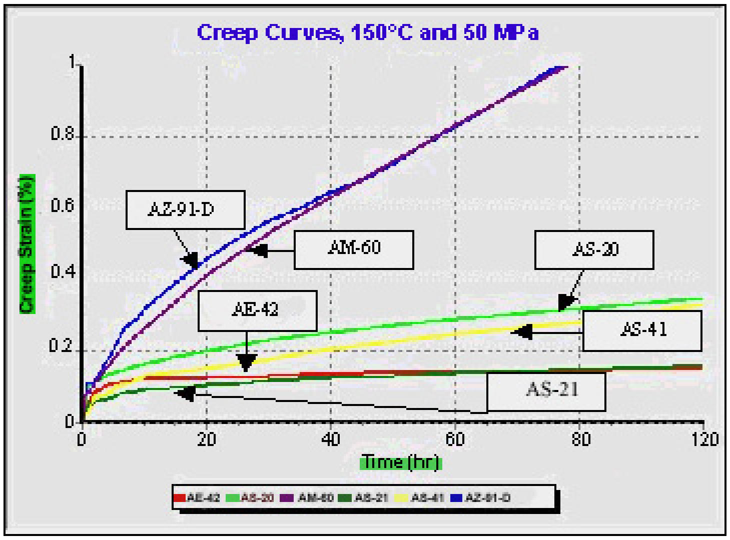

Figure 2. *Values for creep under load for various common magnesium alloys.* (Source: International Magnesium Association [Washington, D.C.])

Alloys such as AE-42 and AS-21 exhibit good creep characteristics even at elevated temperatures and extended times, while the AZ and AM alloys drop off quickly as time increases and temperatures remain above 302°F (150°C).

Some recently developed creep alloys meet and exceed the properties of AE-42 and AS-21. The alloys are available from: (1) Noranda (Toronto)—AJ52X, AJ62X; (2) Dead Sea Magnesium Ltd. (Beer Sheva, Israel)—MRI 153M and MRI 230D; and (3) Hydro Magnesium (Brussels, Belgium)—AS2/X. These alloys all show promise because of their improved castability and corrosion performance.

Magnesium Safety Issues

Probably the most widely known safety issue surrounding the use of magnesium is that it burns. While it is important to take this fact into account when designing a component, we must give it the proper weight in our considerations.

- Magnesium will only burn in the molten state. We must melt the solid component before it will burn, and that takes temperatures in excess of 950°F (510°C).
- Burning is section sensitive. Sections thicker than .040 in. (1 mm) will ignite only if the heat source is kept in continuous contact. If the heat source is removed, the ignition will cease.
- Finely divided magnesium, such as powder, is easily ignited and must be handled in the prescribed manner.
- Magnesium's combustion rate is slow, and the white smoke (magnesium oxide) is nontoxic.
- Magnesium fires should be smothered using proper extinguishing materials. Never use water on a magnesium fire.

Magnesium is the easiest of all structural metals to machine. Cutting tools should be kept sharp, and chips should not be allowed to accumulate in the machine. They should be stored properly when removed from the machining equipment.

Once the magnesium is converted to molded components, no special safety concerns apply. Molded components may be shipped as any other molded metal component via common carrier.

Painting and Coating

A wide variety of paints and coatings are applied to Thixomolded components for corrosion protection, wear resistance and cosmetic appeal. Most paints and coatings require a conversion coating to be applied to the cleaned magnesium surface to ensure good adhesion. Some recently developed UV-cured coatings are being applied directly to the cleaned magnesium surface without the use of conversion coatings.

Conversion Coatings and Pretreatments. Chromate-type conversion coatings are losing favor because of environmental issues. However, they provide additional corrosion resistance when applied before top coatings or paints. Many non-chromate coatings have been developed and successfully used on Thixomolded components. More information can be obtained from Thixomat concerning these pretreatments, but a brief list is as follows:

Phosphate pretreatments:

- Iron phosphate
- Dow #18
- Bonderite 1000
- Surcoat 65

Anodizing pretreatments:

- Tagnite
- Anomag
- Keronite
- Magoxid-Coat

Surface Coatings. Generally, surface coatings are applied to Thixomolded components for one of the following reasons:

- to provide a decorative finish;
- to form a protective barrier against the service environment;
- to improve wear resistance; and
- to provide insulation to prevent galvanic corrosion.

Surface coatings that have been successfully applied to Thixomolded components include:

Wet and powder coat paints
Solvent spray, electrostatic or electrophoretic deposited
Electroless nickel, black chrome, black oxide
Velour chrome and hard chrome
Wear-resisting coatings
Magoxide, tagnite, anomag, thermoplastic resin
Liquid two-part urethane
Soft-feel paint
UV-cured coatings
Anodizing

Anodizing has been found to be an effective pretreatment for magnesium-painted or coated components that will operate in corrosive atmospheres.

General Design Tips for Thixomolded Components

The general design tips for Thixomolded components are outlined in *Table 2*.

