SSR^{TM} Process (Semi-Solid Rheocasting)

A Process Technology Licensed from the Massachusetts Institute of Technology

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Aluminum Automotive Casting Usage in North American Light Vehicles

Part	*2002*	*2006*	*2009*
Engine Block	30%	62%	74%
Cylinder Head	85%	96%	98%
Intake Manifold	50%	28%	16%
Transmission Case	95%	94%	92%
Wheels	70%	78%	80%
Brakes, Suspensions	5%	18%	25%

Courtesy of Advanced Materials and Processes, Jan. 2002

Besides engine blocks, the majority of growth in aluminum castings is predicted to be in safety critical castings such as wheels and suspension components

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Current Aluminum Casting Processes

Process	*Advantages*	*Limitations*
High Pressure Die Casting	• Fast Cycle Time • Complex Shapes	• Mechanical Properties • Thick-wall sections • Difficult to heat treat
Squeeze Casting	• Heat Treatable • Superior Mechanical Properties	• Long cycle times • Thin-wall sections • Expensive equipment
LPPM or GPM	• Heat Treatable • Inexpensive Equipment • Simple Process	• Long cycle times • Limited ductility • Thin-wall sections

There is a clear need for a high volume, high quality casting process!

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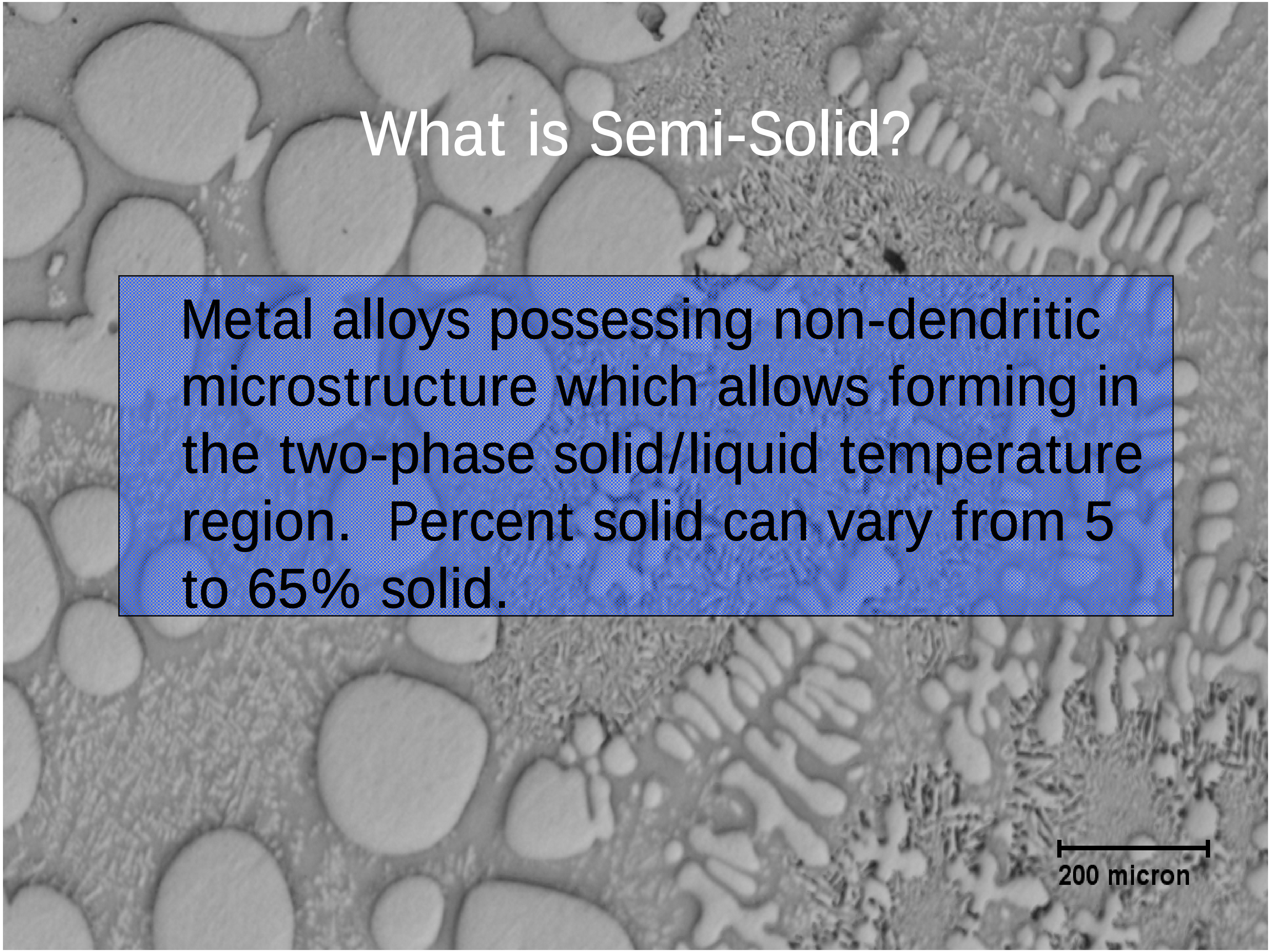
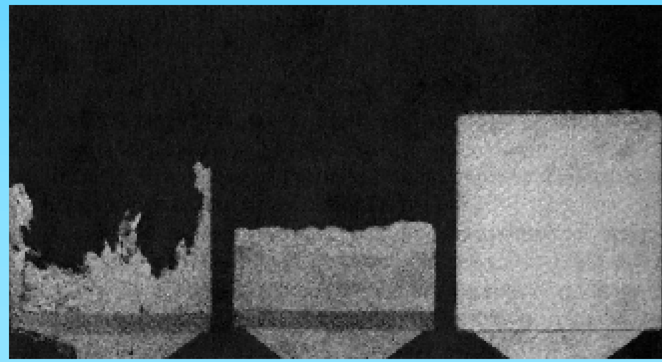
What is Semi-Solid?

