MAGNESIUM IN METALLURGY

CASTING

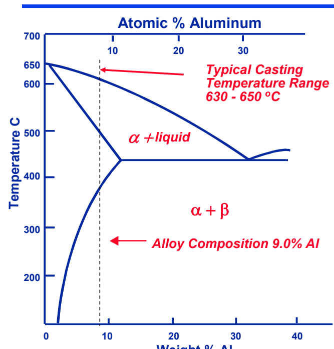
Henry Hu, Ph.D.

Professor
Engineering Materials Program
Department of Mechanical, Automotive & Materials Engineering
University of Windsor

OUTLINE

- *Melt Preparation and Transfer*
- *Die Casting Technologies*
  - *Hot Chamber*
  - *Cold Chamber*
- *Thixomolding*

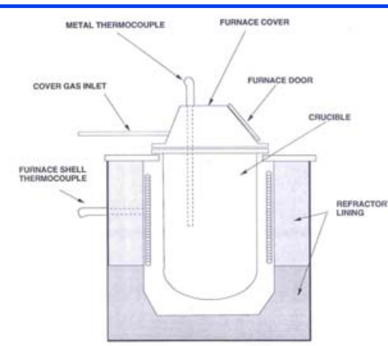
Mg Alloy Phase Diagram



Die Casting Alloys

- AZ91D
- AM60B
- AM50A,

Melting Furnace for Mg Alloys



Crucible for Holding Liquid Mg

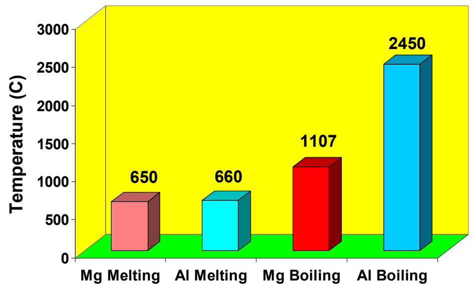
Materials:

- Cr-Mo Nickel Free Steel (life: 24 months)
- Laminated Cr Steel outer Shell (heating)
  Mild Steel Inner (life: 6-12 months)
- All Mild Steel (life: 6 months)

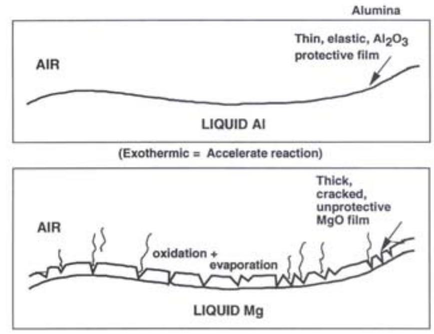
Charging Ingots Prior to Melting

- Clean
- Dry
- Storage:
  - Dry to remove $MgCO_3 \cdot H_2O$
    $MgO + CO_2 + H_2O \rightarrow MgCO_3 \cdot H_2O$
- Preheated (> 150 ^{o}C)

Prevention of Melt Burning /Oxidization



Prevention of Melt Burning /Oxidization



Prevention of Melt Burning /Oxidization

- ***Protective Gases***

0.2% SF_6 + CO **or** *0.5% SO_2 + Dry Air*

Advantages:
- *No flux contamination*
- *Lower % of metal loss*
- *Non-toxic (SF6)*
- *Create strong, thin metallic film*
- *Small quantity needed if well distributed over the melt*

Disadvantages:
- *Need crucible cover + gas mixing system*
- *High concentration causes corrosion problems (if not used properly)*
- *Not efficient at very high T*
- *Green house effect*
- *Health concerns (SO_2)*

