Comparative Analysis Of Aluminium Metal Matrix Composites Reinforced With TiC And TiB₂ Using Stir Casting Process

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Abstract: Composite materials are playing major and vital role in various sectors especially in aeronautical, defence and automotive sectors. It is preferable because of obtaining unique characteristics such as high specific strength, high stiffness, high corrosion resistance and low density. In the present work deals with the influence of Titanium carbide and Titanium boride reinforcements in different percentages with the aluminium composites were prepared by stir casting process and analysed mechanical characterization and wear characteristics. The result reveals that increasing percentage of TiC directly increasing of ultimate tensile strength, yield strength, elasticity of modulus and decreasing the percentage of elongation. Also shows that for TiB₂, increasing of TiB₂ is directly increasing of tensile strength and coefficient of friction.

Keywords: Metal matrix composite (MMC), Aluminum metal matrix composite (AMC), Stir casting, Reinforcement, Titanium carbide (TiC), Titanium boride (TiB₂)

I. INTRODUCTION

Composite materials are comprised from two or more Constituent materials with significantly different physical, chemical properties or different phases that are to be combined and to produce a material with significant properties different from that of the individual alloys. The individual components remain separate and distinct within the finished structure. In composites, materials or phases were combined together in such a way as to enable us to sustain better use of composite materials. Aluminum matrix composite materials have enormous advantages such as high specific strength, high stiffness, high wear resistance, dimensional stability, high corrosion resistance and low weight of the finished part [1]. Composite materials are playing major and vital role in various sectors especially in aeronautical, defence and automotive sectors. Right now in the competitive environment in the manufacturing scenario expecting very good quality of the composite material.

Scientists, engineers or developers are might be aware of using conventional materials in the routing practice in the industry. It is possible to make use of tougher and lighter materials, with properties that can be tailored to suit particular design requirements because of the ease with which complex shapes can be manufactured, the complete rethinking of an established design in terms of composites can often lead to both economic and better solutions. Manufacturing methods of composites can be categorized [1-4] into following: solid state processing, semi-solid state processing and liquid state processing. Solid state processing can be divided into powder metallurgy, mechanical alloying and diffusion bonding methods. Liquid state processing is the most economical of all the available sources for metal matrix composite and it may be categorized into four categories: stir casting, infiltration, spray deposition and in-situ processing. Comparing to the four methods stir casting is the best method for obtaining following advantages. 1) Simple and inexpensive processing 2) Better matrix particle bonding 3) Easier to control of matrix structure 4) Flexibility 5) Excellent to suitable for mass production and flexibility when compare to other process.

Stir casting process is initiated and formulated by S.Ray during 1968, it’s a most economical and easier method to produce aluminium metal matrix composites. Aluminium and its alloys might be followed by producing aluminium matrix composites. Stir casting is one of the simplest and easiest methods to produce castings. Stir casting process suit for mass production when compared to other manufacturing methods. The major problem in this technique is to obtain sufficient wetting of reinforcement particle by the liquid metal and to get a homogeneous dispersion of particles [2]. Later on Lloyd (1989) analysed the processing parameters such as processing
temperature, holding time and velocity of particles in liquid metals. M. K Surappa [1] suggested that microstructural inhomogeneity can cause notabably particle agglomeration and sedimentation in the melt and subsequently during solidification in the aluminium matrix composite. Inhomogeneity in reinforcement distribution in these cast composites could also be a problem as a result of interaction between suspended ceramic particles and moving solid-liquid interface during solidification. Generally it is possible to incorporate up to 30% ceramic particles in the size range 5 to 100μm in a variety of molten aluminium alloys. The melt ceramic particle slurry may be transferred directly to a shaped mould prior to complete solidification. Stir casting also known as compo-casting. This technique has been used successfully used in aerospace and automotive industries.

Titanium boride reinforced aluminium metal matrix composites have higher strength, better wear resistance and better compatibility between the reinforced phase and the matrix compared with aluminium matrix composites compared with other reinforcements. Titanium boride is a ceramic material with high strength, melting point (2800°C), hardness(960 Hv), modulus(530 GPa) and corrosion resistance. The combination of its excellent properties has made titanium boride increasingly important for a wide range of application such as abrasive, erosive, corrosive or high temperature environments. TiB$_2$ particles do not react with molten aluminium thereby avoiding the formation of brittle reaction products also TiB$_2$ is an attractive strengthening agent for aluminium based composites. The main purpose of this study is to develop an enhanced and simplified stir casting process route to producing fine TiC and TiB$_2$ particle reinforced with aluminium metal matrix composite. Also confirming that the homogeneous dispersion of the particle in the AMC and reporting of mechanical characteristics and optimum wear rate in AMC.

