Mechanical Properties And Wear Behaviour of Aluminium Matrix Composites – An Overview

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Abstract- *Aluminium alloys havve been used in various applications such as automotive, aerospace and marine engineering because of its less weight, better fluidity, excellent mechanical properties and corrosion resistance. But they exhibit poor resistance to abrasion and wear. Reinforcement of hard particles, whiskers and fibers improves the mechanical properties and wear resistance. Advanced manufacturing technique such as squeeze casting process employs the development of metal matrix composites by pouring composite melt into the die cavity. Aluminium matrix composites (AMC) have been used in automotive industry components like brake pad, connecting rod and pistons. This paper presents an overview of mechanical properties and tribological behaviour of aluminium matrix composites with various types of reinforcements and the manufacturing methods to produce composites.*

Keywords- CSTR-PID-ZN-Fuzzy-MRAM-MATLAB.

I. INTRODUCTION

Composite material consists of two or more materials when they are in different physical and chemical properties. Continuous phase is termed as matrix and reinforcements are added to the matrix to improve the mechanical and wear resistance of matrix. Composites are classified as metal matrix, ceramic and polymer matrix composites. Out of all types of composites, aluminium matrix composites are used in various applications because of its high strength to weight ratio, high stiffness to weight ratio, stability at elevated temperature, better resistance to abrasion and wear [1–5]. The reinforcements such as aluminium oxide, silicon carbide, boron carbide, boron nitride, aluminium nitride, titanium carbide, zirconium carbide, titanium nitride, carbon, steel, graphite, fly ash are added in aluminium matrix to improve the properties of composites. Based on the types of reinforcements, aluminium matrix composites are classified as particle reinforced composites and fiber reinforced composites.

II. MANUFACTURING OF AMC

Aluminium matrix composites can be manufactured using solid state processing and liquid metallurgy route. Out of these manufacturing processes, casting process is mainly used in various industries because of its ease method of manufacture, viability and low cost [3]. Stir casting and squeeze casting process are used to prepare aluminium matrix composites with superior mechanical and wear resistance compared to gravity die casting process [3, 6–12]. In stir casting process, required wt% of reinforcement is added to the molten metal and composite melt is stirred at high speed to produce vortex. Subsequently, the composite melt is poured into the die to produce components with required shape and size. In squeeze casting process, after pouring the composite melt, a constant pressure is applied during the solidification of casting which eliminates the porosity and offers higher mechanical properties compared to stir cast process.

While selecting the reinforcement for particle reinforced composites, particle size and wt% of reinforcement should be considered which significantly influencing the mechanical and wear behaviour of composites. Fiber diameter, length, fiber orientation, bonding between matrix and reinforcement must be considered while preparing fiber reinforced composites.

2.1 Stir casting process:

Particle reinforced composite can be manufactured using stir casting process as shown in Fig1. In this stir casting process, raw aluminium is charged in crucible and the temperature is raised beyond melting temperature. Reinforcement is preheated in a separate furnace to remove the moisture content and added to the melt after removing the slag. While adding the reinforcements, an electric stirrer is used to stir the melt which produces vortex. This stirring process can help to achieve uniform dispersion of reinforcement throughout the matrix. Subsequently the composite melt is poured into the preheated die to obtain the castings of required shape.

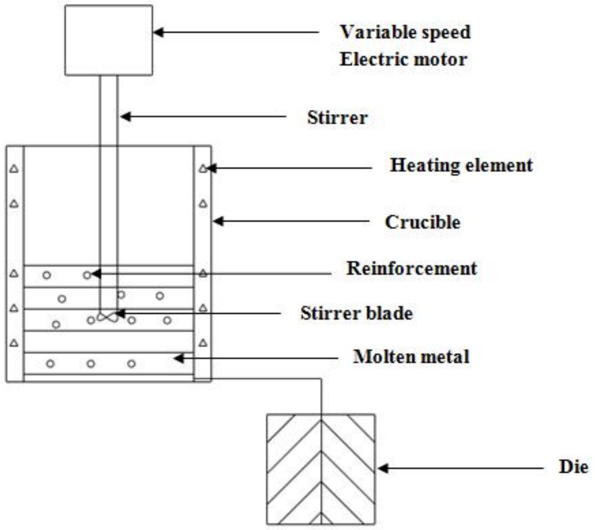

Fig.1 Stir casting process

Stir process parameters have greater influence on the improvement of mechanical properties of composites. Various process parameters are listed as follows:

1. Stirrer speed
2. Stirrer blade angle and number of blades
3. Stirring duration
4. Preheating temperature of reinforcement
5. Weight percentage or volume fraction of reinforcement
6. Die preheat temperature
7. Die material
8. Time duration of pressure application

Particle agglomeration is common problem encountered in stir casting process while preparing composites. Particle agglomeration can be prevented by using the stirrer speed above 500 rpm while adding reinforcement in matrix. Also longer stirring time causes particle deposition at the bottom surface of crucible since the reinforcement has higher density than matrix. Sufficient stirrer speed can be used to produce vortex during processing which results homogenous distribution of reinforcement throughout the matrix.

2.2 Squeeze casting process

Squeeze casting process is a combine technique of gravity die casting and closed die forging. In this process, composite melt is poured into the preheated die and subjected under a constant pressure during solidification of casting. Fig.2 shows the representation of squeeze casting process used for preparing aluminium matrix composites.

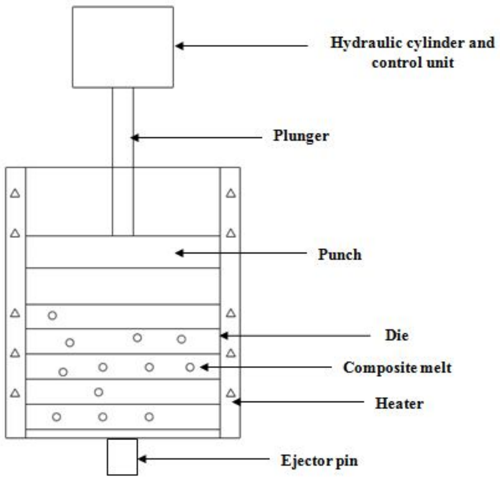

Fig.1 Squeeze casting process

Squeeze casting machine consist of a die and an upper punch used to apply pressure during solidification of casting. Die is made up of hard metal which posses the load applied during the process. Punch is made up of special metal such as steel and fitted to the hydraulic plunger. Hydraulic system is used to apply the pressure since the pressure range used in the process is beyond 75 MPa and a control unit is provided to set the desired level of pressure for manufacture. Single pattern die used in this process and the component is ejected using ejector pin. Split die eliminates the use of ejector pin and the two equal halves clamped using bolt and nut.

Aluminium alloy is sliced into small pieces, charged into the crucible and the temperature increased to the melting point. Reinforcement is preheated in a muffle furnace and slowly added to the melt and the melt is stirred using an electric motor. Subsequently the composite melt is poured into the preheated die using bottom pouring arrangement. A squeeze pressure is applied on composite melt through punch until the solidification is complete. This process produces the components of required shape and size with superior mechanical properties compared to gravity casting process. Since the component is subjected under pressure during the processing minimises the porosity, increases the cooling rate and produce castings with fine grain structure.

Squeeze cast process parameters have greater potential which influencing the mechanical properties of composites. The process parameters have been listed as follows:

9. Squeeze pressure
10. Melt temperature
11. Die preheat temperature
12. Material for die and punch
13. Time duration of pressure application

Senthil and Amirthagadeswaran [7] discussed the effect of squeeze cast process parameters viz., squeeze pressure, melt temperature, die preheating temperature, die insert material and compression holding time on mechanical properties of AC2A aluminium alloy. L_{16} orthogonal array was used to design the experiments and regression equations were developed to predict the hardness and tensile strength AC2A aluminium alloy. From the analysis of variance, it is observed that squeeze pressure, die preheating temperature and compression holding time were significantly influencing the properties of aluminium alloy. Also squeeze pressure is identified as major contributing factor for the improvement of mechanical properties.

Vijian and Arunachalam [11] investigated the effect of squeeze pressure, die preheat temperature and duration of pressure application on the mechanical properties of LM24 aluminium alloy. Taguchi design was used to design the experiments and L_9 orthogonal array was used in experimental work. The results reveal that application of pressure increased the hardness and tensile strength of aluminium alloy. Squeeze pressure of 106 MPa and die preheating temperature of 150 °C were obtained as optimum parameters for obtaining maximum hardness and tensile strength.