Metal alloys possessing non-dendritic microstructure which allows forming in the two-phase solid/liquid temperature region. Percent solid can vary from 5 to 65% solid.



Semi-Solid Metal Casting

Utilizes the high volume platform of the high pressure die casting to make structurally sound castings. Castings have decreased entrapped air and shrinkage porosity.



Liquid Metal   Semisolid   Full Chamber

High Pressure Die Casting Machine

The SSR "Knife" Test

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The Advantages of Semi-Solid Processing

Physical Characteristics

- Non-Dendritic Microstructures
- Partially Solidified Alloy

Process Characteristics

- Enhanced Feeding in the Mushy Zone
- Planer Front Flow at High Injection Speeds
- Reduced Solidification Shrinkage
- Decreased Heat Content of the Alloy

Product Characteristics

- No Air Entrapment
- Thick Wall Sections with Zero Porosity
- Thin Wall Sections
- Small Dendrite Arm Spacing

Casting Process Advantages

- Decreased Solidification Time
- Longer Tool Life
- Heat Treatable and Weldable
- Complex Casting Designs
- Superior Mechanical Properties
- Pressure Tightness

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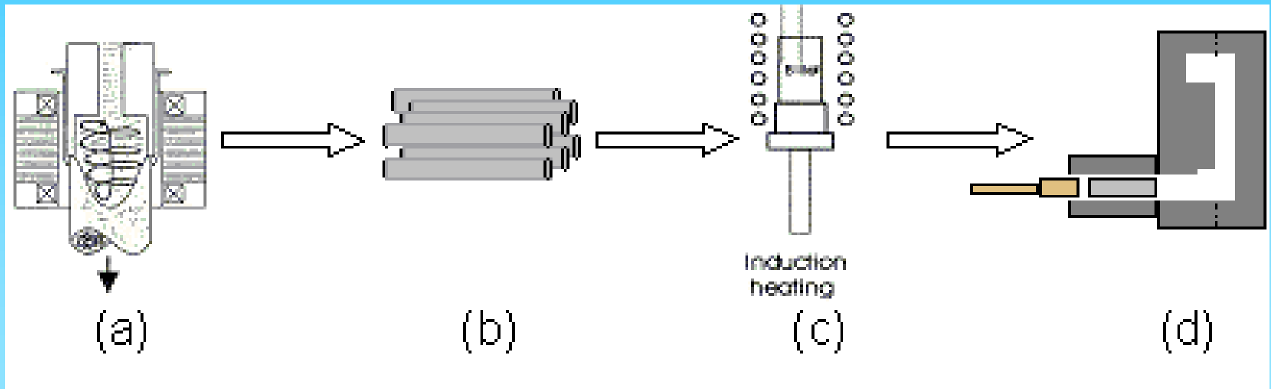
Thixocasting *(a.k.a. slug or billet forming)*