II. LITERATURE SURVEY

Investigation [4] has carried out for the tensile performance and fracture behaviour of aluminium matrix composites reinforced with TiB$_2$ nano and microparticles of different volume fractions were separately incorporated into molten A356 aluminium matrix by a mechanical stirrer. Composites were produced at various casting temperatures and observed that the level of porosity content of the composites increased with increasing volume fraction and decreasing particle size of ceramic reinforcements. Nano composites reveal that different tensile performance compared with that of the microparticle reinforced samples. Compared with a non-reinforced alloy, significant improvements in tensile strength (43%) and elongation (27%) were attained in the 1.5 vol.% TiB$_2$ Nano composite. Further increase in TiB$_2$ nanoparticle content led to reduction in strength values and elongation of nanocomposites. Due to an increase in porosity content, the tensile properties of composites tangibly decreased with an increase in casting temperature.

Microstructure and mechanical properties [6] of extruded aluminium matrix reinforced with Al2O3 composites fabricated by stir casting process. Different mass fractions of micro alumina particles injected into the melt under the stirring speed of 300rpm. Further samples are extruded ratios of 1.77 or 1.56. Microstructure reveals that the injected particles and extruded in the matrix particles are distributed uniformly also shows that the porosity in the composites increased with increasing the mass fraction of reinforcement and stirrer speed and decreased by extrusion process. Investigations [7] on dry sliding wear behavior of in situ casted aluminum with titanium carbide formulated with 4 and 8% of TiC. Examine the significance of reinforcement quantity, load, sliding velocity and sliding distance on wear rate. Optimum process parameters are identified for the minimum wear rate.

Mechanical behavior of aluminium reinforced with micron sized[8] silicon carbide with different weight percentages of composites produced by stir casting. Standard mechanical tests were carried out for finding tensile force and sliding force. It shows that addition of SiC particles the resistance against indentation is increased and the resistance against tensile force is initially increased and then decreased. Experimental study has been conducted to determine the abrasive wear behaviour of bamboo[9], which is a cellulosic fibre reinforced composite in different directions. Unidirectional vascular fibre bundles present in bamboo provide unique directional abrasive wear properties. Wear anisotropy magnitude of bamboo is a function of load and abrasive grit size. Worn surfaces and debris after wear test were observed by using a SEM. It has been noticed that the debris generated were of fibrous type in longitudinal direction, which came out after ploughing and micro cutting of vascular fibres, while in normal fibre direction, debris were of particulate type. This unique difference in the nature of worn debris explains the difference in abrasive wear behaviour in three different directions of bamboo. Preparation of Al7050 alloy [10] via mechanical alloying and hot pressing techniques. The effect of milling time on the mechanical properties of the samples including microhardness, compression strength, and wear resistance were examined. The results of the experiments proved that by increasing the milling time the crystallite size was reduced, which has a significant effect on improving the mechanical properties. In addition, porosity formation increased when the milling time was increased due to reduction of the compressibility of finer particles. By increasing the milling time to more than 40 h, a relatively invariable crystallite size was obtained and it was observed that the porosities expanded in the samples. Therefore, the compressive strength, hardness, and wear resistance were enhanced up to 40 h milling time and then the strengthening effect was relatively diminished. On observing surfaces with SEM, the dominant wear mechanism was recognized as abrasion, delamination and adhesion.

Surface treatments and coating of the reinforcement are some of the important techniques [11] by which the interfacial properties can be improved. This review reports the state of art knowledge available on the surface treatments and coating work carried out on reinforcements and properties of aluminium alloy matrix composites. The metallic coatings improved the wettability of reinforcement but at the same time.
changed the matrix alloy composition by alloying with the matrix. Al–TiC composites [12] prepared by three different volume fractions 0.07, 0.12 and 0.18 of TiC by in melt reaction method. Dry sliding wear tests have been carried out using a pin-on-disk wear tester at normal loads of 9.8, 14.7, 19.6 and 24.5N and at a constant sliding velocity of 1.0 m/s. Weight loss of the samples has been measured and the variation of cumulative wear loss with sliding distance has been found to be linear for both the pure aluminium and the composites. The wear rate varies linearly with normal load which is indicative of Archard’s law. The wear rate decreases linearly with increasing volume fraction of titanium carbide. Average coefficient of friction also decreases linearly with increasing normal load and volume fraction of TiC.

In-situ Al–TiB2 [13] composite produced by stir casting route evaluated by dry sliding wear. Wear evaluation was carried out on composites with varying volume fraction of TiB2. It was observed that increased volume fraction of the TiB2 reinforcement had not led to an appreciable increase in the wear resistance of the composite. The wear resistance of Al–10 Vf% TiB2 composite was found to exhibit a wear resistance 18.5 times higher than the unreinforced Al, whilst the Al–Cu–15 Vf% TiB2 composite was 3.1 times higher in resistance than unreinforced Al–Cu matrix. Replacement of the Al matrix with Al–Cu in the 15 Vf% composite did not improve the wear performance. The Al–15 Vf% TiB2 composite was shown to have almost the same wear resistance as plain carbon steel. Microstructural examination revealed that Al3Ti flakes gave way immediately to the crushing load during the wear process. However, the TiB2 particles resisted the wear process until rounded edges were configured.

