RESEARCH ARTICLE OPEN ACCESS

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

R. Kasilingam[1,], R.Narayanan[2] and T.R.Vijayram[3]
[1] Research Scholar, SMBS, VIT University, Chennai-600 127, India
[2,3] Professor, SMBS, VIT University, Chennai-600 127, India
*- Author for correspondence; R.Kasilingam

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 Al_2O_3, SiC, Si_3N_4, TiC, TiB_2. 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.**

I. 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 continous fiber-reinforced composite. In discontinously 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 indusctrial applications as it offers wide range of attractive propoerties. Aluminum matrix composites refer to a class of materials where aluminum is the metal matrix being reinforced by materials like SiC, Al_2O_3, TiC, TiB_2, graphite and certain other ceramics. Graphite and SiC based composites are widely used in automotive 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 Al_2O_3.

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.

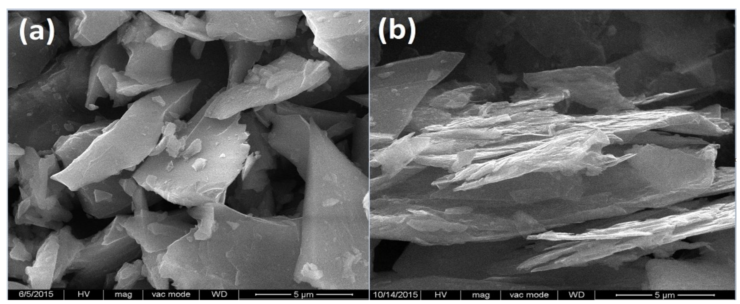

Fig.1 SEM micrographs of as-received (a) SiC (b) Gr particles

III. FABRICATION METHODS

1 Powder metallurgy

Powder metallurgy processing are used to fabricate particulate or short fiber compostes 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).he 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 simillar 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 paramaters 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.

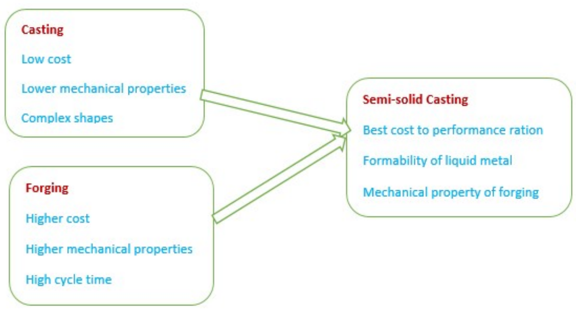

Fig.2 Advantages of semisolid processing

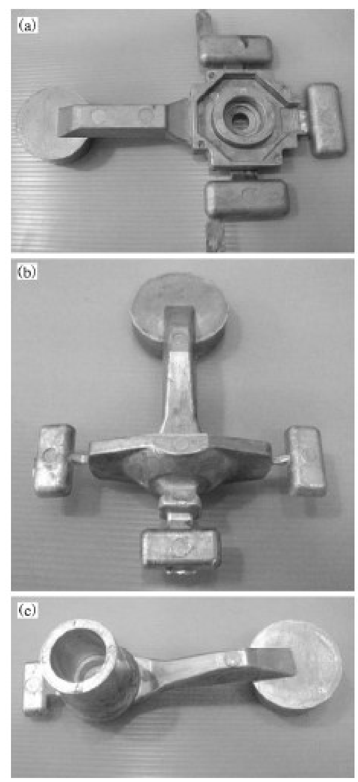

Fig.3 Applications of semisolid casting

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.

