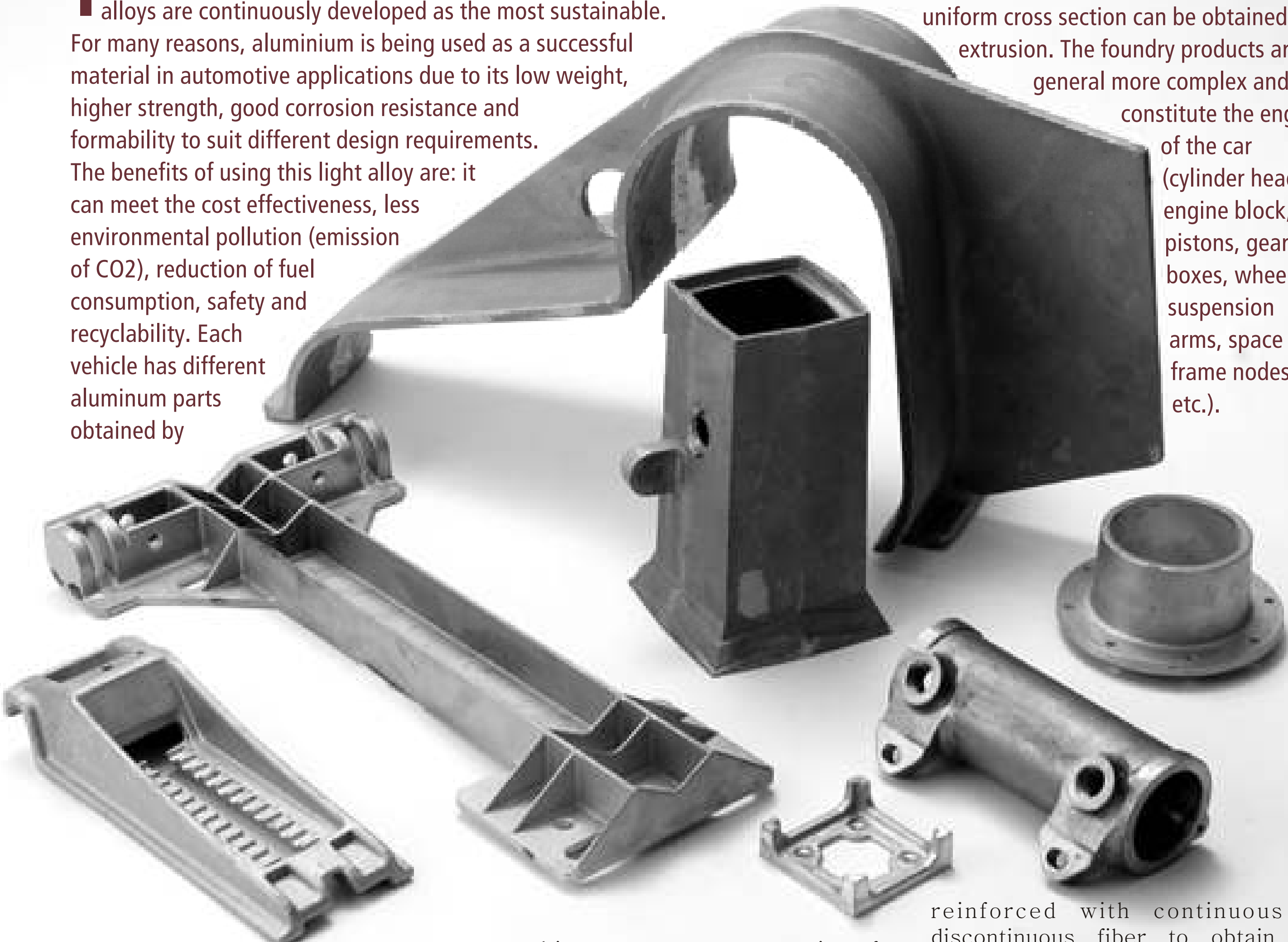
# Semisolid Processing of Metal Matrix Composite Castings



DR. THOGULUVA RAGHAVAN VIJAYARAM
PhD Profesor
School of Mechanical & Building Sciences
VIT University, Chennai


