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A Critical Review of Wear and Machinability Studies of Aluminium Metal Matrix Composite

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ABSTRACT

Aluminium metal matrix composites is tribute to satisfy the sophisticated engineering applications which were initially first generation metal matrix composite and now it reached a destination that made it to call as hybrid aluminium metal matrix composite (AMMCs – a newer generation metal matrix composite. They were used in multifarious fields as a result of their good tribological, physical and mechanical properties. On behalf of the peculiar demands such as enhanced hardness, fatigue, stiffness, corrosion, strength, creep and wear properties in materials, AMMCs are selected excluding the traditional engineering materials. AMMCs' properties are governed by the type of reinforcement particulates, matrix material and the method for processing them. This paper delineates the pandect of behavior of different particulates reinforced aluminium alloy Al 6061. The wear properties and machinability characteristics of AMMCs are anatomized exclusively for greater understanding of these novel composite materials.

Keywords: AMMCs, Machinability characteristics and Wear properties.

1. INTRODUCTION

To create a superior and unique material two or more different materials with distinctive properties and disparate boundaries are combined together referred as a "composite". The two disunited components, the matrix and the filler are in composite material. The matrix is the element that holds the filler together to form the bulk material. The material that has been impregnated in the matrix to contribute its advantage (usually toughness and strength) to the composite is known as filler. Carbon fiber, sand, glass bead, or ceramic are some types of fillers. Composition and microstructure variation in materials throughout their thickness are known as Gradient composites. During the fabrication, spatial variation is introduced in the composition to achieve the desired gradient in the properties of material. A number of distinct advantages can be provided by gradient composites when compared to conventional homogeneous composite materials. Those benefits provided by gradient are reduced stress concentrations, a smoother stress distribution, greatly improved fracture toughness and bond strength and elimination of stress singularities [1]. Material with single or more discontinuous reinforcing phases and a continuous metallic matrix is known as Metal matrix composites. Fibers, whiskers or particles may be the forms of the reinforcing phase. A Fiber has high length to diameter ratio and its diameter approximates its crystal size. They are stronger than bulk materials. Whiskers are similar in diameter to fibers, but usually they are short and have low length- to- diameter ratios, hardly exceeding a few hundreds. They are stronger than fibers because the degree of perfection is higher than fibers. Over other factions of composites MMCs have multifarious benefits like elevated modulus, elevated strength, less sensitivity is exhibited when thermal shock or temperature varies, greater impact properties, higher toughness properties, on behalf of surface flaws less sensitivity is seen, surface durability is higher and conduction of electricity is higher. The distribution of reinforcement particulates in the matrix and the morphology of secondary matrix deeply influence the MMCs' mechanical properties [2]. Metal matrix compositions (MMC) have become noteworthy materials and multifarious metals or alloys of nickel, copper, zinc, stainless steel, magnesium or aluminum are most probably chosen as matrix materials in MMCs. In the class of above matrix materials, from the perspective of industrial as well as research fields, the most extensively utilized materials are aluminium alloys. Based on the composites' final desired properties, various reinforcements are used in AMMCs. B_4C, Al_2O_3, SiC are the very common particles that have been used so far as reinforcement in AMMCs [3]. Aluminum MMCs reinforced particles owing to their excellent mechanical properties has inherited appreciable attention. Metal matrix composite (MMC) are time-honored materials which are utilized in automotive, aerospace, electronics and medical fields. They have spiffing mechanical properties like low weight, high strength, low ductility, low thermal expansion, high wear resistance and high thermal conductivity. Reinforcement element, matrix and interface manipulate the above carving properties [4]. AMMC reinforced with ceramics is familiar for par excellence tribological properties and corrosion resistance behavior and exclusively higher strength to weight ratio owing which the monolithic alloys are replaced by them [5]. The grain size of particles in the composite, the % reinforcement, the type of fabrication process used and the final microstructure of composite after fabrication decide the strength of the composites. Due to the reinforcement of ceramic particulates the metal matrix composite shows the improvement in their properties especially the tribological properties which were shown in recent studies [5]. Machining- which is the utmost important in MMC is different from machining an ordinary material due to the reinforcement particulates. The machining of MMC obviously depends on the reinforcement particulates; either it may be a particle, whiskers or fibers. Not only this, but also the type of reinforcement material, its distribution in matrix material and finally the volume fraction or weight percentage of the reinforcement materials. Thus it is hard to machine a ceramic reinforced metal matrix composite than a normal material [5]. The hardness of MMCs escalates with increased weight percentage of ceramic particles in matrix. Fact reviles that the cutting tool faces different materials when they pass through a composite and this factor really influences the tool to face higher tool wear. This leads to the production process to become more uneconomical or sometimes even impossible. So in order to overcome these problems, peculiar demands on the tools' geometry and wear resistance property arises [6]. Hybrid reinforcement lead to the improved MMC's with enhanced material properties, in which ceramic considered as primary reinforcement develops drastic elevation in the strength of the matrix material and the secondary reinforcement will be a material that is readily available and which automatically reduces the cost and weight of the hybrid composite.