Prevention of Melt Burning /Oxidization

- ***Salt Flux***

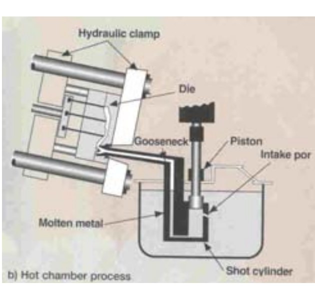
e.g., 50% MgCl, 30% KCl and 20% NaCl

Problems: Flux comtamination, corrosion, HCl fume, Cl_2 pollution

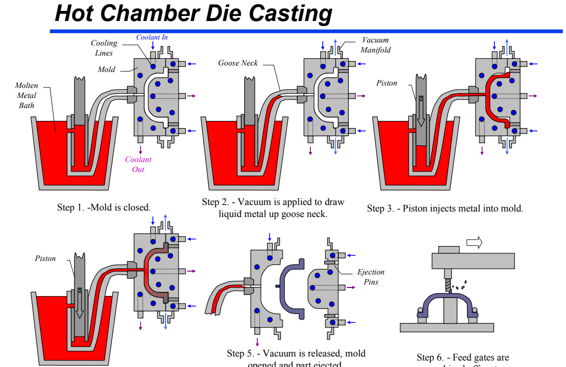
- ***Burning Inhibitors***

Addition of 0.0005% (5 ppm) Be

Hot Chamber Die Casting



Hot Chamber Die Casting



Hot Chamber Die Casting

The hot chamber process is used extensively for casting of smaller magnesium parts with shot weights up to 2-3 kilograms.

This process is not used for aluminium parts. Static metal pressures are usually less than in cold chamber machines,typically in the range of 20-30 MPa (2900-4400 psi).

A typical wall thicknesses of castings is around 1.50 mm for the complex stiffener frame or could be less than 1 mm for simple gemetries such as notebook computer and cellular phone cases.

Hot Chamber Die Casting- Vacuum

Vacuum is used to a limited extent in hot chamber magnesium die casting. The technical literature is limited as to the effect of vacuum assistance on the properties of magnesium die castings. Further investigations are needed to document the extent to which vacuum provides significant improvements of properties in magnesium die castings.

Hot Chamber Die Casting- Applications

notebook computes

Telecommunication

Power Tool

www.cwmdiecast.com, www.lunt.com

Cold Chamber Die Casting – Cell Layout

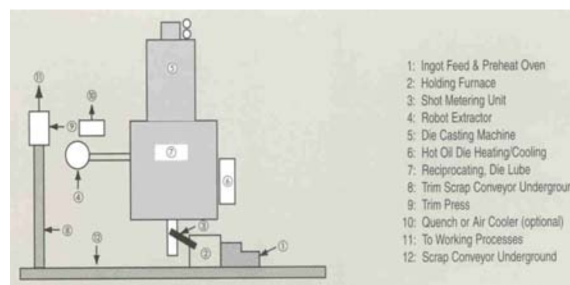
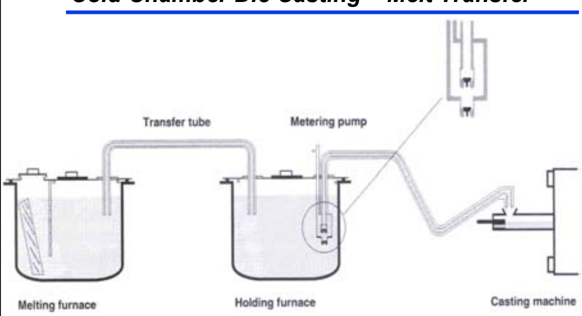


Figure 1. Fully automated cold chamber die casting cell, schematic.

Cold Chamber Die Casting – Melt Transfer



NADCA

Cold Chamber Die Casting

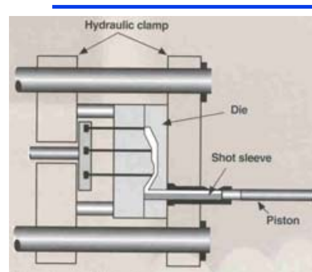
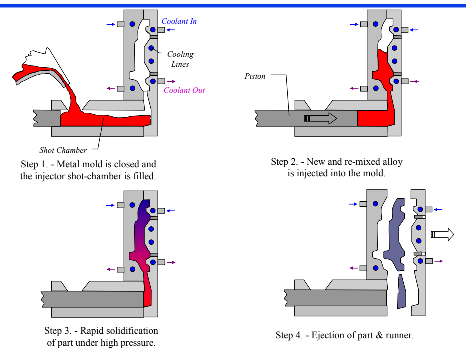