- Uses alloy that has been specially prepared to create the desired non-dendritic microstructure (normally at the primary producer)
- Material is cut to length and reheated into the two-phase, solid/liquid temperature range prior to casting
- Thixocasting has had limited commercial acceptance because of a few major drawbacks
  - Expensive raw material
  - Inability to recycle material back into the process
  - Difficulty increasing the billet diameter for larger castings

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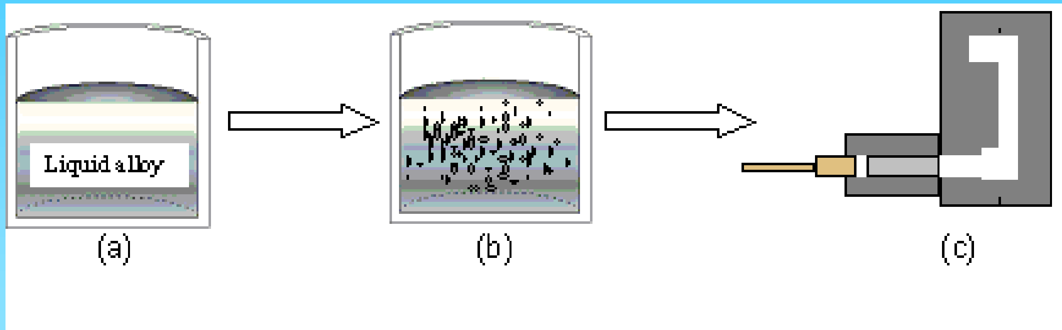
Rheocasting *(a.k.a slurry-on-demand)*



- Conventional alloy is modified as it cools from the liquid to the solid/liquid temperature range to achieve the desired non-dendritic microstructure
- After formation of the desired microstructure, the alloy is immediately formed into a part
- The original vision of semi-solid casting utilized rheocasting; however, it proved difficult to produce equipment that could withstand the corrosive behavior of molten aluminum alloys.
- Different mechanisms for the formation of non-dendritic microstructures have led to rheocasting processes that are more robust than their predecessors.

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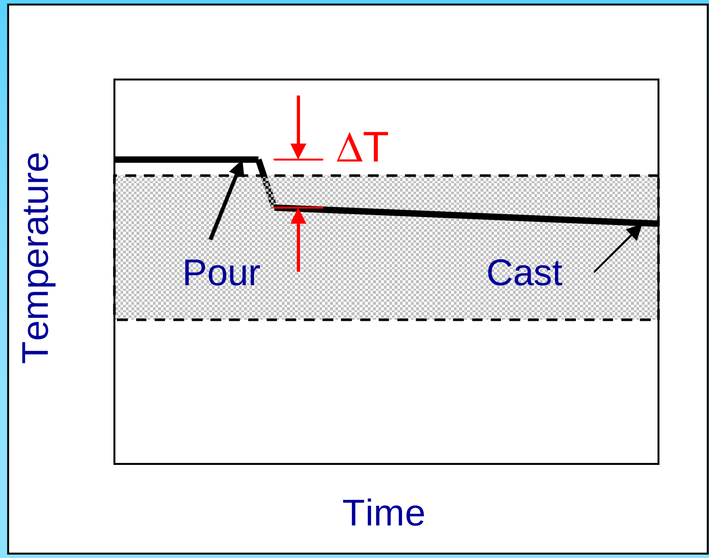
Low-Temperature Pouring

- It has long been known that pouring an alloy with little superheat into a cold mold will form an equiaxed, fine-grained dendritic microstructure. The convection of the pour and the rapid heat removal upon contact with the walls induces this phenomenon.
- More recently, it was recognized that if the low-temperature poured, partially solidified alloy was maintained in the solid/liquid temperature range, the alloy quickly coarsened into the desired non-dendritic microstructure.
- The cold mold can take the form of either an external vessel or the cold chamber of a die casting machine.