The aim of this paper is to scrutinize the attainability of low price highly performing ceramic reinforced AMMC's that are suitable for aerospace and automobile applications. Apart from this wear properties and machinability by various conventional and non-convention machining processes are reviewed and reported.

2. MULTIFARIOUS REINFORCEMENTS IN AMMCS

Amid of profuse MMCs, aluminium metal matrix composites provides two ultimate beneficial factors like lower density and higher strength. As there is a need for properties like stiffness, hardness, wear resistance and toughness, these aluminium matrixes are to be infused with harder particles to attain the above properties to the maximum extent [7]. The Harder particles that can be reinforced in aluminium matrix to obtain these properties are different kinds of nitrides, oxides, borides and carbides in the form such as B_4C, BN, TiC, TiB_2, Al_2O_3, TiO_2, Si_3N_4, SiC, and AIN. Amid of varied factions of reinforcement, over the whisker and fiber reinforcements, particulate reinforcement offers isotropic properties. These particulate type reinforcements are cost effective which can be produced by traditional methods easily. The reinforcement's weight percentage, shape, spatial distribution and size are the factors that influence the mechanical properties and it also depends on the transformation of applied external load to the particulates of reinforcement. Particle reinforced aluminium metal matrix composite exhibits higher mechanical properties than the unreinforced one. But the fiber or whisker reinforced composite exhibits more higher mechanical properties than the particle reinforced AMMCs. The percentage of ceramic reinforcement is 30% and 70% for structural applications and electronic packaging applications respectively.

3. PRODUCTION METHODS OF AMMCS

One of the essential factors in producing AMMCs is the method of fabrication that decides the end product properties. To fabricate AMMCs the most widely used methods are liquid state method (liquid infiltration, stir casting technique, compo-casting technique) and solid state method (Powder Metallurgy).

3.1 Stir Casting Method

Easiest as well as cost effective technique to fabricate AMMCs is blending the particulates of reinforcement that are in solid form in the matrix material that are in liquid form. At last solidification of blended mixture is done in a preferable molded pattern. While the reinforcement particulate is progressively added to the liquid metal, the mixture is to be continuously stirred.

Before adding the reinforcement material, melting of matrix material is done in the temperature that is more than the materials' melting point temperature. But making good wetting between the melted aluminium alloy and the reinforcement particles is the key thing. In order to exhibit and with hold a best dispersion of reinforcement particulates in matrix material, one of the approaches known better is the vortex method. Here [8], after the melting of matrix material, vortex is formed at the melting surface when the melted liquid metal is agitated vigorously, after which reinforcement particulates is infused in the vortex formed. Before casting the slurry, agitation is pursued for some more time. Turbine or impeller stirrer is used most popularly. Stirring helps in order to maintain the particulates in a state of suspension and to transfer particulates into the melted liquid metal during stir casting. Fig.1 shows the stir casting set up. Various factors that has to be taken into consideration while fabricating MMCs by the stir casting method, includes wettability between the two matrix and reinforcement, the trouble of achieving a uniform distribution of particulate reinforcement material in the matrix material, chemical instability between matrix alloy and reinforcement material and the casted AMMCs' porousness. To acquire AMMCs with properties at optimum level, matrix alloy should be inculcated with uniformly distributed reinforcement material.

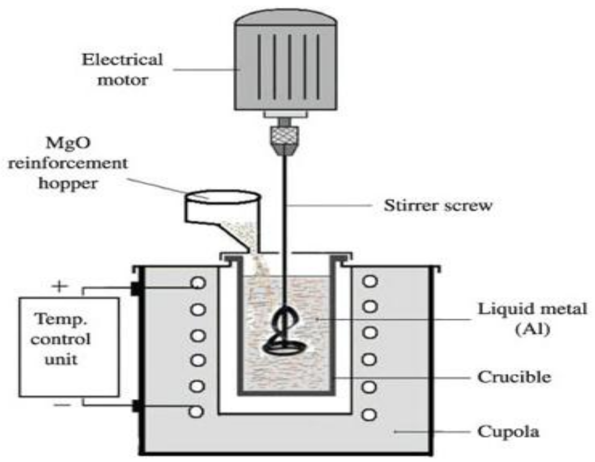

Fig.1 Stir casting set up

Bonding or wettability of the reinforcement materials in the matrix must be optimized. The review shows that uniform scattering of reinforcement material by utilizing lower cost traditional machine set up for commercialized applications will be the major problem. The agitating speed effect on porousness in MMC of aluminium silicon alloy reinforced with short length SiC_p is investigated at [9] 100, 300 and 500 rpm stirring speed and was found that the composite made at 300 rpm exhibits lower porousness and the composite with uniformly distributed reinforcement particles in the matrix. Metallographic study reveals some amount of grain refinement and a fairly uniform distribution in the composite parts produced by the process of stir casting.