Draft	• Draft is 0.5° to 3°; normal draft is 1°

	• Zero draft is possible if sufficient ejection surface is available.
Design or Pattern Shrink	• This is the shrink factor that is applied to the print dimensions when cutting the tooling to account for dimensional changes during molding and cooling. • +0.5% or +.005 in. (+0.013 cm) per inch of dimension • This shrink factor is consistent in all directions.
Ribs	• Use ribs to strengthen sections and reduce mass required. • Ribs should be from 0.5 to 1.0 times the adjoining wall thickness.
Fillets and Radii	"T" Junctions R = wall thickness "X" Junctions 45° angle R inside = 0.7 x wall thickness R outside = 1.5 x wall Thickness 30° angle R inside = 0.5 x wall thickness R outside = 2.5 x wall thickness "L" Junctions R inside = wall thickness R outside = 2 x wall thickness Note: Too large of a fillet radius can cause porosity and a reduction in strength.
Cross Sections	Design wall thickness as uniform as possible. Generally, rapid changes in wall thickness cause porosity and internal shrinkage. The Thixomolding process is better equipped to handle changes in wall thickness because the process can vary the percent solids and reduce cross-section porosity. Higher-percent solids reduce porosity in heavy sections.
Ejector Pin Marks	The designer should consult with the customer to determine where ejector pin marks are allowed and where cosmetic surfaces are located.
Thixomolding Machine Clamping Forces	• Machine sizes 75 to 650 t • 7 tons/sq in. of component projected area • Machines over 650 t • 6 tons/sq in. of component projected area • Component projected area is the total projected area of all parts in all cavities plus an allowance for the projected area of gating.

Table 2. *General design tips for Thixomolding.*

Case Study

This case study is a classic illustration of one of the strengths of the Thixomolding process, "Design to Combine." By taking advantage of the design flexibility and tight tolerances that Thixomolding allows, the design engineers at UNiSYS Corp. (Plymouth, Mich.), working with the Thixomolding experts at Phillips Magnesium Injection Molding (Menomonie, Wisc.), were able to reduce a complex and costly assembly to a single Thixomolded component (a NDP base plate for a high-speed check sorter shown in *Figure 3*).

Figure 3. *UNiSYS Corp.'s NDP document processor.*

During the development stage, a complex, 55-component base plate assembly (*Figure 4*) was devised. The base plate consisted of a machined aluminum main plate with plastic and steel components attached to produce the final assembly. As UNiSYS entered the production phase, the company knew that such a costly assembly would reduce the marketability of the check-sorting machine. The company knew that there had to be a better way to make this component. UNiSYS therefore enlisted the services of Phillips Magnesium Injection Molding, and the Thixomolding process was utilized.

Figure 4. *Complex and costly 55-piece assembly.*

The design that resulted from this collaboration reduced this 55-piece assembly to a single Thixomolded AZ-91-D magnesium component (shown in *Figure 5*). Component manufacturing costs were significantly reduced, while component quality improved dramatically.

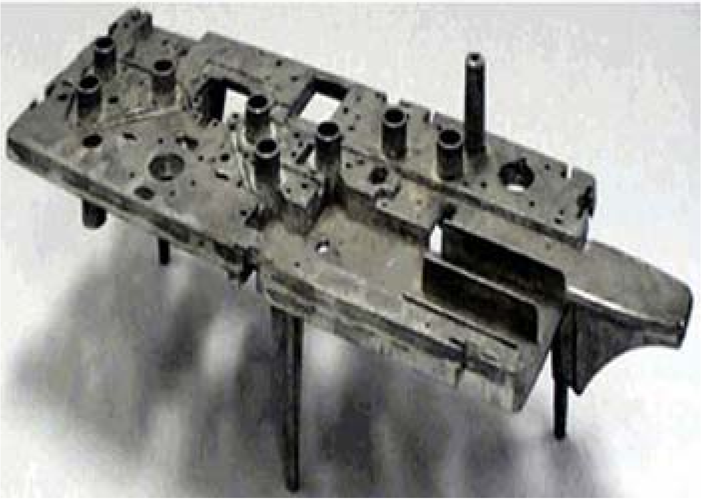

Figure 5. *Fifty-five piece assembly reduced to one component.*

The die-casting process was also considered for the production of this component. Zinc and aluminum die casters, both domestic and foreign, were contacted for quotes. Base plate flatness was a big concern for UNiSYS. The die casters contacted would only commit to an overall flatness of 0.035 in. (0.09 cm). Phillips was able to mold the component flat within 0.015 in. (0.04 cm) and further hold a flatness of 0.0025 in. (0.006 cm) in the critical "check track guide."

The ability of the Thixomolding process to mold the base plate to near-net shape allowed Phillips to greatly reduce secondary machining operations and overall component costs. A relative cost comparison is shown in *Table 3*.

Manufacturing Method	Relative Component Cost
Thixomolding	100%
Foreign aluminum die caster	145%
Domestic aluminum die caster	172%
Zinc die caster	241%

Table 3. *Cost comparison of different manufacturing methods.*

This project was a success for both the customer, UNiSYS Corp., and the molder, Phillips Magnesium Injection Molding, because of the molder's early involvement in the component redesign. Thixotropic injection molding of magnesium has many advantages, and the licensed molders as well as Thixomat can help component designers take advantage of this advanced molding process to improve design quality and lower manufacturing costs.

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