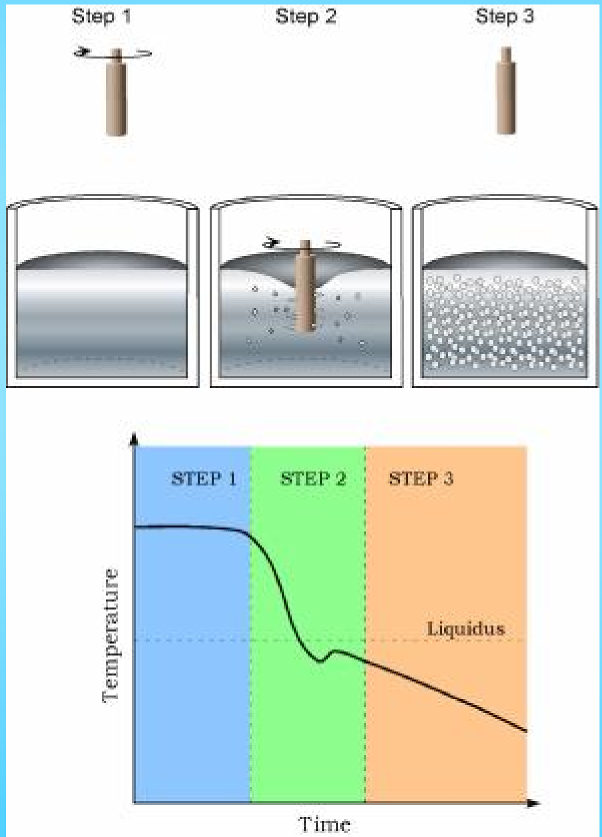


The temperature of the alloy after the pour is a function of:

- Molten alloy superheat
- Vessel temperature
- Vessel surface area

SSR^{TM} Casting

How does it work?



Based on the fundamental principle that a fine grain structure is created at or near the liquidus, a modified rheocasting approach was developed at MIT that externally agitates molten alloy while rapidly extracting heat for a short amount of time at the liquidus. *Stirring beyond this point does not affect the microstructure.*

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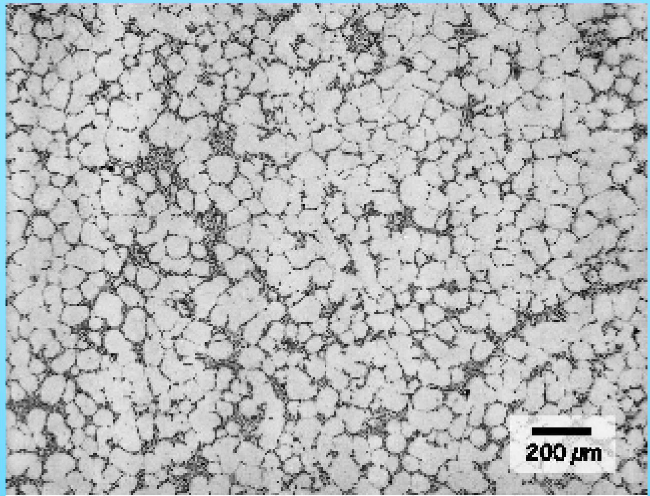
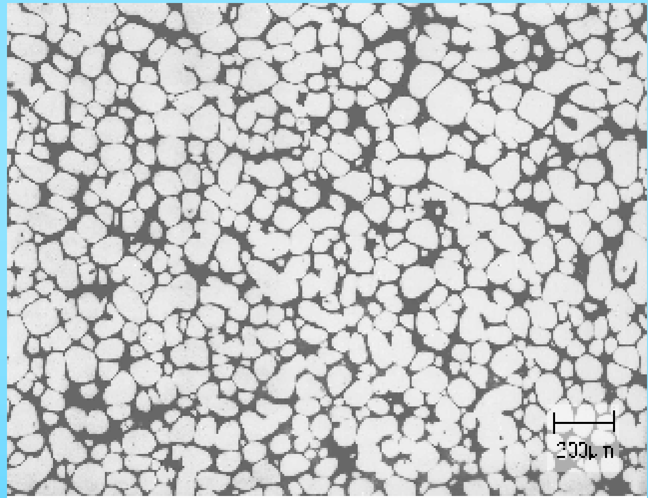
SSR^{TM} Casting Microstructure