3.2 Compo Casting Method

Particulate AMCs are being fabricated by the most probably used stir casting technique. While stirring, the dendrites in the form of solid are shattered into particles of spheroidal shape which are expelled in the form of fine particles into the melted liquid. Even after complete solidification the solitary feature of most alloys is thixotrophy which can be reclaimed by elevating the temperature. Yet, the maximum innate issues emerging are substantially the non-wettability and the different density between the two phases. The outcome of above criteria is the heterogeneous partition of the reinforcement particulates in the matrix alloy, formation of brittle phases and extensive interfacial reactions at the matrix and particle interface and also a higher porosity level. So as to overcome the above drawbacks, new technique called compo-casting technique has been used for fabricating these MMCs [10].

To fabricate discontinuously reinforced MMCs one of the most economical methods used is Compo-casting. This casting process has many merits in which the lower spouting temperature might be utilized in spite of regularly employed one as in case of stir casting, which results in the reduction of reactions in between the interfaces. It results in a defect-free product by offering forming in the semisolid state at low pressure. Another limitation in this method is obtaining the complete elimination of the leftover pores in the space separating two fibers are impossible. And also, the above technique is not convenient for fabricating AMCs stiffened with continuous fiber.

3.3 Infiltration Method

A liquid state method that is used to fabricate reinforced MMCs is Pressure infiltration casting. In this type of casting, a form in which the fiber is placed prior the injection of molten metal into it. This technique is utilized when the reinforcement particulates are to be non-heterogeneously distributed and high volume fraction are required. The infiltrating system should be aware whether a threshold pressure is applied for a successful infiltration. By applying theoretical approaches for various systems, the threshold pressure can be calculated. The only difference between infiltration casting and squeeze casting is gas instead of mechanical pressure is used to promote consolidation.

Capillary forces and viscous forces are the most important forces in order to attain a good particulate dispersion as well as a good bonding [11]. In order to maintain the properties inhibited by the composite as flawless, chemical alterations such as usage of nickel or copper coated reinforcement particulate might be taken into consideration which tends to stop the reaction that takes place chemically in between the molten metal and reinforcement particulate. Enhancing the wettability is done by applying external pressure to the metal in order to force the contact. According to Borgonova, chemical alterations were avoided and instead mechanical forces were preferred, since the chemical alterations exhibits consequences such as phases of instability and limited usage of matrix alloy range [23].

3.4 Powder Metallurgy Method

The powder metallurgy technique is the most commonly used solid state process. This technique involves matrix materials mixed with discontinuous fiber or particulates reinforcements. The utility of two materials owes to trouble-free mingling and amalgamation where metal matrix powders and ceramic reinforcements are meticulously blended, compressed into a compact form and then finally sintering is carried out [12].

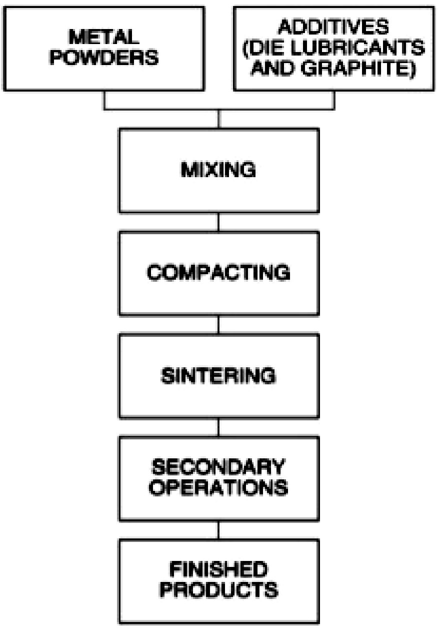

Fig. 2 PM process

The foremost stage in PM method is mixing or blending process where the matrix is introduced with reinforcement by the usage of various blending and mixing methods which includes planetary mill, roll mill as well as ball mill methods. Usually, the material to be reinforced resembles as particulates or whiskers. In the matrix, the reinforcement distribution is determined by the blending process which is most important in powder metallurgy technique. Normally, operation of blending is chosen in the form of wet or dry which depends on the matrix and reinforcement selection. Almost all significant properties of MMCs are meant to be achieved by blending steps ultimately though it is a simple concept [13]. Fig. 2 shows the flow chart of PM process.

