

A Review on Effect of Reinforcement and Squeeze Casting Process Parameters on Mechanical Properties of Aluminium Matrix Composites

Saravanakumar. P¹, Soundararajan. R², Deepavasanth. PS¹, Parthasarathi. N¹

Final year PG Student, Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, India¹

Assistant Professor, Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, India²

ABSTRACT: In the present scenario, aluminium matrix composites (AMC) are the potential candidate for weight saving in structural application and have the ability to meet the stringent government norms. AMC's provide the synergetic effect of both aluminium and the reinforcement on the mechanical properties resulting in high specific strength, high hardness at elevated temperature, better wear resistance and good corrosion resistance. With various technologies and various grades of aluminium AMC were developed day-by-day and used for numerous applications. But still its production through liquid metallurgical route is a challenging task due to the lack of control over the type, size, weight fraction of the composite. Squeeze casting combines the advantages of forging and liquid metal casting, it annihilates all the defects in the stir casting and produce the castings with near net shapes and nil porosity. Proper selection of the process parameter is the key for enhancing the mechanical properties of the composite. Hence in this paper vast study on the reinforcements and effect of the process parameters on the mechanical properties AMC's were done.

KEYWORDS: Aluminium Matrix Composite, Reinforcements type & size, Stir casting limitations, Squeeze casting

I.INTRODUCTION

Metal matrix composites are one of the most important innovations in the development of advanced materials which find their applications in marine, automobile and aerospace industries [1]. MMC consists of at least two components, among which one is matrix phase usually the continuous phases like aluminium, magnesium and second components is a discontinuous phase like fibers, whiskers or particles or fillers called reinforcement [2]. Nowadays aluminium matrix composites draw the interest of the researchers because of the ability to alter their physical, metallurgical and mechanical properties by varying the filler phase [3].AMMC can be reinforced with various oxides, carbides, nitrides and borides in the form such as SiC, Al₂O₃, B₄C, TiC, TiB₂, TiO₂, AlN, BN, and Si₃N₄. Among various types of reinforcement, particulate reinforcement offers isotropic properties over the whisker and fibre, they are cost effective reinforcement and can be easily produced by conventional routes [4]. Mechanical properties enhancement of the composite is a function of the volume fraction, size, shape and spatial distribution of the reinforcement and also depends on how well the externally applied load transferred to the reinforcement [5].

Effect of Reinforcement micron size and volume fraction on properties of AMC's

Huseyin Sevik & Can Kurnaz, S (2006) have investigated metal–matrix composites of an aluminium–silicon

alloy (LM6) reinforced with Al_2O_3 particles having 5, 10 and 15 vol% and in the size of 44, 85 and 125 μm were produced using pressure die-casting technique. The composites having 44 micron particles show uniform distribution. The hardness of the composites is maximum for 15 vol. % and 44 microns of reinforcement while the tensile strength decrease with increasing Al_2O_3 particle above 10% content may be attributed to the fracture of Al_2O_3 during tensile loading. **Canacki, A et al (2013)** investigated the effect of volume fraction and particle size of the B_4C particles on the mechanical properties of 2024 aluminium matrix composite produced by stir casting method. The matrix alloy was reinforced with varying B_4C 3, 5, 7 and 10 vol. % in two different sizes of 29 and 71 microns. **Kok, M (2005)** developed 2024 AMC reinforced with Al_2O_3 particles with 10, 20, 30 vol.% in size of 16, 32, 66 micron. Both of them observed that the density of the composite decreased with increasing vol.% and reducing the particle size, whereas the porosity and hardness of the composites increased with increasing particle content and decreasing particle size. The coarser particles are uniformly distributed in the matrix where the finer particles lead to agglomeration. The better results were obtained when the matrix is reinforced with 10 vol.% in both the cases. **Sahin, Y (2003)** examined the effect of SiC in 2024 aluminium matrix composite, and the composites were fabricated by stir casting with argon setup. The particles sizes were 45 micron, 105 microns and weight fraction of 10 and 20%. The results reveal that the hardness and density of the composite increase linearly with increase in weight fraction of SiC, but the porosity increases slightly with an increase in weight fraction and particle size of the reinforcement. This trend may attribute to the entrapment of air surrounding the particles during mixing, as the percentage of particle increase the amount of entrapped air increases resulting in high porosity levels. **Aleksandar Vencl et al (2010)** studied the mechanical properties of A356 aluminium alloy reinforced with 10 wt.% of SiC and Al_2O_3 having particles size 39, 35 microns respectively. The composites were produced by the compo casting process, and their result depicts the composite produced with SiC particles have higher hardness and yield strength compared to the other composites. The SiC composite shows homogeneous distribution while the Al_2O_3 particles forms clusters in the matrix, these clusters acts as the stress initiating zone during the loading which results in the brittle fracture. According to Orowan bowing mechanism, the yield strength of the particulate reinforced composites was inversely proportional to the mean interparticle distance. The agglomeration of the particles could lead to the deterioration of mechanical properties of composites. It could be concluded that if the particles were uniformly distributed, it would be accepted to have improved yield strength.