R. KASILINGAM
PhD Research Scholar
School of Mechanical & Building Sciences
VIT University, Chennai


In the recent years, evolution of automotive production has been driven by competitive materials. The light weight alloys are continuously developed as the most sustainable. For many reasons, aluminium is being used as a successful material in automotive applications due to its low weight, higher strength, good corrosion resistance and formability to suit different design requirements. The benefits of using this light alloy are: it can meet the cost effectiveness, less environmental pollution (emission of CO2), reduction of fuel consumption, safety and recyclability. Each vehicle has different aluminum parts obtained by different processes. Structural elements, panels and body parts are produced by presswork methods and components with uniform cross section can be obtained by extrusion. The foundry products are in general more complex and it constitute the engine of the car (cylinder head, engine block, pistons, gear boxes, wheels, suspension arms, space frame nodes, etc.).



## Metal Matrix Composites

Metal matrix composites (MMCs) typically based on Al alloys are the materials of choice for many lightweight structural applications. Recent developments in nano-crystalline (NC) metals and alloys with different grain sizes typically smaller than 100 nm, has attracted considerable research interest in seeking a new opportunity for substantial strength enhancement of materials. This is primarily due to superior mechanical properties found in this class of materials, including high strength and high toughness. For lightweight structure applications requiring high strength, an increase in material strength consequently leads to a reduction of structure weight.

Metal matrix composites are reinforced with continuous or discontinuous fiber to obtain the required properties of matrices. The purpose of reinforcement is to get superior level of strength and stiffness in the composite in a continous fiber-reinforced composite. The fibers provide virtually all the strength and stiffness and in the particulate reinforced composites and significant improvement obtained. In discontinously reinforced composites, matrix provides a solid form to the composite which supports handling during manufacturing. In continous phase, the matrix helps the compsite to control the transverse properties, interlaminar strength and better strength at elevated temperatures.

### Particulate Reinforced Metal Matrix Composites

Particulate reinforcement in MMCs typically use abrasive grade ceramic grit which includes silicon carbide, alumina, boron carbide and titanium carbide. Among these, Silicon carbide offers the best strength and stiffness for aluminum matrices,but is slightly more expensive than alumina.This is being used in aerospace and indusctrial applications which offers wide range of attractive propoerties.

The interaction between the metallic matrix and particle reinforcement is the basis for the enhanced material and physical properties. Composite propoerties can be tailored to meet engineering requirements by selecting a particular reinforcement and varying the amount added to the metal matrix. Increasing the reinforcement volume in a composite increases the mechanical propoerties such as elastic modulus, ultimate strength,and yield strength while reducing the thermal expansion and density of the compiste system.

### Al-SiC Metal Matrix Composites

The combination of light weight and useful mechanical properties has made aluminum alloys very popular and this makes aluminum well siuted for use as a metal matrix. Continous fiber reinforcement matrices are more expensive than discontinous reinforced (particle or whisker) aluminum MMCs because of their ease of manufacture. The most commonly used reinforcement materials in discontinously reinforced aluminum composites are SiC, Al2O3/alumina, although boron and titanium are being use in tribological applications. The most widely used MMC casting alloys are based on aluminum-silicon,which improves the castability and to reduce the chemical interaction with SiC reinforcement during melting. The major portion of the MMC market relies upon components in near-net shape process other than conventional casting process. The most commonly used processes are infiltration casting and squeeze casting. Silicon carbide is the most commonly used particle reinforcement with aluminum alloy matrix. The benefits of SiC reinforcement are more stiffness, strength, good thermal conductivity, wear resistance, fatigue resistance, and thermal expansion. Particle size and shape are the important factors in determining material properties. Fatigue strength greatly improved with fine particles and the below Figure.1 summarizes the benefits of particle size.

**Figure 2 : (c)**
**SiC Particle in Platelet-Shaped Geometry**

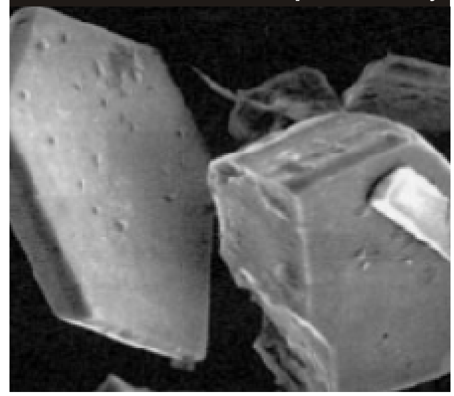


**Figure 1 : Effect of Reinforcement Particle Size**

| Reinforcement Particle Size and Effects | | Yield Strength | Ultimate Strength | Modulus | Ductility | Fatigue Strength | Crack Initiation Resistance | Formability |
|---|---|---|---|---|---|---|---|---|
| | Fine ↑ Coarse | ↑ Increase | ↑ Increase | ↑ Increase | Increase ↓ | ↑ Increase | ↑ Increase | Increase ↓ |