The succeeding step of PM method to fabricate MMCs is compaction. To get the desired shape the mixture is compacted using a die. The prime parameters of processing that influence the end product’s density are sintering of green compacts produced in earlier stage and the process of free powders compaction by means of pressure applied externally. The applied pressure as well as yield stress of the powder particles is the factors that influence the densification behavior under compaction. The hot isostatic, outgassing and cold compaction method are involved in the compaction process in powder metallurgy. The method of blending frequently utilized in PM process is cold compaction. The cold compaction step’s chief function is to produce a green strength end product. Sintering process is the rearmost and highly significant step in PM process. It’s the technique that involves fortification of powder grains by means of raising the temperature of green compact part below the melting point, at that point of time diffusion of the separate material particles to the powder particles that are adjacent [14]. Usually, at 0.75-0.8 Tm of metal matrix, the sintering process is carried out [8].

4. WEAR CHARACTERISTICS OF AMMCS

AMMC AA 6061 being reinforced with different weight percentage of titanium carbide particles is fabricated in the presence of argon by enhanced stir casting technique [15] and its properties are studied with the aid of friction monitor and a pin on disc wear monitor. With the normal load, linear increment in loss due to wear is noticed. But, with elevated TiC inclusion the wear rate increased marginally. Thus the wear resistance increases. Optical micrographic image of the specimens subjected to wear test (3% TiC) is shown in Fig3.

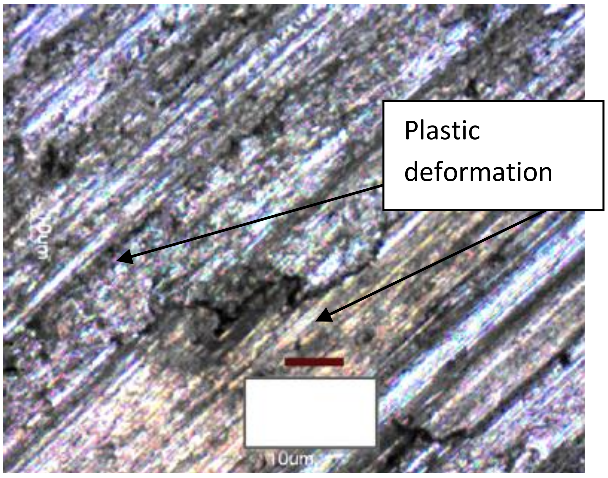

Fig.3 Optical micrographic image of the specimens subjected to wear test (3% TiC) [15]

By varying the CNT content from 0 wt.% up to 5 wt.% experiment was conducted [21] and these samples were tested at different sliding speeds and acted upon by different loads. The results showed a notable improvement in the wear resistance and the hardness, at the same time drop in the wear rate and the coefficient of friction. The frictional coefficient was observed to decrease with increase in speed of the slide; the rate of wear increased while the frictional coefficient reduced on enlarging the applied load. The SEM observations [16] shows the presence of a carbon film formed due to crushed or worn out CNTs which acted as a solid lubricant and thus was instrumental in reducing the frictional coefficient and wear rate. The non-embedded CNTs in the matrix reduced the wear of the surface directly in contact with the rubbing surface, thereby improving the wear characteristics.

Using Stir Casting technique, the fabrication of composite AA6061 is done, which has been reinforced with Silicon Carbide (SiCp) whose weight percentage is kept constant as 10% weight percentage of AA and graphene whose weight percentage is kept varying from 0% to 0.7%. By utilizing Pin on Disc Apparatus aided with computer, wear test of Al6061-sic-Gr (0%-0.7%) was carried out on the prepared Specimen. The test was carried out by changing the load range of 5, 10 and 15 N and keeping the time constant and constant speed in 100rpm and changing the load range of 5, 10 and 15 N .It was found that, under mild wear state, the composite revealed lower coefficient of friction and wear rate when compared to aluminum. It has been revealed that the wear and friction behavior of aluminium–SiC - graphene composite is highly impelled by the load applied and there is an existence of a critical load later than which graphene nano particles could have a negative result on the abrasion resistance of AA [17].

AMMCs is prepared using compocasting method [18] with AA6061 as matrix and rice husk ash (RHA) (0, 2, 4, 6, 8 wt. %) as reinforcement. At room temperature, with the help of pin-on-disc apparatus investigation of the dry sliding wear operation is performed. As a result of adding RHA particles the abrasion resistance of the composite material is improved and the damage on the worn surface is reduced. Due to the extension of the applied load as well as RHA particles content, changes has been observed in wear mode. Fig.4 shows the result of RHA particles presence upon erode rate of aluminium alloy 6061/RHA AMMCs.