No entrapped eutectic phase, smaller and more spherical in size and shape (A356 alloy)



As-Cast



Reheated

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SSR Apparatus

- Molten aluminum, in a cylindrical ladle, is brought to the machine via a robot
- Metal is stirred for a short duration, enough to rapidly cool the metal through the liquidus temperature
- Molten metal is delivered either to a cooling station or to the machine at a low fraction solid
- Rod is cleaned and cooled before its next cycle
- Numerous alloys have been tested with SSR, including: 356, 357, 380, and 390
- Machine footprint is approximately 1.2 m (48”) x 0.75 m (30”) - ideal for retrofitting to a horizontal die casting machine

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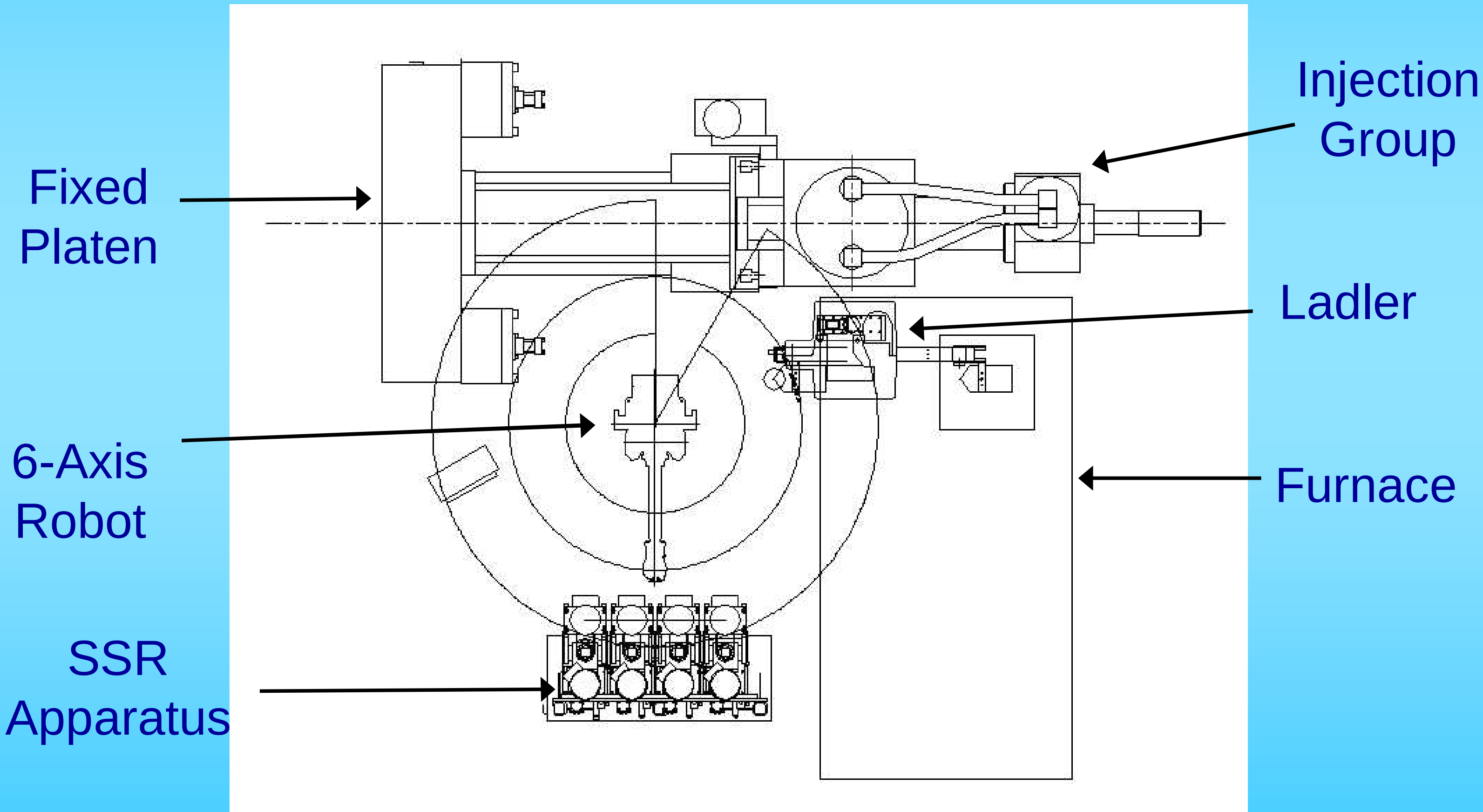
SSR Die Casting Cell Layout

