A Review on Aluminium Matrix Hybrid Composites by Semisolid Processing and its Process Parameters

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Abstract:
Evolution of automobile production has been driven by competitive materials. Light-weight alloys are continuously developed as most sustainable for automotive sector. Aluminum 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. Since aluminium has the potential to be used as replacement of the current automotive materials like steel and cast iron, its demand has increased greatly. In a further development aluminium metal matrix composites (MMCs) were developed and these have improved wear resistance, high fatigue strength and better thermal stability, as compared with those of aluminum. In automobile sector, wear is a major problem, specifically in engineering assemblies and materials used for this purpose should have good tribological properties. To this effect Al MMCs have attracted significant attraction since they have improved wear resistance. Metal matrix composites are usually produced with secondary particles in the form of either continuous or discontinuous fiber or particles. From the viewpoint of good mechanical properties aluminium matrix is generally reinforced by oxide or carbide, nitride or boride ceramics (like Al₂O₃, SiC, Si₃N₄, TiC, TiB₂). Reinforcement of the matrix with only one of these reinforcements may not yield desired properties and the matrix may need to be augmented with other reinforcements also. Graphite and SiC are the reinforcements used widely in automotive industries to achieve better mechanical and tribological properties and dampen the vibrations with less operational costs. Aluminum metal matrix composite can be produced by various methods including powder metallurgy, conventional casting technology, etc. Among the casting methods semisolid processing of composites yields better mechanical strength. This review deals with various manufacturing methods of metal matrix composites processing and insight on semisolid processing and its process parameters.

Keywords - Metal matrix composites, semisolid processing.

1. 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, have 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 fibers to obtain the
required properties of matrices. The purpose of 
reinforcement is to get superior level of strength and 
stiffness in the case of a continuous fiber-reinforced 
composite. In discontinuously reinforced composites, 
matrix acts as scaffold to the composite which 
supports handling during manufacturing. Particulate 
reinforcement in MMCs typically use abrasive grade 
ceramic like 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 industrial 
applications as it offers wide range of attractive 
properties. Aluminum matrix composites refer to a 
class of materials where aluminum is the metal matrix 
being reinforced by materials like SiC, Al₂O₃, TiC, 
TiB₂, graphite and certain other ceramics. Graphite 
and SiC based composites are widely used in 
avtomotive industries for better mechanical and, 
tribological applications, vibration damping and with 
less cost requirements.

II. HYBRID COMPOSITES

Conventional materials which are 
monolithic have limited properties and 
applications whereas MMCs have lot of 
applications and hence, are in great demand. 
Hybrid composites are produced as combination 
of two or more secondary particles and are shown 
to yield desirable properties. Hybrid composites 
can be made with the combination of synthetic 
ceramic particles (silicon carbide, graphite and 
tungsten carbide) or industrial waste (fly ash, rice 
husk ash). The final property of the hybrid 
composite depends on i) combination type, ii) 
particle size and shape, iii) volume or weight 
percentage of the reinforcements and iv) 
manufacturing process parameters. Aluminum 
hybrid composites are a new generation of metal 
matrix composites which will resolve the demands 
of advanced engineering applications. The 
advanced requirements can be met with the right 
selection and optimization of reinforcing 
elements, improved mechanical properties and 
manufacturing techniques involved.

Hybrid aluminum metal matrix composites 
are being increasingly used due to their improved 
mechanical and wear resistance. The combination 
of light weight and reasonable mechanical 
properties has made aluminum alloys very popular 
and well suited for use as a metal matrix. 
Continuous fiber reinforcement matrices are more 
expensive than discontinuous reinforced (particle 
or whisker) aluminum MMCs. The most 
commonly used discontinuously reinforced 
aluminum composites are based on SiC and 
Al₂O₃.

Hybrid composites are used in automotive 
applications like pistons, liners, driveshaft, 
connecting rods, wheels, chassis parts and brake disks 
where a synergetic combination of high production 
rates, light weight and safety requirements are 
required strictly.