Material properties and formability can be defined based on function of reinforcement particle size. The shape of a particle is characterized by its aspect ratio,the ratio of its longest to shortest linear dimension. Figure.2 shows the different shape of SiC particle.

**Figure 2 : (a)**
**SiC Particle in Block Shaped Geometry**

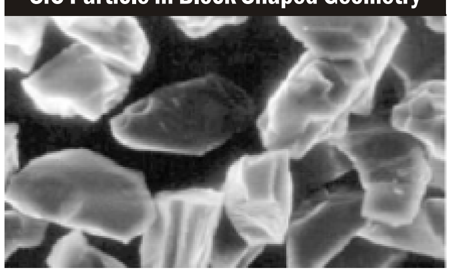


**Figure 2 : (b)**
**SiC Particle in Block Spherical Geometry**

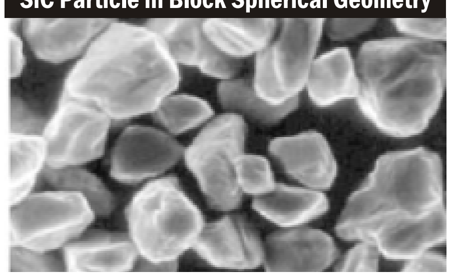
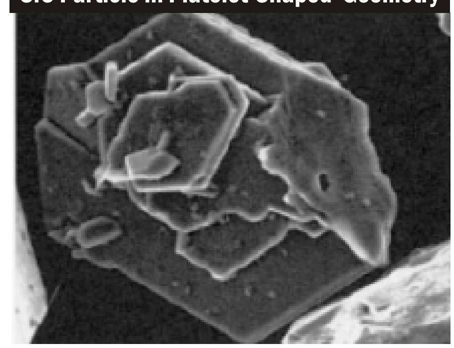