Figure 2. a) Cold chamber process

Cold Chamber Die Casting



Die Casting: Magnesium vs. Aluminum

Advantages

- lower density for weight reduction (up to 50%)
- faster shot speed (up to 50%)
- longer die life (2-5 times)
- thinner wall casting (1 - 2 mm)
- lower machining cost (up to 40%)

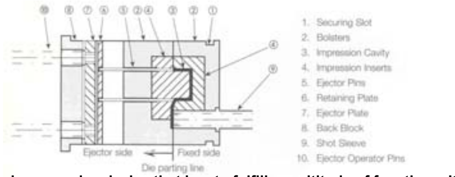
Disadvantages

- higher material cost (1.3 times in volume)
- poorer high temperature Properties
- lower elastic modulus
- more difficulties in scrap recycling

Cold Chamber Die Casting- Machines

In general, the cold chamber die casting process, can be used for magnesium and aluminium alloys. However, the lower heat content in magnesium compared to aluminium is important to the die casting process. To avoid solidification of the magnesium alloy during die filling, a shorter fill time is required for magnesium than for aluminium. For this reason, some magnesium die casters specify machine designs with maximum shot plunger speeds exceeding 10 m/s. Static casting pressures are commonly in the range of 30- 70 MPa (4400-10000 psi). The locking force of the machine holding the two die halves together exceeding 4000 tons are commercially available.

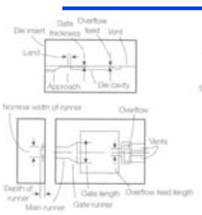
Cold Chamber Die Casting – Die Design

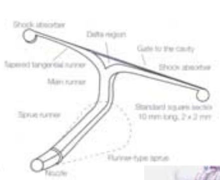


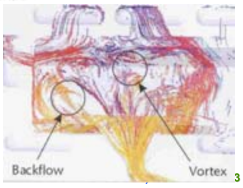
The die is a complex device that has to fulfill a multitude of functions. It defines the general geometry of the part and has a strong influence on the dimensional variations from shot to shot. The use of fixed or moveable cores adds to the flexibility to cast complex, near net shapes. The geometry of the runner and gate system determines the die filling characteristics. The thermal conditions in the die determine the solidification of each part and thereby the microstructure and quality. Over a large number of shots, the heat transfer characteristics of the die determine the attainable cycle time. The die is fitted with a system to eject the part after solidification.

www.hydro.com/magnesium/en/

Cold Chamber Die Casting – Die Design







Cold Chamber Die Casting – Die Materials

• steel resistant to thermal shock (commonly, H13 steel or a steel with similar qualities)
• H13 premium quality steel is commonly supplied to the die manufacturers in a soft annealed condition with spheroidized carbides to improve machinability. After machining, the die cavity parts are hardened and partially annealed to a hardness typically in the range of 46-48 HRC.
• Only the die cavity and special parts of the die need to be made of H13 steel. This usage typically corresponds to 20-25 % of the die weight. The remaining parts of the die are made from mild steel and medium carbon steel. Frequently, standardized unit dies are used, especially for smaller castings with relatively simple geometries. Such unit dies consist of the main frame of the die, including the ejector system.
• The die cavity inserts can be exchanged, and the same unit die can thus be used for a number of different castings.
•Magnesium die casting alloys contain less heat per unit volume than aluminium alloys, and the solubility of iron in the molten metal is very low. This leads to a considerably longer lifetime for the dies used for magnesium, a factor of two or more being quite common.