III. FABRICATION METHODS

1 Powder metallurgy

Powder metallurgy processing are used to 
fabricate particulate or short fiber composites which 
involves cold pressing and sintering. The metal 
matrix and secondary reinforcement particle are 
blended to produce a homogeneous distribution. 
Hybrid Al2024-SiC-Gr composites have been 
developed by powder metallurgy method which 
yields improved wear property than when SiC alsone 
is added as reinforcement. Process involves the steps 
of i) mixing the powder elements, ii) compacting the 
powder elements in die and iii) heating under 
controlled environment to enable the particles bond 
with each other. Blending of aluminum alloy powder 
with ceramic short fibre/whisker particle is versatile 
technique for the production of aluminum matrix.
composite. Blending is followed by cold compaction, canning, degassing and high temperature consolidation stage such as pressure or extrusion.

2 Spray Deposition

Spray deposition techniques fall into two distinct classes, depending whether the droplet stream is produced from a molten bath (Osprey process) or by continuous feeding of cold metal into a zone of rapid heat injection (thermal spray process). The spray process has been extensively explored for the production of AMCs by injecting ceramic particle/whisker/short fiber into the spray. AMCs produced in this way often exhibit inhomogeneous distribution of ceramic particles. Porosity in the as sprayed state is typically about 5–10%. Depositions of this type are typically consolidated to full density by subsequent processing. Spray process also permit the production of continuous fiber reinforced aluminum matrix composites. For this, fibers are wrapped around a mandrel with controlled inter fiber spacing, and the matrix metal is sprayed onto the fibers. A composite monotype is thus formed; bulk composites are formed by hot pressing of composite monotypes. Fiber volume fraction and distribution is controlled by adjusting the fiber spacing and the number of fiber layers. AMCs processed by spray deposition technique are relatively inexpensive with cost that is usually intermediate between stir cast and PM processes.

3 Casting

Nearly twice the volume of MMCs are produced by casting and other liquid routes compared to solid state fabrication although the latter technique is widely employed in 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 similar to the unreinforced aluminum alloys. But the stirring is important to avoid the concentration of ceramic (like SiC) at the bottom because it is denser than aluminum. Add details on casting methods and shortcomings of conventional casting techniques. How best this new process is

3.1 Sand casting

Sand casting is one of most widely used casting process because of its ability to produce low cost and wide variety of casting. This is very much suitable for small volume of large or complex shape with intricate shapes. Sand casting process offers simple medium for production of aluminum, zinc, copper alloys. Ferrous and non-ferrous alloys can be cast with good strength and surface finish. Casting quality depends on the variables namely sand type particle size, clay type, percentage of moisture, permeability, mould type, moulding hardness, pouring temperature and time.

3.2 Squeeze casting

Squeeze casting is an pressure infiltration process where the pressure is applied onto the molten metal surface to drive the liquid into the preform. Liquid metal is injected into the interstices of an assembly of short fibers, usually called preform which are commonly fabricated by ceramic particles, fibers. It combines the advantages of traditional pressure die casting, gravity die casting and forging process. Process parameters are applied load, applied pressure, initial melt temperature, temperature at the time of pressure, mould cooling, cooling rate etc contributes better quality castings. For aluminum alloys, the application of a holding pressure during cooling plays a very important role in defining casting properties.

3.3 Stir casting

Stir casting method is extensively used among the different processing techniques available. The simplest and most commercially used technique is the vortex or stir casting technique. Stir casting usually involves prolonged liquid reinforcement contact, which can cause considerable interaction. This involves stirring the melt with solid ceramic particles and then allowing the mixture to solidify. This can usually be done using fairly conventional processing equipment and can be carried out on a continuous or semi-continuous basis. Stir casting usually involves prolonged liquid-ceramic contact, which can cause substantial interfacial reaction which may degrade the final properties of the composite and may raise the viscosity of the slurry, making subsequent casting difficult. The rate of reaction is
reduced, and can become zero, if the melt is Si-rich, either by prior alloying or as a result of the reaction. The reaction kinetics and Si levels needed to eliminate it are such that it has been concluded that casting of Al-SiCp involving prolonged melt holding operations is suited to conventional (high Si) casting alloys, but not to most wrought alloys.

3.4 Semisolid 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). When temperature of the metal rises it will become soft and its flow stress decreases. In order to get 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 of both liquid and solid metal and the same can be allowed to cool in the mould to become solid product. Isothermal mixing of alloy melt and secondary particles was done under mechanical stirring condition to break dendrite structure that was formed during cooling of the melt. Also this mechanical stirring facilitates the infiltration of particles. With the application of ultrasonic vibration in semisolid state, the secondary particles distributed uniformly which yields porous free casting with enhanced product mechanical characteristics.