**Figure 2 : (d)**
**SiC Particle in Platelet-Shaped Geometry**



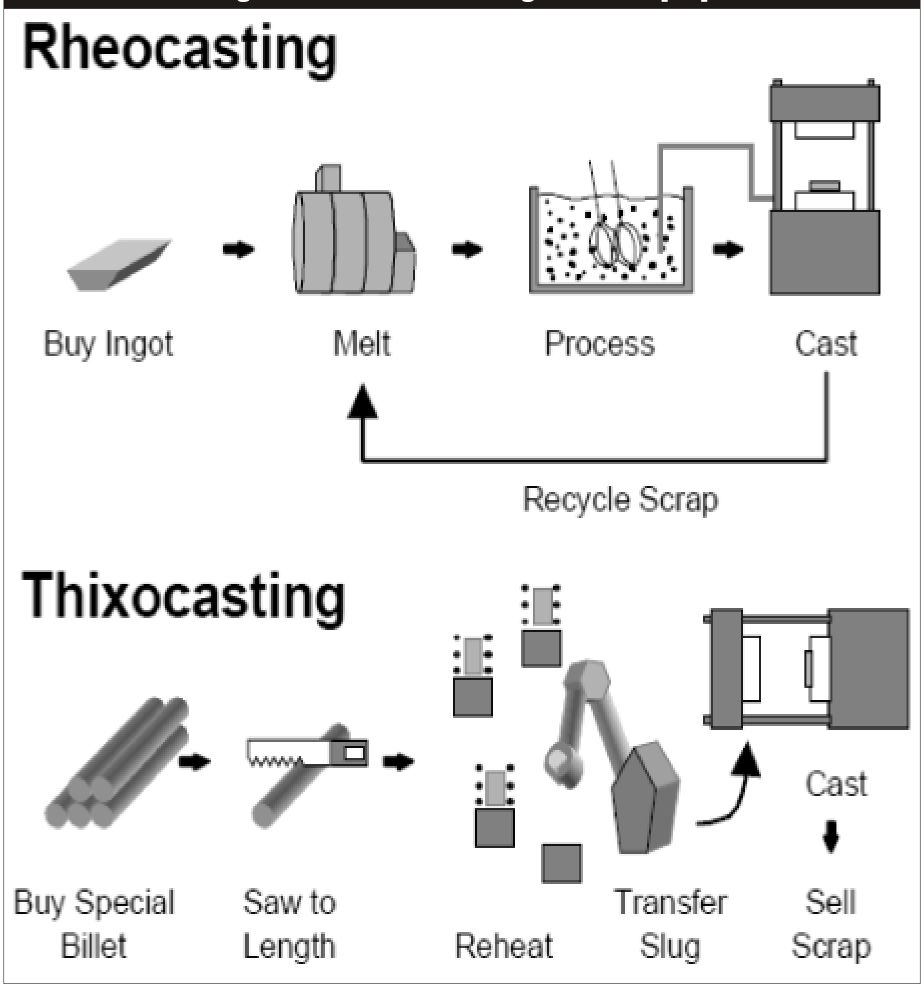
### Fabrication Methods

Nearly twice the volume of MMCs are produced by casting and other liquid routes compared to solid state fabrication which is being widely used for automotive applications like cylinder block liners and brake liner. Aluminum MMCs can be produced by conventional casting methods like sand,gravity,pressure die casting and squeeze casting methods. The melting of matrix is simillar to the unreinforced aluminum alloys.But the stirring is important to avoid the SiC concentration at the bottom because it is more denser than aluminum.

## Semi-solid Casting

Semi-solid casting technology is a near net-shape approach to manufacturing wherein the metal, in a semi-solid state (i.e., at a temperature between its solid and liquid states) is formed, using pressure, in dies. This combination of slush and pressure results in a final product with fewer voids. More conventional processing uses either molten metal (casting) or solid metal (forming). Semi solid casting processes are shown below in Figure.3.

Figure 3 : Semi Solid Casting Processes [13]




When temperature of the metal arises it will become soft and its flow stress decreases. This behaviour of hot metal is being used in hot metal forming processes. But flow stress of the molten metal is low as compared to the cold metal which requires additional force todeform the hot metal.When the metal is melted till reaches the liquid state, it will be able to flow into the mould and fill the cavity as it can adjust its shape. When the temperature drops the molten metal will get solidified and this quality of molten metal is used all conventional casting processes.

In order to get the better quality,surface finish,and core strength the combination of hot metal forming and casting can be combined as semi-solid forming. By stirring and cooling the molten metal in parallel, the denrites will be broken into fine solids and gets dispersed in the molten metal. This will become as semi-solid metal consisting liquid and metal grains and the same can be allowed into the mould to cool and become solid product. The benefits of SSC are shown in Figure.4.

## Advantages Over Conventional Casting Process

Suitability for the production of high quality near-net shape components, are well known since many years as alternative solution of forging and the high pressure die casting. The

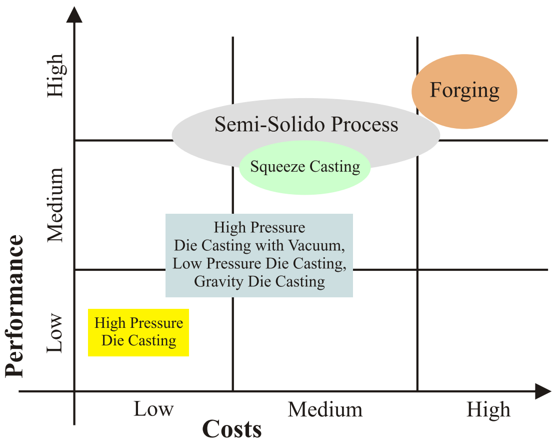
apparent viscosity of semi-solid materials can be varied over a wide range depending on processing conditions that can be optimized by means of numerical simulation. The metal structure (fluid plus solidified globules) and its rheological properties are retained after a solidification and partial re-melting or share rate action during the solidification. The non-newtonian behavior is potentially a positive aspect of this technology able to avoid turbulence and reduce solidification shrinkages. Parts produced by SSM have higher structural integrity than castings and can be produced at lower costs than forgings. The process is capable of producing parts that are essentially free of the porosity associated with conventional high-pressure die casting. Following benefits can be achieved through semi-solid casting process:

- Thick or thin walled structures can be produced
- Cast and wrought alloys can be produced
- Low forming pressure or force is sufficient
- Complex shapes can be produced
- Near net shape can be achieved
- Loss due to burr or flashes are less or even nil

## Applications of Semisolid Casting

The SSM alloys are being used in automotive applications pistons, liners, driveshaft, connecting rods, wheels, chassis parts and brake disks where a synergetic combination of high production rates, light weight and safety requirements is more and more strongly needed. Some of the automotive components are shown below in Figure.5.