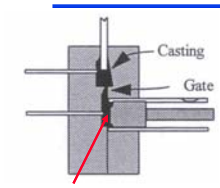
Cold Chamber Die Casting – Part Design

- Section thickness
  - 1-4 mm due to excellent die filling characteristics
  - Uniform to avoid local hot spots causing solidification shrinkage
  - Gradual change in section thickness
- Easy die filling
  - Round edges and cornersto facilitate smooth filling
- Rib for strengthening
  - Strength and stiffen parts instead of increasing section thickness
- Local overheating
  - Direct impact of molten metal at high speed causing local overheating of the die especially at small protrusions
- Draft Angle
  - Normally 2-5 degrees
  - Possibly 1-3 degrees, or even zero draft due to low thermal contraction of Mg

Cold Chamber Die Casting- Process

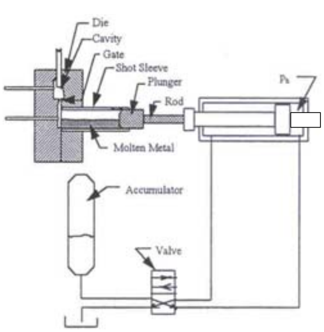
PQ^2 Diagram

Cold Chamber Die Casting – Max Metal Pressure [1]

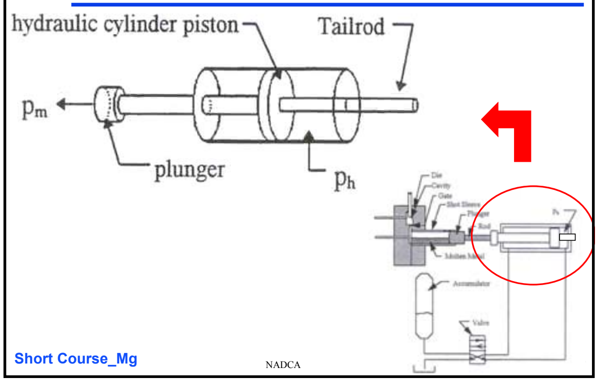


Metal Pressure, p_m

The pressure required to force molten metal through the die's gate



Cold Chamber Die Casting – Max Metal Pressure [1]



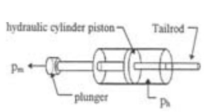
Cold Chamber Die Casting – Max Metal Pressure [1]

$$p_m = p_h \times \left(\frac{d_h^2}{d_p^2}\right)$$

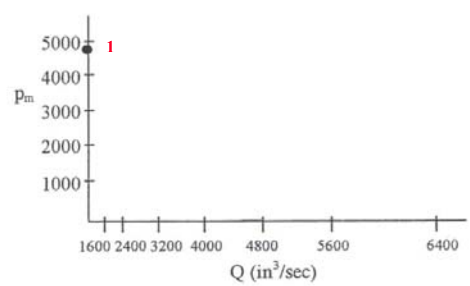
p_m = metal pressure, lb/in^2 (kg/cm^2)
p_h = hydraulic pressure, lb/in^2(kg/cm^2)
d_h = effective hyd. cyl. diameter, in. (cm)
d_p = plunger diameter, in (cm)

$$d_h^2 = d_c^2 - d_r^2$$

d_h = effective hyd. cyl. diameter, in. (cm)
d_c = main hyd. cyl. diameter, in. (cm)
d_r = tailrod diameter, in (cm)



Cold Chamber Die Casting – Max Metal Pressure [1]



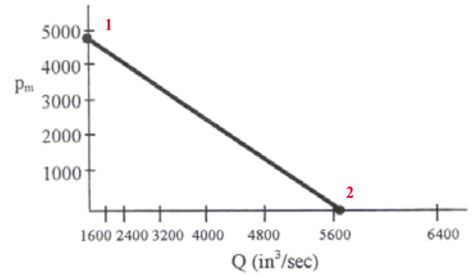
Cold Chamber Die Casting – Max. Fill Rate 2

$$Q_{max} = v_p \times \frac{\pi d_p^2}{4}$$

Q_{max} = maximum fill rate, in^3/sec (cm^3/sec)
v_p = max. dry shot speed, in/sec (cm/sec)
d_p = Diameter of plunger, in. (cm)
π = 3.1416 (constant)

The dry shot speed is determined by having the speed control valve wide open and making a "dry" shot (no metal). For