2.3 Mechanical properties and wear resistance of composites:

Reinforcements in the form of particles, whiskers and fibers improve the mechanical properties and wear resistance of composites. Several researchers have discussed the effect of reinforcements on mechanical properties of aluminium matrix composites.

Suresh et al [13] investigated the effect of beryl particles in Al–Si–Mg alloy produced using squeeze casting process. Wt% of reinforcement varied from 2 - 10, preheated to 900 °C and added to the melt. The composite melt was poured into the preheated die maintained at 200 °C and a squeeze pressure of 80 MPa was applied to produce composites. The results reveal that reinforcement of beryl particles increases the mechanical properties of Al-Si-Mg alloy. 6 wt% beryl particles showed improvement of 11.7% when compared to corresponding gravity cast composites. Wear weight loss reduced to 54% by reinforcing 10wt% of reinforcement in soft matrix by squeeze casting process. Squeeze cast composites offered better mechanical properties while compared to gravity casting process.

Kumar et al [14] discussed the effect of silicon carbide particles (SiC) in Al7075 alloy processed by liquid metallurgy route. Reinforcement is added to the melt when the melt stirred at 400 rpm and stirrer duration maintained as 10 min. SiC particles with average particle size of 150 µm were used and wt% of reinforcement varied from 2 to 6. Micrograph of composite shows fair distribution of reinforcement particles in matrix. The results showed that reinforcement of hard particles increases the hardness, tensile strength and density of composites. Mechanical properties of composites increased with increasing wt% of reinforcement from 2 to 6. Ductility of composite decreased with increasing weight percentage of reinforcement. Reinforcement of 6wt% of SiC improved the hardness and tensile strength of up to 62% and 29% respectively. Weight loss of samples decreased with increasing wt% of reinforcement and increased with increasing load and sliding distance.

Bharath et al [15] investigated the effect of aluminium oxide (Al_2O_3) particles in 6061 aluminium alloy. 6 - 12wt% of reinforcement with average particles size of 125 µm is preheated to 200 °C and added to the melt when the melt stirred at 200 rpm. Microstructure of samples showed uniform distribution of reinforcement in matrix. Also hardness, tensile strength and wear resistance of composites increased with increasing wt% of reinforcement. However ductility of composites decreased by reinforcing hard reinforcements in soft matrix.

Mandal et al [16] discussed the effect of steel fiber reinforcement in Al – Mg alloy processed using stir casting technique. Steel fibers were coated using electroless technique and added to the melt while the melt stirred at 500 -750 rpm to form a vortex. The results shows that amount of porosity increased with increasing wt% of reinforcement from 2.5 to 10. Hardness and density of composites increased with increasing wt% of steel fiber reinforcement in soft matrix. Tensile strength of composites increased with increasing wt% of reinforcement from 2.5 to 5. Further addition of reinforcements decreased the tensile strength. Regression equation is developed to predict the ultimate tensile strength of composites. Fracture surface of matrix showed dimple formation and composites showed steel wire pulled out from matrix.

Sivananthan et al [17] studied the effect of multiwall carbon nanotubes (CNT) in aluminium on mechanical properties of composites. Wt% of reinforcement varied from 0.5 to 3 and hardness, electrical and thermal properties of composites have been analysed. The results showed that relative density and hardness of composites increased with increasing wt% of CNT reinforcement in aluminium. Also electrical and thermal conductivity of composites decreased with increasing wt% of reinforcement from 0.5 to 3.

Kumar et al [18] investigated the effect of titanium diboride (TiB_2) in Al–7Si alloy processed using salt reaction route. Reinforcement of TiB_2 particles increased the young's modulus, hardness and ultimate tensile strength of composites. Also wear loss and coefficient of friction of composites decreased with increasing wt% of reinforcement. Worn surface of composites showed adhesion and ploughing at lower loads and delamination was observed at higher loads.

Dhinakaran and Moorthy [19] studied the reinforcement of boron carbide (B_4C) in aluminium alloy processed using stir casting technique. Wt% of reinforcement varied from 3 to 9 with average particle size of 104 µm is reinforced in AA6061 alloy. Microstructure of sample showed uniform distribution of particles in matrix. Reinforcement of B_4C increased the hardness and tensile strength of composites and higher mechanical properties were obtained for 9wt% of reinforcement in aluminium alloy.