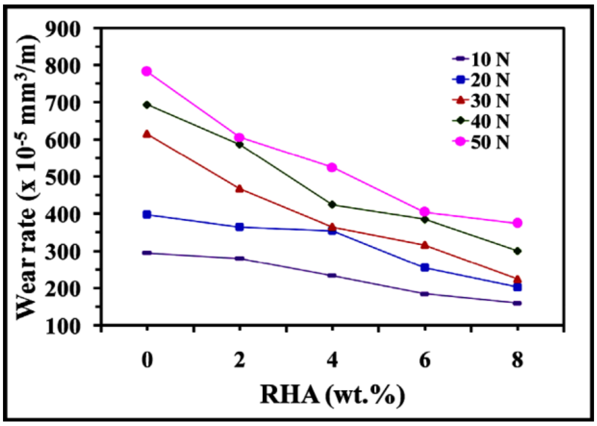

Fig.4 Result of RHA content on rate of wear of AA6061/RHA AMMCs [18].

6061 AMMCs buttressed with Hematite (Fe_2O_3) is fabricated by [19] liquid metallurgy technique as well as their abrasion characteristic is studied. The reinforcement of 40-45 µm size is added in particulate form with a weight percentage of 0%, 2%, 4%, 6% and 8%. By varying speed from 200 – 400 rpm & load from 50 – 100 N, the wear test was conducted on the specimens. By noticing the weight loss of the specimen, wear rate was measured. By observing the results, it indicates that with the rise in the proportion of reinforcement, the abrasion resistance is increased. When compared to base matrix material, at 8 % of reinforcement the wear factor has decreased 30 - 40 %. Graphs of wear factor vs load and wear factor vs speed for different rpm and load values are shown below in figures 5 to 10.

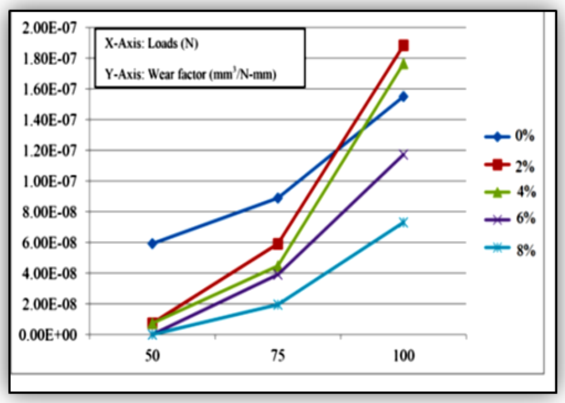

Fig.5 Wear factor v/s load at 200 rpm [19]

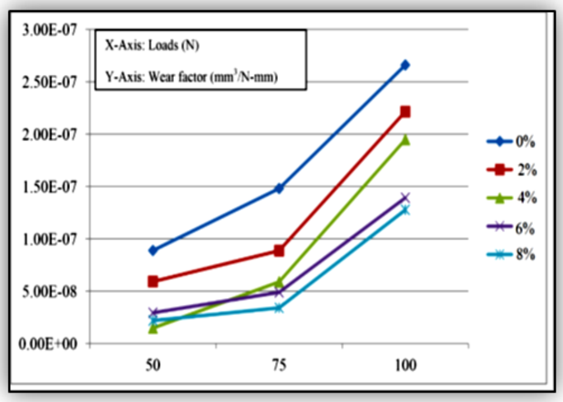

Fig.6 Wear factor v/s load at 300 rpm [19]

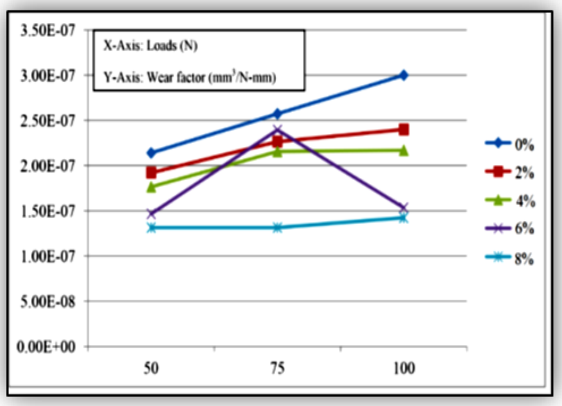

Fig.7 Wear factor v/s load at 400 rpm [19]