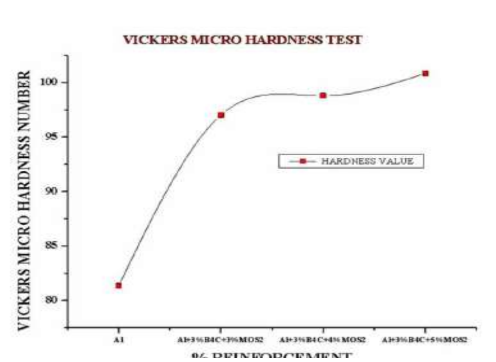

Fig. 4 Change in hardness at variable reinforcement volume

- **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 forms rapidly from about 800˚C. 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

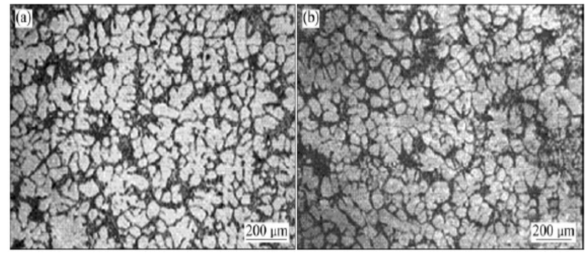

Fig.5 Microstructure of aluminum alloy semi-solid billets: (a) A356 alloy (Near-liquidus pouring); (b) A390 (Ultrasonic vibration)

- **Acoustic streaming effects:** When the high-power ultrasonic is transmitted in the aluminum melt, the sonic-press gradients are built from the sonic source due to the finite amplitude attenuation because of the interaction of the sound wave and the viscous force of the aluminum melt. These induce the acoustic streaming effects: vibration and stirring. The broken-up silicon particles are locally distributed uniformly in the aluminum melt to some degree.

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 thermo-mechanical and tribological properties to the composites. By reducing the secondary particles size and shape good dimensional stability can also be achieved.

ACKNOWLEDGEMENT

I express my sincere thanks and gratitude to my guide R.Narayanan and T.R.Vijayaram, VIT University Chennai, for their immense guidance and support to write this review paper.

REFERENCES

[1] H.Lakshimi, M.C.Vinay kumar,Raghunath, “Induction reheating of A356.2 aluminum alloy and thixocasting as automobile component” in Transactions of nonferrous metals society of china 20(2010),s961-967

[2] Dr.R.Mahadevan,R. Gopal. “Selectively reinforced squeeze cast pistons” in 68th World foundry congress, 2008,pp- 379-384

[3] Houyem Abderrazak, Mohieddine Abdellaoui “Synthesis and characterization of nanostructured silicon carbide” in Materials letters 62 (2008) 3839-3841

[4] B.M. Moshtaghioun, A.Monshi, M.H.Abbasi, “A study on the effect of silica particle size and milling time on synthesis of silicon carbide nanoparticles by carbothermic reduction” in Int.Journal of refractory metals and hard materials 29(2011), 645-650

[5] J. Babu Rao,G.J.Catherin, I.Narasimha Murthy, “Production of nano structured silicon carbide by high energy ball milling” International journal of engineering science and technology, Voume.3, 2011, pp.82-88

[6] J.Hashim, L.Looney, M.S.J.Hashmi, “The wettability of SiC particles by molten aluminum alloy, journal of materials processing technology” in H9 (2001) 324-328

[7] J.Hashim, L.Looney, M.S.J.Hashmi, “The enhancement of wettability of SiC particles in cast aluminum matrix composites” in Journal of materials processing technology, H9 (2001) 329-335

[8] Kenneth Kanayo Alaneme, Kazeem Oladiti Sanusi, “Microstructural characteristics, mechanical and wear behavior of aluminum matrix hybrid composites reinforced with alumina, rice husk ash and graphite” in International Journal of Engineering science and technology, (2015) 1-7

[9] Jung-Moo Lee, Sang-Kwan Lee, Sung-Jin Hong, “Microstructures and thermal properties of A356/SiCp composites fabricated by liquid pressing method”, in Journal of materials and design 37 (2012) 313-316

[10] Aleksandar Vencl,Hija Bobic,Saioa Arostegui, “Structural, mechanical and tribological properties of A356 aluminum alloy reinforced with Al_2O_3, SiC and SiC+ Graphite particles” in Alloys and compounds, 506 (2010) 631-639

[11] Songli Zhang, Yutao Zhao, Xiaonong Cheng, “High energy ultrasonic field effects on the microstructure and mechanical behaviors of A356 alloy” in Journal of alloys and compounds 470 (2009), 168-172

[12] J.Gilbert Kaufman and Elwin L.Rooy, “Aluminum alloy castings properties, processes, and applications” in (#05114G).ASM International, 2004.