Gopala Krishnan[14] investigated that the Aluminium alloy AA6061 reinforced with titanium carbide particulate with different volume percentages in an inert atmosphere by an enhanced stir casting process and proved that specific strength of the composite has increased while adding the percentage of titanium carbide. Also pointed out that the mathematical model of wear loss linearly increased while maintaining the nominal load due to increased percentage of titanium carbide.

Suresh[15] analysed that the Aluminium alloy Al6061 reinforced with titanium boride (TiB2) with different weight percentages by stir casting process it reveals that increasing mechanical properties and improved wear resistance of aluminium metal matrix composite.

III. STIR-CASTING PROCESS

Stir casting belongs to the liquid metallurgy route in which molten slurry of metals with solid-phase additives of different compositions are prepared according to the convenient or process parameters then transferred and allowed to solidify in a preformed die cavity. Stir casting set up is integrated with electric furnace with a maximum capacity 1000°C, stirrer blade made of mild steel material because of withstand high melting point and it rotates by using coupling motor. Separate preheat reinforcement chamber provided along with the setup of stir casting arrangement. In addition to that die preheating provision is provided to preheat the die. Stirred Liquid metal poured into the cavity then allowed to solidify in the mould itself.

IV. RESULTS AND DISCUSSION

Gopalanakrishnan [14] investigated that the aluminium metal matrix composite reinforced with Titanium carbide with different percentages through stir casting method. 3% TiC reinforced with aluminium obtained 9% elongation. TiC percentages gradually increased till 6% magnitude of elongation will be obtained in zigzag manner. TiC 6–7% elongation percentage will be saturated even though percentage of TiC is increased. More than7% of TiC reinforced into AMC is effective less for the aspects of elongation.

Similarly Gopalanakrishnan [14] investigated that the aluminium metal matrix composite reinforced with Titanium carbide with different percentages through stir casting method. 3% TiC reinforced with aluminium obtained ultimate tensile strength of 170MPa. TiC percentages gradually increased till 6% magnitude of elongation will be obtained in zigzag manner. TiC 6–7% ultimate tensile strength will be saturated even though percentage of TiC is increased. More than7% of TiC reinforced into AMC is effective less for the aspects of ultimate tensile strength.

According to the Gopalanakrishnan [14] pointed out that the different percentages of TiC reinforced with aluminium metal matrix composite force applied 29.4N at the velocity of 3m/s, then the result revealing that if the % of TiC is increased then the wear rate is proportionally increased.

In similar manner according to the Gopalanakrishnan suggested that the different amount of load applied in aluminium metal matrix composite reinforcement percentage is 5% and velocity of 3m/s, then the result revealing that if the amount of load increased then the wear rate is directly increased.

According to the Gopalanakrishnan [14] experimented that the different velocity how it affects wear rate of aluminium metal matrix composite. Force applied 29.4N and reinforcement percentage is 5% then the result revealing that if the velocity is increased then the wear rate is proportionally increased.

According to the Suresh [15] investigated that the aluminium metal matrix composite reinforced with Titanium boride with different percentages through stir casting method. Without reinforcement tensile strength id obtained 90 MPa. Different percentages of TiB2 reinforced with aluminium obtained ultimate tensile strength will be in increased trend.

In similar manner Suresh [15] investigated that the aluminium metal matrix composite reinforced with Titanium boride with different percentages and different load condition such as 5N, 10N and 15N based on that co-efficient of friction formulated as shown in graph. In the aluminium metal matrix composite reinforced with different percentage of TiB2 and different load conditions co-efficient of friction high in higher load 15N. It reveals that load is increased co-efficient of friction is also directly increased.
According to Suresh [15] experimented that the aluminium metal matrix composite reinforced with Titanium boride with different percentages and different load condition such as 5N, 10N and 15N. Based on that weight loss percentage increased for the higher load 15N. It reveals that load is increased wear loss is directly increased in the aluminium metal matrix composite reinforced with the TiB2.

V. MATHEMATICAL MODELLING OF WEAR RATE

Wear rate is formulated according to the Archard’s law which states that the total wear volume is directly proportional to the real contact area times the sliding distance.

\[ V = C \cdot A_r \cdot l \]

\[ V = W/L \]

Where \( V \) = Total wear volume (m³)

\[ C = \text{Proportionality constant} \]

\[ A_r = \text{real contact area} \text{ (m²)} \]

\[ W = \text{Load (N)} \]

\[ H = \text{hardness of the softer surface} \]

\[ l = \text{sliding distance (m)} \]

Friction coefficient is calculated according to the following assumption.