Cold Chamber Die Casting – Max. Fill Rate 2



Cold Chamber Die Casting – Theoretical Fill Rate 3

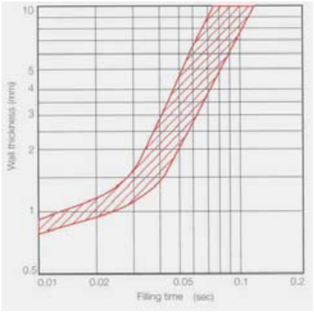
$$Q_{th} = \frac{V_{cav}}{t}$$

Q_{th} = theoretical fill rate calculated, in^3/sec (cm^2/sec)
V_{cav} = casting and overflow volume, in^3 (cm^3)
t = theoretical fill time, sec

$$V_{cav} = \frac{W}{\rho}$$

V_{cav} = volume of metal passing through the gates, in^3 (cm^3)
W = weight of metal passing through the gates, lb (kg)
ρ = molten alloy density, lb/in^3 (kg/cm^3)

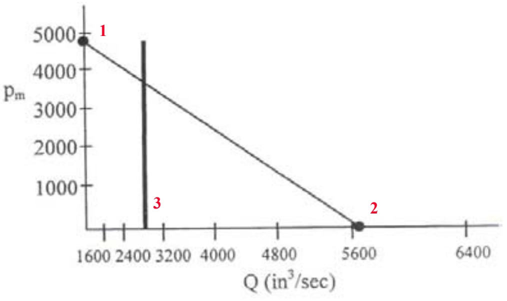
Cold Chamber Die Casting – Fill Time 3



$$t = k\left(\frac{T_i - T_f + SZ}{T_f - T_d}\right)T$$

t = The ideal filling time, sec
k = empirically derived constant, sec/in. (sec/cm)
T_i = temperature of the molten metal as it enters the die, °F (°C)
T_f = minimum flow temperature of the metal, °F (°C)
T_d = temperature of the die cavity surface just before the metal enters, °F (°C)
S = percent solid fraction allowable in the metal at the end of filling, %
Z = Units conversion factor, °F / % (°C / %)
T = casting thickness, in (mm)

Cold Chamber Die Casting – Theoretical Fill Rate 3



Cold Chamber Die Casting – Metal Pressures for Max and Min Gate Velocities 4 ,5

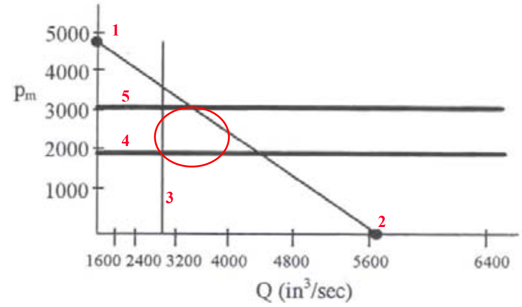
$$p = \frac{\rho}{2g}\left[\frac{v_g}{c_d}\right]^2$$

p = metal pressure, lb/in^2 (kg/cm^2)
ρ = metal density,
0.093 lb/in^3 aluminum (2.580 g/cm^3)
0.221 lb/in^3 zinc (6.130 g/cm^3)
0.063 lb/in^3 magnesium (1.750 g/cm^3)
g = 386.4 (a constant) in/sec^2 (981 cm/sec^2)
v_g = gate velocity, in/sec (cm/sec)
c_d = coefficient of discharge, (0.5 for aluminum) (no units)

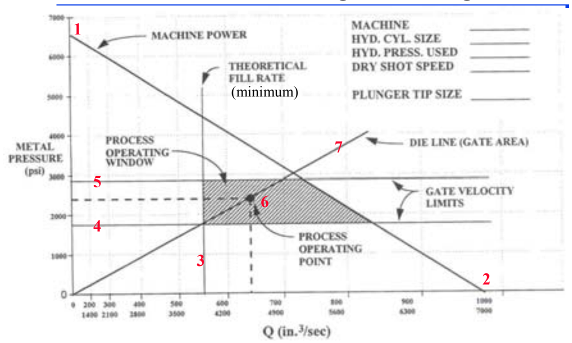
Cold Chamber Die Casting –
Metal Pressures for Max and Min Gate Velocities [4,5]