5. MACHINABILITY OF AMMCS

By in-suit process TiB_2 particle reinforced Al7075 aluminum matrix composite is fabricated and the machinability study was done. Experiments were carried out by utilizing the process of under arid conditions, by using conventional universal lathe machine [19]. Coated carbide, PCBN, and PCD are the tools used for cutting. To process TiB_2/Al metal matrix composites, experimental investigation about criteria like machined surface quality, chip shapes and tool wear were performed. Due to the wear resistance and high surface quality, PCD tools are suitable for the machining of TiB_2/Al MMCs. When cutting this material than that of SiC/Al MMCs, small surface roughness was obtained. hole and groove was seen commonly on the machined in SiC/Al MMCs while it is not seen in TiB_2/Al MMCs. Owing to good adhesion at interfaces of reinforcements and metal matrix and also due to the small size of reinforcements, the surface quality of TiB_2/Al MMCs is better than that of SiC/Al MMCs. In macro-scale the aspect of chip shape is similar for both non-reinforced aluminum alloy and TiB_2/Al MMCs, whereas in micro-scale it is similar to SiC/Al MMCs in micro-scale. Figures 11, 12, 13 and 14 shows SEM image of PCD tool, diffusion wears on tool edge, influence of cutting parameters on surface roughness and chip shapes of MMCs at different parameters respectively.

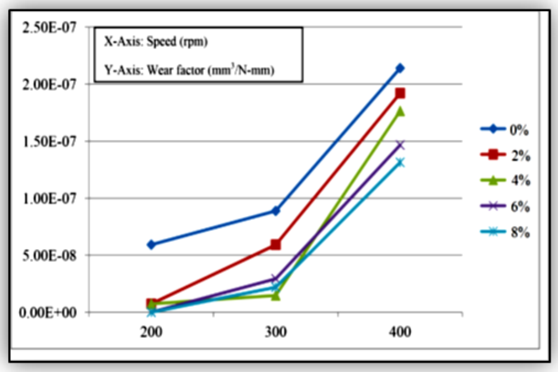

Fig.8 Wear factor v/s speed at 50 N [19]

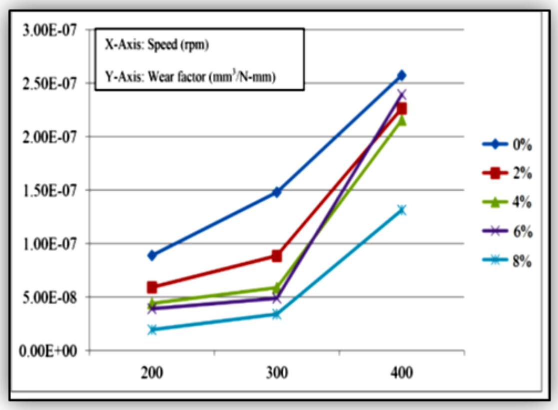

Fig.9 Wear factor v/s speed at 75 N [19]

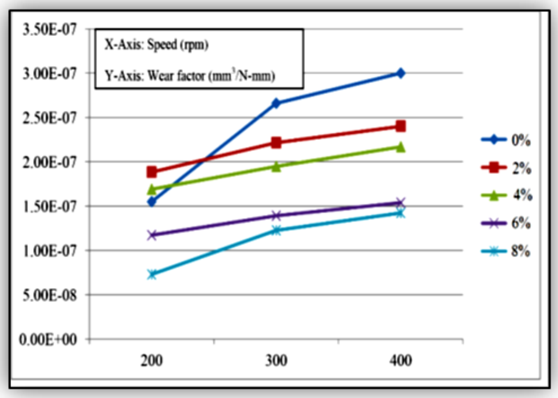

Fig.10 Wear factor v/s speed at 100 N [19]

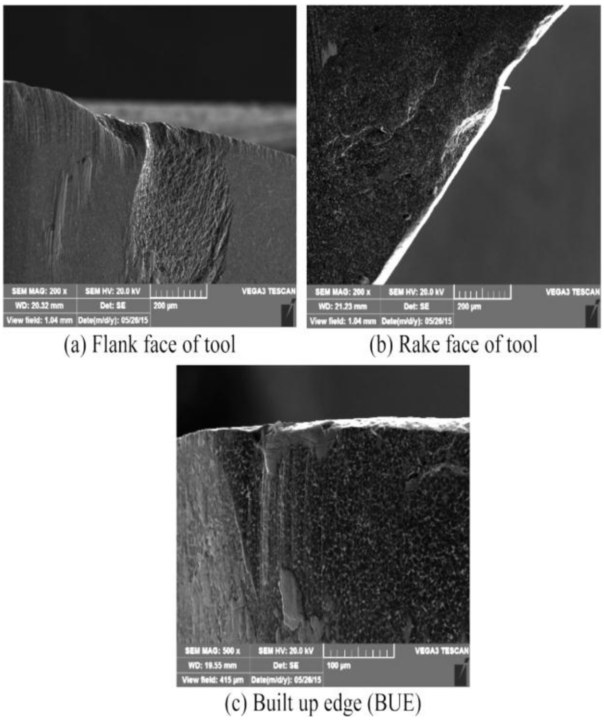

Fig.11 SEM images of PCD tool [19]