**Figure 4 : Benefits of Semi-solid Casting**




**Casting**
Low cost
Lower mechanical properties
Complex shapes

**Forging**
Higher cost
Higher mechanical properties
High cycle time

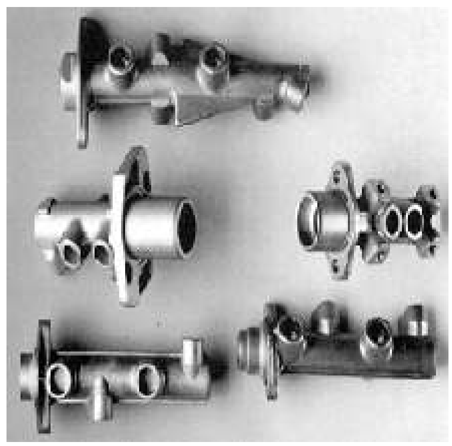
**Semi-solid Casting**
Best cost to performanceration
Formability of liquid metal
Mechanical property of forging
Near-net shape

**Figure 5 : Automotive Application of Semi-solid Casting**

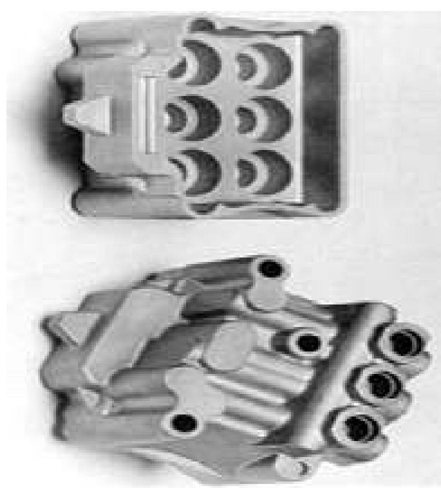
**CONTROL ARMS FOR STEERING**

**PISTON**

**BRAKE MASTER CYLINDER**



**HYDRAULIC BRAKE VALVE**



### Process Control Parameters Involved In Semi Solid Casting Of Metal Matrix Composites

- Uniformity of distribution: Uniform distribution of particle will yield better tensile and fatigue strength to the composites. The segregation of particles leads to lower fracture toughness because of the continuous fracture path available in brittle region. Also the segregation will increase the local stress concentration which reduces the fatigue strength.

- **Stirring Speed :** As SiC particles are wetted by liquid aluminum,they will not coalesce into hard mass but will instead concentrate at the bottom of the furnace if not stirred propoerly. The stirring action should be slow to prevent the formation of vortex at the surface of the melt.Continous stirring of the slurry creates intimate contact between them. Good bonding is achieved by reducing the slurry viscosity as well as by increasing mixing time.