1000 ton machine



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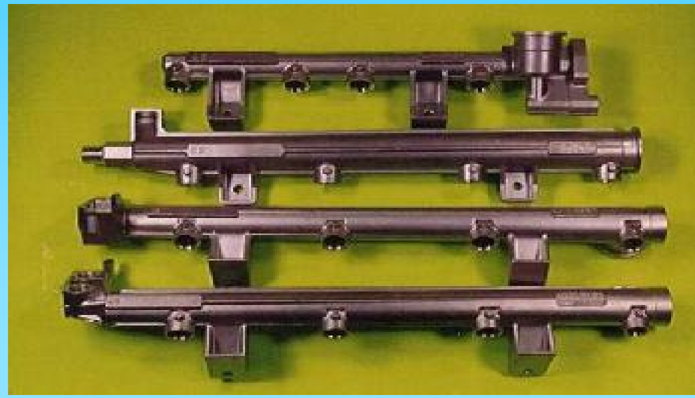
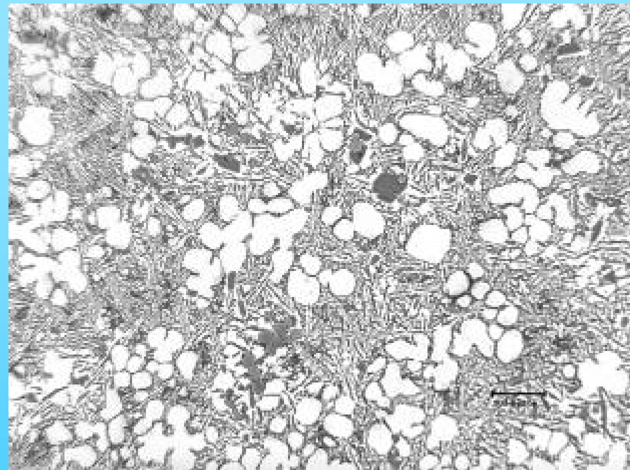
Castings That Can Benefit from SSR

- High Integrity Castings
  - Heat treatable and weldable
  - Currently made from 356 alloys by either squeeze or LPPM
  - Suspension and wheel castings
- Highly Engineered Die Castings
  - Castings with thick sections that have shrinkage problems
  - Castings that require high ductility for better energy absorption characteristics
  - Pressure tight castings
  - ABS pumps, master brake cylinders, fuel rails, rack and pinion, etc.



Courtesy of Magneti Marelli, S.p.A.



SSR 380 Alloy, air cooled

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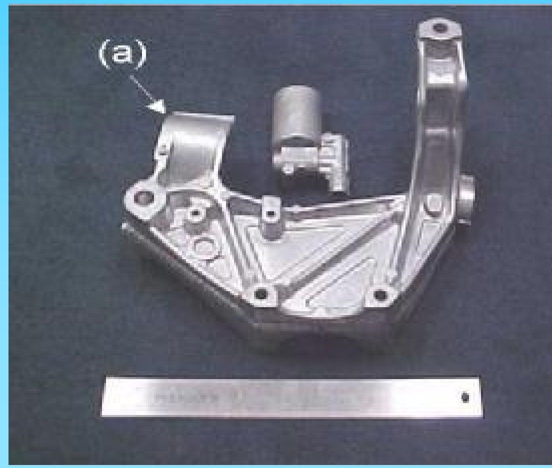
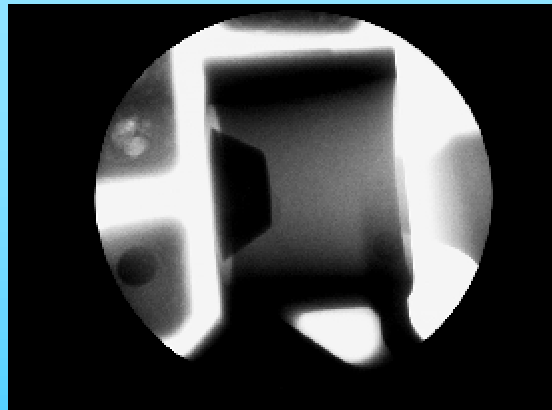
Castings Prototyped with SSR