Anilkumar et al [20] discussed the effect of fly ash reinforcement in Al 6061 alloy processed using liquid metallurgy route. Average particle size of 4 - 25, 45 - 50 and 75 - 100 µm were considered and wt% of fly ash varied from 10 – 20. The reinforcements were preheated to 400 °C and added to the melt while stirring was continued. The micrographs of samples showed uniform distribution of fly ash without any micro pores at the interface of reinforcement and matrix. Reinforcement of fly ash in matrix improves the mechanical properties of composites. Hardness, tensile strength and compressive strength of composites increased with increasing wt% of reinforcement and reduction in particle size. 15wt% of reinforced composites offered better ultimate tensile strength compared to other wt% reinforced composites and aluminium alloy. Also percentage of elongation decreased with increasing wt% of reinforcement.

Shyu and Ho [21] investigated the influence of titanium carbide (TiC) particles reinforcement in Al–5.1Cu–6.2Ti alloy. 6wt% of titanium was reinforced in aluminium using in situ process. Micrograph of composites showed uniform distribution of TiC in matrix. The results showed that hardness, tensile strength and wear resistance of composites increased by reinforcing 6wt% of reinforcement. Hardness of composites increased by 20%, tensile strength and yield strength increased up to 18% by reinforcing TiC in matrix. However wear rate of composites increased with increasing load from 0 to 1 kg.

Karthikeyan and Jinu [22] discussed the effect of zirconia (ZrO_2) in LM25 aluminium alloy processed using stir casting technique. Average particle size of 1-10µm was used and wt% of reinforcement varied from 0 – 15. The reinforcements were preheated to 575 °C and added to the melt when the melt stirred at 950 rpm. The results reveal that weight loss of composites decreased with increasing wt% of reinforcement and increased with increasing normal load and sliding distance. Also wt% of reinforcement in aluminium alloy decreased the surface roughness. Composite containing 15wt% of ZrO_2 offered better wear resistance compared to other wt% of reinforced composites.

Zhang et al [23] discussed the effect of aluminium nitride (AlN) particles in aluminium processed by squeeze casting. AlN particles with mean size of 4 µm, 50 vol.% was considered in experimental work. Micrograph of composite reveals homogeneous distribution of particles throughout the matrix without particle cluster. Composite showed higher tensile strength over matrix. Also tensile strength of composites decreased with increasing temperature. Coefficient of thermal expansion decreased with increasing wt% of reinforcement.

Vijian and Arunachalam [24] investigated the effect of squeeze cast process parameters on surface roughness of LM6 aluminium alloy. Squeeze cast parameters viz., squeeze pressure, die temperature and die materials were considered for experimental design and L_9 orthogonal array was used in experimental work. The results reveals that squeeze pressure had major contribution in the improvement of surface roughness of aluminium alloy. Squeeze pressure of 140 N/mm^2 and die preheating temperature of 250 °C were observed as optimum process parameters for obtaining good surface finish of LM6 aluminium alloy.

Zhang et al [25] discussed the effect of SiC whiskers and nanoscale SiC particles preform reinforcement in 2024Al alloy fabricated using squeeze casting process. 20 vol.% SiC whiskers was considered and 0 - 7 vol.% SiC nanoparticles were used while preparing preform as reinforcement. Micrograph of composites showed The reinforcements distribute homogeneously in the matrix. The results reveal that tensile strength of composites increased with increasing vol% of SiC nanoparticles in matrix. 50 – 60 MPa was identified as optimum squeeze pressure for fabricating hybrid composites.

Kumar and Dhiman [26] investigated the investigation on wear rate of Al7075 reinforced with 7wt% of SiC and 3wt% of graphite fabricated by using stir casting method. The reinforcements were added to the melt when it stirred at 600 rpm. Dry sliding wear test was conducted by varying load, velocity and sliding distance. Response surface methodloy was used to design the experiments and the results reveal that hybrid composite offers lower specific wear rate compared to unreinforced Al 7075 in all levels of loads, sliding speeds, and sliding distances. From the analysis of variance, it was observed that load was significantly influencing the specific wear rate of composites. Regression model was developed to predict the specific wear rate.

Ravindran et al [27] investigated the dry sliding wear behaviour of AA2024 alloy reinforced with 5wt% of SiC and varying wt% of graphite. Experiments were designed by considering the parameters viz., wt% of reinforcement, load, sliding speed and sliding distance. The results reveal that hardness of composites increased with increasing wt% of SiC and decreased with increasing wt% of graphite particles. Sliding distance and load were significantly influencing the wear and friction coefficient. 5wt% of SiC and graphite reinforced composites exhibited superior wear resistance compared to other wt% of reinforced composites and monolithic aluminium alloy.