[13] Haizhi yi, "An overview of the development of Al-Si alloy based material for engine applications" in Journal of material engineering and performance, 288 volume 12(3) June 2003.

[14] S.M.Zebarjad, S.A.Sajjadi,E.Z.Vahid Karimi, "Research letter on Influence of Nano-sized Silicon Carbide on Dimensional Stability of Al/SiC Nanocomposite" in Research letters in materials science, volume 2008, article ID 835746

[15] Ibrahim Sahin and Aysegul Akdogan Eker.2011,"Analysis of microstructures and mechanical properties of particle reinforced AlSi7Mg2 matrix composites", in ASM international (2011) 20:1090-1096

[16] Jessada Wannasin, Sangop Thanabumrungkul, "Development of semi-solid metal processing technique for aluminum casting applications", in Songklanakarin journal of science and technology 30(2),215-220,Mar-Apr.2008

[17] L.Ivanchev, D.Wilkins, G.Govender, "Rheo-processing of semi-solid metal alloys- A new technology for manufacturing automotive and aerospace components" in CSIR

[18] Yucel Birol.2009, "Forming of AlSi8Cu3Fe alloy in the semi-solid state", in Journal of alloys and compounds 470 (2009) 183-187

[19] J.B.Patel, Y.Q.Liu, G.Shao, "Rheo-processing of an alloy specifically designed for semi-solid metal processing based on the Al-Mg-Si system" in Journal of Material science and engineering A 476 (2008) 341-349.

[20] "Rheo-casting of Semi-Solid A357 Aluminum, Tim Basner, Delphi Automotive Systems", in SAE Technical paper series, 2000-01-0059, SAE 2000 World Congress, Detroit, Michigan, March 6-9, 2000, 400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A.

[21] Amal E. Nassar, Eman E.Nassar," Properties of aluminum matrix nano composites prepared by powder metallurgy processing" in Journal of king saud university-Engineering sciences 2015

[22] Michael Oluwatosin Bodunrin, "Aluminum matrix hybrid composites: a review of reinforcement philosophies; mechanical, corrosion and tribological characteristics" in Journal of materials research and technology 2015: 4(4):434-445

[23] Cory A.Smith, and DWA," Discontinuous reinforcements in metal matrix composites" ASM handbook Volume 21- Composites

[24] M.Kiuchi, and R.Kopp," Mushy / Semi-solid metal forming technology – Present and Future"

[25] Karl U.Kainer, "Metal matrix composites" Wiley-VCH Verlag GmbH & Co,KGaA,2003

[26] E.J.Vinarcik, " High integrity die casting processes" John Wiley and sons, New York,2003

[27] LUO Shou-jing, W.C.Keung, Kang Yong-lin, "Theory and application research development of semi-solid forming in china" in Trans.nonferrous Met.Soc.China 20(2010) 1805-1814

[28] J.Wannasin, S.Janudom, T.Rattanockaikul, "Research and development of gas induced semi-solid process for industrial applications" in Trans.nonferrous Met.Soc.China 20(2010) S1010-1015

[29] Siddesh kumar N G, V M Ravindranath, G S Shiva Sankar, "Mechanical and wear behavior of aluminum metal matrix hybrid composites" in Procedia materials science, 5(2014) 908-917

[30] Sivaiah Bathula, R.C.Anandani, Ajay Dhar, "Microstructural features and mechanical properties of Al 5083/SiCp metal matrix nanocomposites produced by high energy ball milling and spark plasma sintering" in Materials science and engineering A545 (2012) 97-102