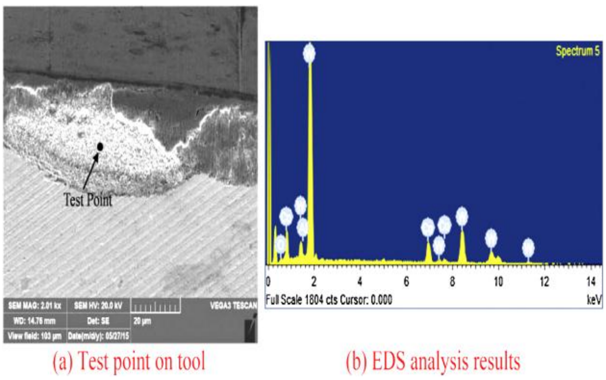

Fig.12 Diffusion wears on tool edge [19]

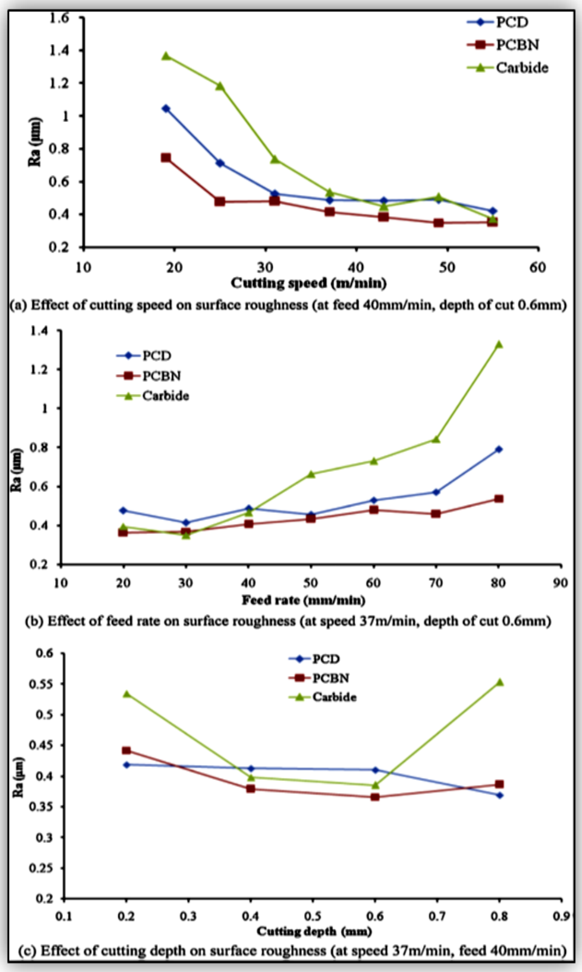

Fig.13 Influence of cutting parameters on surface roughness [19]

AMMCs reinforced with Silicon carbide particle (SiC-p) (5, 10 and 15 wt. %) is fabricated and the machinability studies were done by using conventional universal lathe and the cutting tools used are hard carbide coated with TiN. Under dry cutting process the machining tests were conducted. The sequel of criteria for machining, such as depth of cut, velocity of cutting and feed rate on surface unevenness and tool abrasion was studied. A higher tool wear is produced due to higher SiC-p reinforcement; velocity of cutting and feed rate generally affects the gruffness [20].

TiB_2 particle reinforced aluminum matrix composites (TiB_2/Al MMCs) was fabricated and the machinability studies were done. The influence of TiB_2 particles on the machinability of TiB_2/Al MMCs was investigated experimentally. Beyond which, the optimal machining conditions for this kind of MMCs were investigated. The results concludes that the machining force of TiB_2/Al MMCs is bigger than that of non-reinforced alloy but its control is governed by means of feed rate; non-reinforced alloy exhibits neutral residual stress but in case of TiB_2/Al MMCs it is in the form of compression; with the similar cutting speed surface roughness is smaller for TiB_2/Al MMCs when compared to non-reinforced alloy. While the feed rate increases the results observed were vice versa; the optimal set of combinational parameters was obtained by establishing a multipurpose development model for MMR and gruffness. In distinction to the results it is shown that a huge difference exists between SiC reinforced MMCs and TiB_2 reinforced MMCs, which further gives important guidelines for one step ahead controlling of machining of TiB_2/Al MMCs [19]. Figure 15 shows Pareto optimal solutions.