Matrix - reinforcement interface bonding and wettability on properties of AMC's

Gursoy Arslan & Ayse Kalemantas (2009) reported that wettability is the ability of liquid to spread on a solid surface. Ceramic particles have poor wettability with the liquid aluminium because of the presence contamination, moisture or a gas layer that covers the ceramic particle surface. Various procedures have been recommended to improve the wetting of ceramic particles in the liquid metal. It includes: (i) increasing liquid metal temperature (ii) addition of some surface-active/reactive elements such as Magnesium (Mg), Lithium (Li), Calcium (Ca), Titanium (Ti) into the matrix alloy (iii) coating or oxidizing the ceramic particles, Addition of flux and preheating the particles are commercially available techniques. **Baradeswaran, A & Elaya Perumal, A (2013)** developed 7075 aluminium composite reinforced with B_4C particles of average size 18 micron with the varying volume percentage of 5, 10, 15, 20%. He observed that it is hard to fabricate Al- B_4C composites by mixing particles of the liquid phase, because of the poor wetting between Al and B_4C below 1100°C. Besides wetting, controlling the interface of the Al- B_4C is also significant in the production of cast Al- B_4C composites. As such, in the present work Al- B_4C composites were processed through a casting route with the addition of Potassium Hexa Fluoro Titanate (K_2TiF_6) flux, to form a reaction layer containing Titanium Carbide (TiC) and Titanium di -Boride TiB_2 at the interface, to increase wettability and interface bonding. The ultimate tensile strength, compression and flexural strength have also been observed to increase by increasing the B_4C particle content and are significantly higher than that of the base alloy. **Isil Kerti & Fatih Toptan (2008)** has reported that an effect is made to overcome the wetting problem and undesirable intermetallic phases between B_4C and liquid aluminium metal. Work was carried out using B_4C powders with different particle sizes 10 and 20 microns reinforced with commercially available aluminium using casting technique. It is possible to produce Al- B_4C composites with homogenous microstructure using K_2TiF_6 flux by casting method. An equal amount of flux should be added with the B_4C to maintain the Ti/ B_4C ratio (should be equal to 0.07), which improves wettability. The addition of B_4C particles with bigger particle size results in more homogeneous composite

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microstructure compared to the composite samples containing smaller particle size of B₄C due to agglomeration. **Kennedy, AR (2002)** developed LM25 aluminium composite by reinforcing B₄C particles of average size 25 micron and volume fraction of 5 and 10%. The composites were produced by die casting route, to improve the wettability K₂TiF₆ flux were added to the melt. The results show the modest improvement in the tensile and yield stress while the stiffness improves 2 GPa per volume percentage. This attribute to a strong interfacial bond between the matrix and reinforcement due to the formation of Titanium (Ti) layer around the particles due to the addition of flux.