Suresha and Sridhara [28] studied the effect of graphite and silicon carbide reinforcement in LM25 aluminium alloy. Wt% of silicon carbide and graphite varied up to 10 wt% and experiments were designed using central composite design of response surface methodology. The process parameters viz., % of reinforcement, sliding speed, load and sliding distance were considered in experimental work. Increasing trend of wear was observed in Al–SiC–Gr hybrid composites containing wt% of reinforcement beyond 7.5. Also hybrid composites exhibited better wear resistance over graphite reinforced composite. Wear rate of composites increased with increasing load and reduced with increasing sliding speed.

Mandal [29] discussed the effect of copper and nickel coating on steel fiber reinforcement in aluminium processed using stir casting process. Steel fibers were coated using electroless method and wt% of reinforcement was considered as 5wt%. Microstructure of composites showed better interface bonding between matrix and reinforcement due to copper coating on fibers. Copper coated steel fiber reinforced composites exhibited higher hardness and tensile strength compared to uncoated and nickel coated fiber reinforced composites. Fracture surface of composites showed fiber pull out in nickel coated and uncoated steel fiber reinforced composites and dimples were observed in matrix.

2.4 Applications of aluminium matrix composites:

Aluminium matrix composites have been widely used in automotive, aerospace and marine applications because of its high strength to weight ratio, high stiffiness to weight ratio, low cost, better resistance to wear and corrosion. Several automobile manufacturers in Japan and USA have already used engine parts made up of aluminium matrix composites. Some of the aluminium matrix composites used in automotive industries [3] is listed as follows:

- Al – SiC particulate composites used in piston
- Al – Al_2O_3 particle reinforced composites used in piston ring grooves and piston crown
- Al – Al_2O_3 continous fiber reinforced composites used in connecting rod and drive shaft Gear
- Al – SiC particulate composites used in gear shift fork, transmission components, brake rotor and caliper liner
- Al – SiC whisker composites used for fabricating connecting rods
- Al – Graphite reinforced composites used in cylinder liner and bearings

III. CONCLUSIONS

Aluminium matrix composites have been used in various applications in the area of automotive, defense and marine because of its better mechanical properties and wear resistance. Processing and characterization of aluminium matrix composites have been discussed and the main conclusions drawn from this paper is presented as follows:

1. Hard reinforcements such as aluminium oxide, silicon carbide, boron carbide, aluminium nitride, fly ash, zirconium dioxide and tungsten carbide in the form of particles, fibers and whiskers improve the mechanical properties and wear resistance of aluminium alloy.
2. Hardness and ultimate tensile strength of composites increases with increasing wt% of reinforcement.
   However addition of reinforcement in soft matrix decreases the ductility of composites.
3. Density of composites increases with increasing wt% of reinforcement. However reinforcement of particles and fibers increases the percentage of porosity which decreases the mechanical properties of composites.
4. Stir casting method is a promising technique for producing particle reinforced composites. Higher stirring speed produces turbulence which promotes uniform dispersion of reinforcement in matrix.
5. Squeeze casting is used to produce near net shaped components with superior mechanical properties compared to gravity die casting process. Solidification under squeeze pressure promotes cooling rate which results in fine grain structure, eliminate porosity and minimises post processing operations.
6. Mechanical and wear properties of composites depend on the properties of reinforcement / matrix, particle shape and size, wt% of reinforcement and manufacturing process. Better interface bonding between matrix and

reinforcement results higher mechanical properties. This can be achieved by proper coating on reinforcement.

7. Reinforcement of hard particles improves the wear resistance of aluminium alloy. Wear rate of composites increases with increasing load and sliding distance. However it decreases with increasing wt% of reinforcement.
8. Fracture surface of composites shows pull out and tear of reinforcement with dimples. Fracture mechanism is dominated by fiber / particles pull out in composites. In contrast, dimples are observed in matrix.
9. Worn surface of composites shows ploughing and fine grooves. On the other hand, delamination and severe wear are observed in matrix.
10. Aluminium matrix composites can be considered as a promising candidate in structural and wear resistance applications because of its better mechanical properties and excellent wear resistance over monolithic alloy.

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