- 40 - 85 m/s (1600 - 3390 in/sec) for typical Mg die castings
  (Al: 25 -40 m/s, 1000 - 1600 in/sec
  Zn: 40 – 55 m/s, 1600 – 2160 in/sec)
- 100 m/s (4000 in/sec) for thin-wall castings
- less than 30 m/s for casting with 4-5 mm wall thickness

Cold Chamber Die Casting –
Metal Pressures for Max and Min Gate Velocities [4,5]



Cold Chamber Die Casting – PQ² Diagram

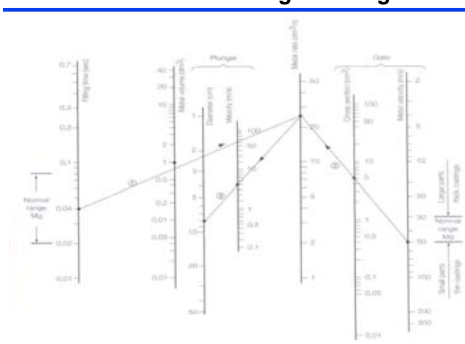


Cold Chamber Die Casting – Gate Area

$$A_g = \frac{Q}{c_d \sqrt{\frac{p(2g)}{\rho}}}$$

Q: volume flow rate
p: metal pressure
c_d : constant (0.5)
g: gravity

Cold Chamber Die Casting – Gating & Plunger



Cold Chamber Die Casting – Gate Velocity

- 40 - 85 m/s for typical Mg casting
  (Al: 25-40 m/s; Zn: 40 – 55 m/s)
- 100 m/s for thin-wall castings
- less than 30 m/s for casting with 4-5 mm wall thickness

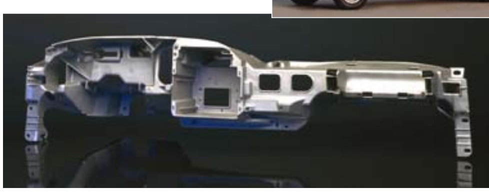
Global Die Cast Mg Applications

Company	Applications
GM	instrumental panels, clutch housing & piston, transmission stators, glove box door, roof frame, seat frame, pedal bracket, steering column bracket, road wheels, transfer case, valve cover, electric motor housing
FORD	IP bracket, sun roof panel, pedal bracket, steering column bracket & component, transfer case, valve cover, clutch housing, steering wheels
Chrysler	air bag housing, steering column bracket, valve cover, steering wheel, instrumental panels, alternator bracket, front headlight retainer
Audi	instrumental panels, manual transmission housing
BMW	wheels, gearbox housing, valve cove
Fiat	seat structure, instrumental panels, steering wheel
Mercedes-Benz	seat frames, sun roof panel, steering column component intake manifold
Honda	Oil pan, cylinder head cover, wheels, valve cover
Toyota	steering wheels, valve cover, bracket

Magnesium Instrument Panel

- Audi and GM
- AM60 and AM50 Alloys
- One-piece die casting vs. 12 steel stampings and plastic parts
- 30-50% weight reduction
- Reduced cost
- More styling flexibility

GM "G" Van Instrument Panel

GM "W" Car Instrument Panel


Magnesium Seat Structure

- Fiat and Mercedes
- AM60 Alloy
- Total part count reduction
- 50% weight reduction
- Reduced assembly operations
- Dimensional accuracy

Alfa Romeo Seat Frames


Magnesium Oil Pan

- Honda
- ACM522 Alloy
- 35% weight reduction
- Gasoline power hybrid car- *Insight*
- Best fuel consumption – 35 km/liter