Limitation of Conventional Casting Methods on properties of AMC's

Hasim, J et al (1999), Belete Sirahbizu Yigezu et al (2013), explained that traditional practice for the preparation of Al-Si alloy - based composites. It involves the addition of particles to the liquid aluminium by the stir casting could lead to segregation of reinforcement particles. Micro porosities and poor adhesion at the interface reported the various problems limiting stir castings: (i) Distribution of reinforcement material (ii) wetting ability between reinforcement material and matrix alloy (iii) Porosity in cast composites. Several authors have addressed porosity formation in the stir-cast discontinuously reinforced MMC. Most of them agree that porosity arises from four causes: (a) gas trap during mixing; (b) hydrogen evolution; (c) shrinkage during solidification; and (d) process parameters such as holding time, stirring speed, and the size and position of the impeller. It is also reported that the distribution of the reinforcement is a function of the solidification rate; in general, the higher the solidification rate, the more uniform is the distribution. It has also been observed that subsequent fabrication, such as extrusion, can modify the particle distribution and decrease the number of pores.

Lee, TW & Lee, CH (2000) performed the die casting processes using a preheated die at the pouring temperature of 700°C. From that, it was concluded that due to rapid cooling rate the SiC particulates were distributed homogeneously in Al alloy matrix, resulting from the refinement of cell size. The tensile strength of the as-die-cast composite was higher than that of the as die-cast aluminium alloy. Furthermore, the tensile strength slightly increased with increasing SiC particulate volume fraction. **Ismail Oezdemir et al (2000)** reported that closed die hot forging of Al-Si alloy reinforced with SiC reinforcement and unreinforced matrix alloy samples was carried out. The microstructure and mechanical properties of the matrix alloy and their composite samples were examined, which showed that forged microstructures had a more uniform distribution of the Silicon carbide particles and the eutectic silicon in comparison to the as-cast microstructures. The mechanical properties showed that the forged samples had strength values superior to those of the as-cast counterparts and yield strength. Further, the tensile properties of the matrix alloy and composite samples were increased. **Seah, KHW et al (2003), Joel Hemanth (2005)** developed Al/quartz particulate composites cast in sand moulds containing metallic and non-metallic chills respectively. During testing, all other factors were kept constant and by the introduction of chills, the faster heat extraction from the molten MMC during casting led to an increase in the ultimate tensile strength and fracture toughness of the castings. Also, it is reported that aluminium boron particulate composites cast fabricated. The size of the boron particulates is between 30 and 100 microns, and boron particle contents are 3, 6 and 9% by weight. Both Ultimate Tensile Strength (UTS) and fracture toughness of the chilled composites were found to increase as the content of boron particulates was increased up to approximately 6% by weight. The copper chill produces specimens of the highest UTS of 134 MPa, followed by steel, cast-iron and SiC chills.

Effect of squeeze casting process on properties of AMC's

Ali Mazahery & Mohsen Ostad Shabani (2012) have reported that the fabrication of different volume fraction of B₄C particles was incorporated into the aluminium alloy by a mechanical stirrer, and squeeze cast A356 matrix composites, and its behaviour is studied. In which the composite is fabricated by squeeze casting process with squeeze pressure of 80 MPa, stirrer speed of 600 rpm for 20 minutes and with the mould temperature of 300°C. The B₄C particles of 1-5 micron sizes with various weight percentages of 5, 7.5, 10, 12.5 and 15 are reinforced with matrix alloy where K₂TiF₆ added as the flux to overcome the wetting problem between B₄C and liquid aluminium metal. Microstructural characterization revealed that the B₄C particles were distributed among the dendrite branches, leaving the dendrite branches as particle-free regions in the material. It was known that the elastic constant, strain-hardening