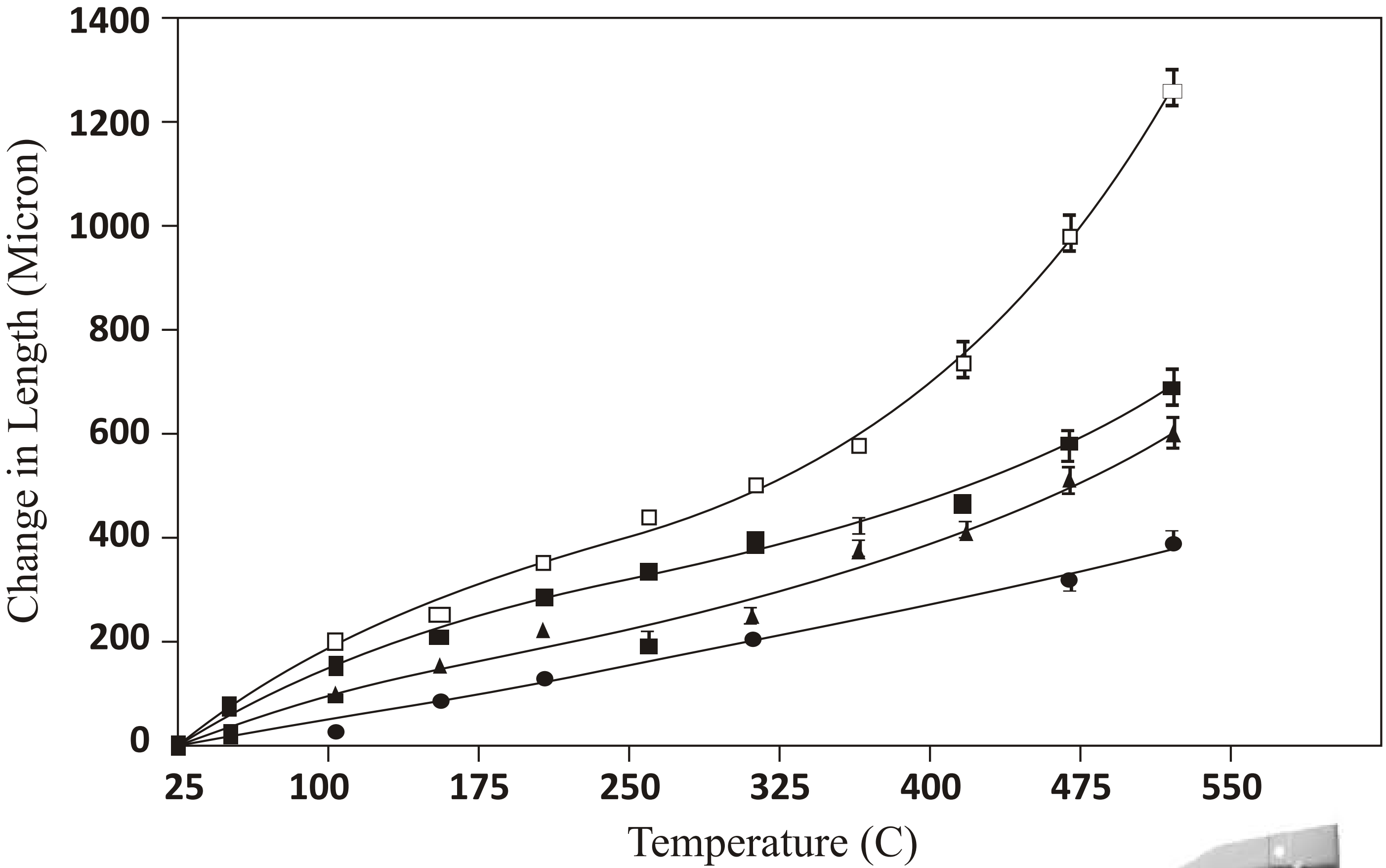
- **Particle Size and Shape :** When the particle size is smaller (nano), the dimensional stability is better than conventional particle size. Because the length changes when the temperature of the matrix increase. Figure.6 shows the change in length Vs temperature with different particle size.

- **Melting Temperature :** Melting temperature control is standard, and in general the pouring temperatures are similar to those used for unreinforced alloys. The overheating of molten metal will cause formation of aluminum carbide which starts very slowly at temperatures about 750°C and increases about 800°C. This aluminum carbide precipitates affects the melt fluidity,wekens the cast material and reduces the corrosion resistance.

- **Forming / Casting Pressure :** The pressure applied during the casting will have effect on the porosity as it will aid to shear the dendrites to small particles.

- Viscosity of semisolid metal
- Die temperature

**Figure 6 : Change in Length at Constant Sic Content**




### Conclusion

Due to increased demand for light weight material in automotive and aerospace applications, the aluminum metal matrix composite are widely used. This is because of its high fatigue strength, creep resistance, wear resistance, good formability, and suitable for mass production. The material produced by the conventional casting process will not suffice the requirement of increased performance demand. Hence by combining the casting and forging process in semisolid state the thermo-mechanical properties of the material can be improved. Using the suitable reinforcing material at different size and controlling the process parameters the application of this semi solid casting can be widely used for mass production.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