If \( F \) is the load applied and \( f \) is the frictional force obtained,

\[ \mu = f/F \]

Wear rate calculated based on formula

\[ W = V/\rho D \]

Where \( \rho \) is the density of material

\[ V = \text{weight loss} \]

\[ D = \text{sliding distance} \]

Specific wear rate \( w = W/L \)

Where \( L = \text{applied load} \)

According to the Rajnesh[12] the Al–TiC composites containing three different volume fractions 0.07, 0.12 and 0.18 of TiC have been fabricated by in melt reaction method. Friction and wear characteristics of Al–TiC composites have been investigated under dry sliding and compared with those observed in pure aluminium material in the dry sliding wear tests have been carried out using a pin-on-disk wear tester at normal loads of 9.8, 14.7, 19.6 and 24.5N and at a constant sliding velocity of 1.0 m/s. Weight loss of the samples has been measured and the variation of cumulative wear loss with sliding distance has been found to be linear for both the pure aluminium and the composites. The wear rate varies linearly with normal load which is indicative of Archard’s law and it is significantly lower in composites as compared to that in base material. This layer inhibits metal–metal contact and the wear rate is reduced. The wear rate decreases linearly with increasing volume fraction of titanium carbide. Average coefficient of friction also decreases linearly with increasing normal load and volume fraction of TiC.

According to the Sivananth[16] investigated that the effect of adding reinforcement TiC into the AMC mechanical properties are increased. Mechanical characteristics of unreinforced alloy and Aluminium reinforced with TiC percentages are 10, 12 and 15 are considered [16]. The Young’s modulus value of cast unreinforced alloy is observed 73 GPa and it increases with the weight percentage of TiC reinforcement in aluminum melt. Improvements in the stiffness of the composite observed when comparing with the unreinforced alloy due to the mechanical stirring and fine dispersion of high modulus TiC particles in the matrix. Good wetting of the reinforcement particles by the liquid metal and the nucleation of solid aluminium on the reinforcing particle surfaces significantly reduced the particle clustering in Al/TiC composites.

Tensile strength and yield strength of Al–15 wt% TiC increase up to 323 MPa and 265 MPa respectively. This trend due to formation of eutectic silicon in the matrix which is refined and completely spheroidized along with TiC particles and the strength is increased. Also increased percentage of TiC particles offers more resistance to plastic deformation, thereby increasing ultimate tensile strength. It is observed that ductility decreased due to the addition of TiC. The composite with 15 wt% of TiC shows only 5.7% elongation, which is 50% lesser than that of the unreinforced alloy. This trend reveals that effect of increasing of TiC percentages reducing percentage of elongation. Also observed that the impact strength of an Al–15 wt% TiC mmc increases from 4 J to 13 J due to the presence of high modulus(87GPa) TiC particles. Fatigue strength of Al–15 wt% TiC mmc is observed as 248 MPa. This is increased in strength when compared to unreinforced alloy (133 MPa) is observed due to the presence of crack deflecting mechanism of TiC particles in the matrix. The TiC particulate does not allow the crack to propagate easily, and it increases the time required to begin a crack and increases the fatigue life. Fatigue strength of Al–15 wt% TiC AMC is 248 MPa. This increase in strength 86% compared to unreinforced alloy (133 MPa). Impact strength of an Al–15 wt% TiC AMC increases from 4 J to 13 J.

In the above graph reveals the influence of percentage of TiC and TiB2 reinforced with aluminum matrix produced by stir casting technique shows that TiC tensile values were dominated the TiB2.

VI. CONCLUSION

In the present work aluminium metal matrix composites reinforced with various reinforcements such as TiC and TiB2, materials were studied and analysed in detail about the mechanical characterization of composites. The distribution of TiC or TiB2 in the aluminum matrix is obtained homogeneous and interface between the reinforcements and aluminum matrix were clean without the presence of voids and pores.
A TiB₂ particulate reinforced magnesium matrix composite was successfully fabricated by adding a TiB₂–Al alloy and using the stir casting technique obtained uniform dispersion of reinforcement.

The wear rate decreases linearly with increasing volume fraction of titanium carbide. Average coefficient of friction also decreases linearly with increasing normal load and volume fraction of TiC.

The influence of percentage of TiC and TiB₂ reveals that TiC tensile values are dominate the TiB₂.

The wear rate decreases linearly with increasing volume fraction of titanium carbide. Average coefficient of friction also decreases linearly with increasing normal load and volume fraction of TiC.

Wear loss is directly increased in the aluminium metal matrix composite reinforced with the TiB₂ when loads were increased.

REFERENCES