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and the UTS of the MMCs are higher than those of the unreinforced aluminium alloy and increase with increasing B₄C content. The elongation to fracture of the composite materials was found very low, and no necking phenomenon was observed before fracture. **Zhang Wei-Wen et al (2007)** investigated the particle distribution, and the interfacial reaction of Al-Si alloy reinforced with B₄C particles processed by pressure die casting. The pressure varies between 30-80 MPa. He discussed the mechanism of the particle migration during solidification, at the early stage of crystallization, the solid fraction of particles near the wall surface was maximum. As the primary alpha grain grows it pushes the particles to the centre of the casting, longer solidification range lead to the formation of particle clusters. Since the B₄C was not stable in the aluminium melt small amount of Ti particles were added to avoid the formation of intermetallic phases.

Rajan, TPD et al (2007) studied the effect of three stir casting technique using fine fly ash particles reinforced Al-7Si-0.35Mg alloy composite is evaluated. Among liquid metal stir casting, compo casting (semi-solid processing), modified compo casting followed by squeeze casting routes evaluated. It is noted that latter has resulted in a well-dispersed and porosity free composites. Interfacial reactions between the fly ash particle and the matrix leads to the formation of Mg Al₂O₄ spinel and iron intermetallics are more in liquid cast composites than in compo cast composites. Modified compo casting cum squeeze casting route results in the best distribution of fly ash particles followed by compo casting alone and liquid metal stir casting in metal moulds. The severe interfacial reaction has been observed in liquid metal stir casting composite than one processed by compo casting. The compression strength of Al-fly ash composite prepared by modified compo casting cum squeeze casting is enhanced compared to the matrix alloy. However, the tensile strength has been reduced due to particle fracture and particle-matrix debonding. **Young-Ho Seo & Chung-Gil Kang (1995)** fabricated Al-Si matrix composite through squeeze casting process with varying pressure of 70-130 MPa. The silicon carbide particles of 15% and 22-micron size were added to the melt through vortex method. The size of the casting was 44 mm diameter and 80 mm height. The optimum conditions of the melt stirring process were that the temperature of the molten metal alloy was 680-700°C, the stirring speed was 750 rpm and the stirring time was 5 min. He observed that applied pressure improved the wettability and the bonding force between Al alloy/SiCp and approximately 10% also increased tensile strength. The greatest strength was shown at an applied pressure of 100 MPa in this study. The hardness increases with increase in pressure and found to be maximum at 130 MPa. **Sukumaran, K et al (2008)** developed 2124 aluminium alloy matrix composite with 10% SiC by squeeze casting process. The improvement in the mechanical properties can be attributed to the refinement of the microstructure obtained by the application of pressure during solidification. The slurry is poured into the die maintained at the temperature 120-130°C. The squeeze pressure of 45-120 MPa is acted upon the melt. The composite shows lower UTS initially compared to the alloy due to the presence of higher defects. However, the value of UTS for the alloy and composite are well comparable when the applied pressure is around 100 MPa, at which the porosities are eliminated entirely. Applied pressure not only demolished shrinkage and porosity but also it helps in the distribution of second phase particles.

Ali Kalkanli & Sencer Yilmaz (2008) investigated the squeeze casting of aluminium alloy 7075 reinforced with 10, 15 and 20 wt.% SiC particles. The alloy was melted in the furnace at 750-780°C, and the ceramic particles were added to the melt using vortex method. Then the molten melt is poured into the preheated die, which is maintained at 280-300°C. Subsequently, the squeeze pressure of 80 MPa was acted upon the melt. It is observed that the homogeneous distribution of SiC particulates was obtained using vertical pressure/squeeze casting of the SiC composites. Some agglomeration was observed, but there was no evidence of porosity among the SiC particles when they were close to each other. Both for as-cast (450 MPa) and heat treated conditions (588 MPa) 10 wt.% SiC aluminum matrix composites showed the maximum flexural strength. It is increased to about 40 MPa (10%) for the as cast and 180 MPa (44%) for heat-treated composites. Hardness test was conducted to find the maximum value. For the as-cast specimens, the hardness value increased from 133 to 188 Vickers due to an increase in silicon carbide content from 0 to 30 wt.% and for the heat treated specimens the hardness values increased from 171 to 221 Vickers hardness. **Sivaprakash, A & Sathish, S (2014)** have reported that LM6 alloy with varying contents of Al₂O₃ and Silicon Nitride (Si₃N₄). It is fabricated due of its excellent mechanical, microstructure properties like high hardness, good thermal shock resistance, strong bonding, resist strong acid attacks, wear resistance, long life and so on. In which the composites is fabricated by squeeze casting technique with squeeze pressure of 75 MPa, pouring temperature of