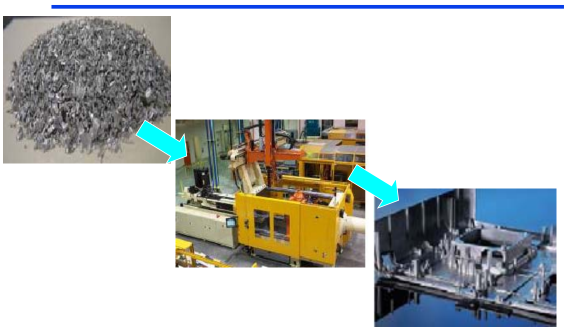
Honda Engine Oil Pan


GM 4 Wheel Drive Transfer Case


Potential Die Cast Mg Applications

- Transmission housing
- Road wheels
- Engine cradle
- Body panels (door and hood)
- Engine block
- Radiator support
- Knuckle
- Bumper reinforcement beam
- Oil pan
- Oil/water pump housing
- Pulley
- Break disk rotor and caliper

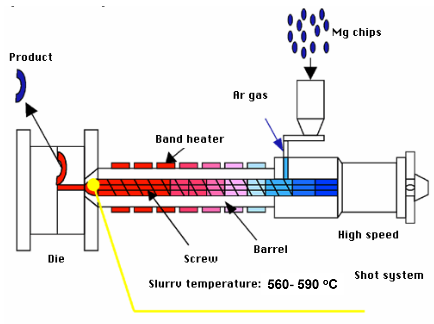
Thixomolding



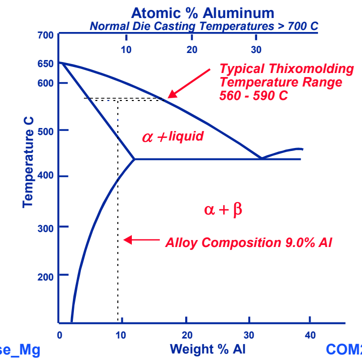
Why Thixomolding?

- *Net shape metal part production*
- *Higher quality than diecast*
- *Increased design flexibility*
- *Reduced gas permeability*
- *Lower energy and operating costs than diecasting*
- *Better environmental cleanliness*
- *Better worker safety*

Thixomolding



Mg Alloy Phase Diagram



Typical Processing Parameters

- ***Barrel Temperature:*** **565 585°C**
- ***Mold Temperature:*** **175 250°C**
- ***Injection Pressure:*** **700 1000 bar**
- ***Screw Rotation:*** **100 250 rpm**
- ***Max. Linear Inj. Rate:*** **400 cm/s**
- ***Typical Inj. Rates:*** **150 250 cm/s**

Thixomolding

Thixomolding process

- Lower melting temperature than die casting
- Smooth melt flow

Thixomolded product

- Fewer blow holes
- Less shrinkage
- Fewer hot cracks
- Smaller distortion
- Higher dimensional accuracy

Thixomolding

Mold Requirements

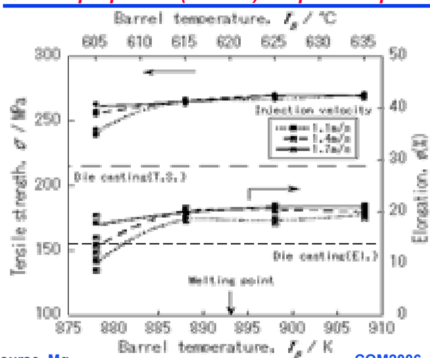
- ***H13 steel***
- ***High temperature tolerances***
- ***More robust design***
- ***Vacuum venting***
- ***Hot oil heated (250 °C)***
- ***Technical Thin wall Mold***

Thixomolding vs. Die Casting

Item	Thixomolding	Die-Casting	
		Hot-Chamber	Cold-Chamber
Molding temp. °C	590~610	630~650	680~700
Injection speed m/s	1~4	1~4	1~8
Injection pressure kgf/cm^2	500~1200	250~350	400~700
Material	Chip	Ingot	Ingot
Project area at same clamping force	Medium	Large	Medium
Max. machine size	1600t	900t	4500t
Blow hole	Few	Small	Many
Surface defect	Few	Small	Many
Shrinkage crack	Few	Small	A few
Fluidity	Excellent	Good	Good
Surface roughness	Excellent	Good	Good
Flash	Small	Few	Much
Shrinkage	Few	Small	Many
Mold shrinkage Dimension accuracy	3.8~4.5/1000 Excellent	5~5.5/1000 Good	7~8/1000 Poor
Warp	Few	Small	Much
Mechanical properties	Excellent	Good	Good
Corrosion resistance	Good	Good	Poor
Shot cycle	1(Standard)	0.8	0.9
Material cost	1(Standard)	0.85	0.9
Material yield	1(Standard)	1	1.2
Die's life	1(Standard)	0.9	0.8
Safe operation	Excellent	Good	Poor
Protection gas	Ar	SF6	SF6
Dross/Sludge	Nothing	Much	Much