Fig.2 Advantages of semisolid processing

Fig.3 Applications of semisolid casting
IV. PROCESS CONTROL PARAMETERS INVOLVED IN ULTRASONIC CAVITATION OF HYBRID COMPOSITES

Soundness of sample improved with increasing melt temperature and holding time; these factors improved the fluidity of the aluminum melt and improved wettability by decreasing the contact angle between SiCp and aluminum. In addition pre-treatment of SiCp by thermal oxidation at 900ºC improved infiltration kinetics by the formation of SiO$_2$ on the surface of SiCp.

- **Uniformity of distribution:** Uniform distribution of particles will improve the tensile and fatigue strength of the composites. Segregation of particles reduces the fracture toughness because of availability of continuous fracture path in brittle region. Also segregation will increase local stress concentration and reduce the fracture 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 properly. The stirring action should be slow enough to prevent the formation of vortex at the surface of the melt. Continuous stirring of the slurry creates intimate contact between them. Good bonding is achieved by reducing the slurry viscosity and also by increasing mixing time.

- **Particle size and shape:** Dimensional stability of composites is better when the particle size is smaller (of the order of few nanometers), than the conventional larger size. Melt temperature is very critical as the particle size increases with increasing melt temperature. It is commonly known that the size of the soft particles used in composites influences wear rate and coefficients of friction of composites under sliding wear conditions. Larger particles lower the wear rate and coefficient of friction.

- **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 750ºC and forms rapidly from about 800ºC. This aluminum carbide precipitates affects the melt fluidity, weakens the cast material and reduces the corrosion resistance.

- **Wettability:** Mechanical strength of metal matrix composite primarily depends on the bonding between primary and secondary constituents of the composite. Wettability is defined as the ability of a liquid to spread on a solid surface, and represents the extent of intimate contact between a liquid and solid. Presence of oxide film in the case of molten aluminum alloy is unavoidable and this film affects the bonding between primary and secondary constituents. The oxide film layer formed during melting will act as barrier between particles and aluminum alloy. In order to improve the mechanical properties, particles are added in smaller size. But complete wetting of small-sized will be difficult. Smaller particles are also more difficult to disperse because of their inherently greater surface area. Additionally smaller particles show an increasing tendency to agglomerate or clump together. Few
methods are attempted by researchers to improve wettability [6] and these are:
- Addition of alloying elements to the matrix
- Coating of the ceramic particles and
- Treatment of ceramic particles

Flemings and co-researchers have studied the properties and application of semi-solid, rather than fully liquid alloy slurries. They concluded that the introduction of non-metallic particles into highly viscous and partially solidified alloy, prevents settling, floating or agglomerating of the particles.

- **Effect of ultrasonic vibrations:** In 1878 Chernov proposed the original idea of improving cast metal quality by elastic oscillations. Ultrasonic treatment is applied in metallic melts during their casting in order to obtain a non-dendritic and a fine grain solidification microstructure due to its abilities of mass transfer and energy transfer. High energy ultrasonic oscillations also improve the wettability between the reinforcement and the metal matrix. When high energy ultrasonic field is applied into the melt, cavitation are induced, which produce large instantaneous pressure and temperature fluctuations. This is likely to induce heterogeneous nucleation in the melt and dendritic fragmentation by enhancing solute diffusion through acoustic streaming.

- **Cavitation effects:** Cavitation effects of the high-power ultrasonic are due to the expanding-clogging-bursting dynamics of the ultrasonic bubbles. When the high-power ultrasonic is transmitted in the aluminum melt, the melt bears the tensile stress and initiates the cavitation effect. Then the cavitation is expanded, leading to clogging and bursting in the aluminum melt.

**V. DISCUSSION**

Due to increased demand for light weight material in automotive and aerospace applications, 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 materials at different sizes and controlling the process parameters the application of this semi solid casting can be widely used for mass production. Ultrasonic cavitation during production of Al MMC gives the composite better mechanical strength, increased thermal conductivity, good wear resistance and low coefficient of thermal expansion. Using two-stage stirring, uniform mixing of secondary particles are ensured and dendrites are broken into small globular form which gives improved thermomechanical and tribological properties to the composites. By reducing the secondary particles size...
and shape good dimensional stability can also be achieved.

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