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730°C and the mould temperature of 220°C. The optimized parameters are pouring temperature 730°C, forming pressure 75 MPa, filling velocity 0.50 m/s, and mould preheating temperature 220°C. The tensile strength, elongation, and hardness of Al-Si-Cu family alloy AlSi9Cu3 obtained in squeeze casting were improved by 16.7%, 9.1%, and 10.1%, respectively, as compared with those of sand castings. **Adem Onat et al (2007)** investigated the mechanical and microstructural properties of the Al-4.5Cu-3Mg aluminium composite reinforced with 5,10,15 vol.% of SiC particles through squeeze casting. Ceramic particles were incorporated through with vortex method. The temperature of melt is maintained at 650°C. Then the melt is poured into the preheated die kept at 350°C. Then the squeeze pressure of 100 MPa was applied to the melt for the 60s. Casted samples of size 110 mm diameter and 20 mm height were prepared for mechanical and microstructural characterization. During solidification of an alloy the applied pressure result in fine-grained equiaxed macro-structure with microstructure being characterized by small Dendritic Arm Spacing (DAS), small constituent particles and more homogeneous distribution of structural components. In the case of composites, porosity increased with increasing volume fraction of SiC. The lowest porosity obtained in 5% SiC as 1.84% and the highest porosity in 15% SiC as 2.69%. Interdendritic segregation of particles during casting of discontinuously reinforced Al matrix composites is a serious problem. In some situations, this separation causes severe agglomeration. In this study, since solidification rate was very high in squeeze cast composites, so major agglomerations have not been observed. **Gurusamy, P (2015)** investigated the effect of melt temperature and die temperature on the mechanical and microstructural properties of the A356 aluminium alloy reinforced with 10 vol.% SiC particles. Preheated ceramic particles were added to the molten metal maintained at a temperature of 750°C and stirred for 10 minutes. Then the slurry is poured in the preheated die. Eight set of specimens of size 50 mm diameter and 150 mm height were fabricated at varying melt temperatures of 750, 800, 850 and 900°C by keeping 400°C as the die temperature value. Like, another eight set of specimens were fabricated for varying die temperatures of 250, 300, 350, 400°C keeping the melt temperature value constant at 800°C. The squeeze pressure was maintained at 100 MPa during the entire specimen manufacturing process. It was concluded that both melt & die temperatures have a significant influence on the microstructure, impact strength, tensile strength and hardness. Also, there was hardly effect on density due to both melt and die temperatures. The particles distribution is more uniform, and the resultant mechanical properties improve when the melt and die temperature are at 850°C and 350°C, respectively. The microstructure was found to be uniform for the corresponding processing condition

II. CONCLUSION

In this paper a vast study on the various grades of aluminium alloys, reinforcement type, size and the process parameters of stir casting and squeeze casting were done. It was concluded that there should be a proper control over reinforcement type, weight fraction and size for uniform distribution of the particles. From the study the weight fraction and should be within 15 wt.% and 30-80 micron respectively above which the agglomeration occurs in both the cases. Squeeze casting the has the potential to annihilate the defects like porosity and shrinkage due to the pressurization on the molten melt. The process parameter for the squeeze casting may vary according to the size and volume of the casting and ranges between 40-150 MPa of squeeze pressure, 650-800°C of melt temperature and 150-300°C of die temperature.

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