Thixomolding

Tensile properties (AM50A) vs. process parameters



http://www.jsw.co.jp/en/mg_f/mg_indexe.htm

Tensile Properties

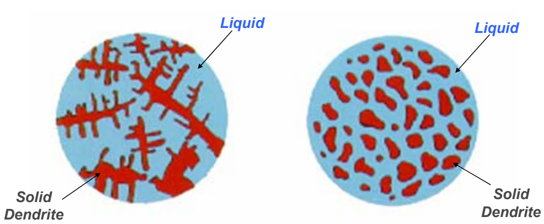
Thixomolding vs. Cold Chamber Die Casting

Material	Process	Barrel Temperature (K)	Injection velocitiy (m/s)	Y.S. (MPa)	U.T.S. (MPa)	El. (%)
AZ91D	Thixomolding	878	1.4	180	299	10
	Die casting			160	240	3
AM60B	Thixomolding	893	1.4	148	278	19
	Die casting	963	2.9	115	239	12
	(Die casting)*			130	225	8
AM50A	Thixom olding	898	1.4	140	269	20
	Die casting	963	2.9	112	232	13
	(Die casting)*			125	210	10
AS41B	Thixom olding	903	1.7	157	249	9
	(Die casting)*			140	215	6

* Values from the literature

http://www.jsw.co.jp/en/mg_f/mg_indexe.htm

Thixomolding – Tensile Properties



Conventional Dendrite Formation in Cast Alloy

Thixotropic Structure of Semi-solid Alloy Resulting From Stirring

Thixomolding – Applications

Digital Camcorder

SHARP VL PD1

- Five components
- 0.8 to 1.0 mm thick
- by Nifco, Japan

Sony DCR- PC10

- Right side housing
- 0.8 to 1.0 mm thick

Thixomolding – Applications

Mini-Disc Players

Panasonic SJ MJ5/7

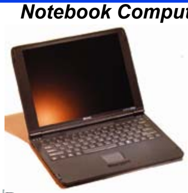
- 0.4 to 0.6 mm thick

Sony MZ E50

- 0.6 mm

Thixomolding – Applications

Notebook Computers



HP Sojourn

- base and LCD cover
- 1.0 mm thick

Toshiba

- Libretto: base and LCD cover- 0.7 mm
- Portege

Thixomolding – Applications

Digital Cameras

Fuji DS 300
- Three components
- 1.0 mm thick

SHARP VL-EF1 EVA Excellent & Valuable Art

Canon *CV11*

Thixomolding – Applications

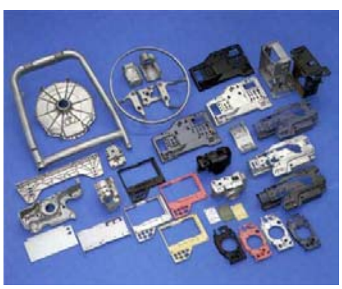
Digital Projectors

EPSON **Powerlite 7300**

Sony VPL X600U

Thixomolding – Applications

Cellular Telephones



Technical Challenges for Magnesium Expansion

Technical Challenges

Component Requirements

- Creep Resistant Alloys
- Mechanical Properties
- Interaction of Mechanical properties with the Vehicle Environment
- Failure Analysis
- Surface Protection
- Corrosion & Erosion
- Composites

Technical Challenges

Manufacturing Issues

- Elimination of SF_6 for Mg Melt Protection
- Recycling
- New Casting Processes (Squeeze, Semi-solid, Vacuum)
- Techniques for Melt Cleanliness Evaluation
- Rapid Prototypes
- Joining
- Wrought Products
- Heat Treatment