- Control Arm
  - Shot weight was approximately 5 kg
  - X-ray of critical sections show no porosity
- Fuel Pump
  - Pressure tight critical application



Photograph of Castings

Blister Test of Semi-Solid and Liquid Die Cast Fuel Pump (520 °C)



X-Ray of Control Arm Section

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SSR Status

- An SSR apparatus is currently being assembled that can produce 5 kg (11 pound) shots of metal every 30 seconds.
- Testing will occur with 356 and 380 type alloys.
- A modular addition that cools 356 type alloys to a fraction solid of ~0.50 is currently being designed.

Cost Savings of SSR

- Rheocasting processes have the potential to substantially decrease the cost per casting relative to the other high-integrity casting techniques of low-pressure permanent mold and squeeze casting. Savings can be gained from:
  - Reduced cycle time
  - Increased tool life
  - Reduced part weight in non-critical areas
- If rheocasting becomes as efficient as the liquid casting processes, and it is shown that die-life is significantly increased and cycle time decreased, the process could compete economically with conventional high-pressure die cast component.

Process-Based Cost Model

Part Name	Steering Knuckle
Part Mass	2.9 kg (6.4 lbs.)
Part Dimensions	290 x 250 x 128 mm (11.5 x 10 x 5 in.)
Surface Area	887 cm^2 (137.5 $in.^2$)
Avg. Wall Thickness	24 mm (0.94 in.)
Max. Wall Thickness	45 mm (1.77 in.)
Estimated Runner and Overflow Area	20%
Parts per Die	2
Die Life	100,000 shots
Production Volume	500,000 parts/year

Cost Model Assumptions

- Squeeze/Rheocasting/Low Pressure equipment cost ratio is 2:2:1
- Low Pressure cycle time is 50% longer than Squeeze casting
- Other variables are equal for each process, including: up-time, reject rate, labor costs, electricity, consumables, etc.

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Cost Model Results

- Cycle time reduction alone would have a major impact on the cost per casting for a steering knuckle
- Increases to tool life and reduced part mass further increase the cost savings
- The most important conclusion from this analysis is the relative change in cost between rheocasting and squeeze casting

Process	Cost per Casting	Variable Cost	Fixed Cost
Low-Pressure	$13.16	$7.64	$5.53
Squeeze Casting	$13.09	$7.28	$5.81
S.S.R.™ Casting with decreased cycle time	$12.71	$7.20	$5.51
S.S.R.™ Casting with decreased cycle time and increased tool life	$11.59	$7.20	$4.38
S.S.R.™ Casting with decreased cycle time, increased tool life, thinner wall casting	$10.84	$6.46	$4.38

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Conclusions

- Rheocasting opens up new markets for semi-solid forming by expanding the range of alloys and fractions solid at which castings can be produced compared with thixocasting.
- The low-temperature pouring mechanism for creating non-dendritic, semi-solid slurries has changed the landscape of rheocasting; SSR is a controlled process that improves on this mechanism by removing the heat and applying convection with an external device.
- Horizontal die casting machines coupled with a rheocasting process will offer existing foundries the ability to produce high integrity castings that were previously only cast with other processes.
- A *reliable* rheocasting process will be able to capture a significant share of North American automotive casting growth because of shorter cycle times than the competing processes, potentially extended die life, and lighter weight castings.

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Future Work

- Test SSR under commercial scale conditions - fast cycle times, start-ups and stops, fluctuations in incoming metal temperature, rod life, etc.
- Examine quantitative benefits of low-fraction solid SSR with conventional alloys such as 380 (Al9Si3Cu) on a high pressure die casting machine
- Continue work on design of isothermal high fraction solid SSR (40-60% solid)
- Scale up the process to shot weights of 20-30 pounds (9-13.5 kg)
- Use SSR with magnesium alloys and MMCs

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