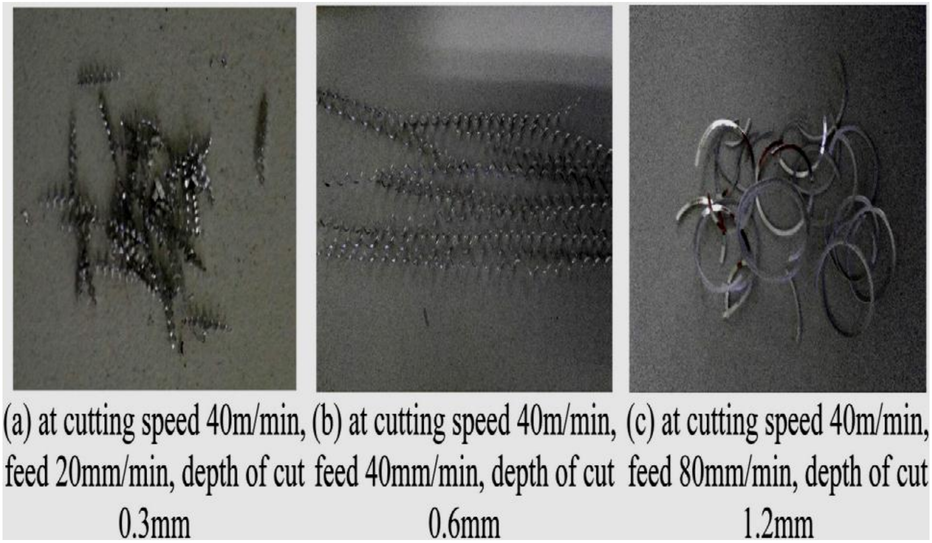

Fig.14 Chip shapes of MMCs at different cutting parameters [19]

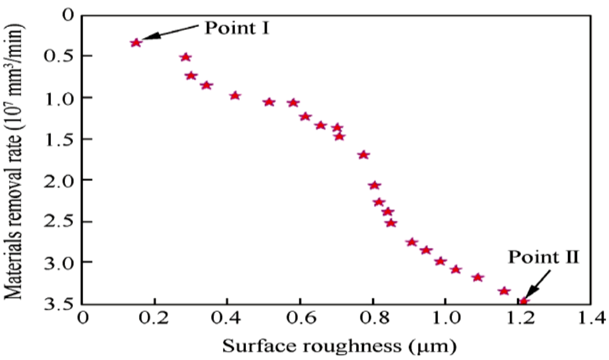

Fig.15 Pareto optimal solutions [19]

AMMC reinforced with silicon carbide particulates were fabricated and by utilizing rhombic tools that are fixed, the machinability study was conducted. During experimentation, the investigation involving impel of machining criteria namely feed, depth of cut as well as cutting speed upon the surface finish and the cutting force were done. In addition to this the investigation of the combined effect of cutting speed and feed on the flank wear was done during experimentation. Analysis regarding impel of tool travel per revolution of part, depth of cut as well as cutting speed on edges where chips been built up (BUEs) and tool wear has been performed. Utilizing SEM micrographs examination of the BUE and flake formation at multifarious sets of examination was done. Based on the results, it shows that at the time of machining Al/SiC-MMC, keeping depth of cut as low and speed as high formation of BUE is null. From the test results revealed and various SEM graphs appropriate cutting speed, range of feed and depth of cut can be picked for proper machining of Al/SiC-MMC [21].

The machinability studies on boron carbide (B_4C) reinforced the aluminum 6061 metal matrix composite was carried out [22]. Four compounded specimen with each different weight percentage of B_4C, 5-20 wt.% were fabricated using a powder metallurgy and hot-extrusion method. The milling tests with an uncoated carbide insert under compressed-air cooling and dry conditions were conducted to elicit the impact of B_4C quantity on energy consumption and surface nature for multifarious cutting parameters Based on the Taguchi mixed-orthogonal-array for experiments, L_{16}. Review of the obtained results indicates that, subsequent to the milling operation performed on all composites materials at under dry machining conditions, lower cutting feed and higher milling speed, magnificent surface quality is acquired and the elevating content of B_4C in the matrix exhibits the improved surface finish. Surface roughness and the power consumption increases when cooled with compressed air [22].

6. CONCLUSION

This paper presents a review of influence of reinforcements in aluminium metal matrix composites through different fabrication techniques. The outcomes of the review are:

1. At optimum stirring speed in stir casting technique (liquid metallurgy) the composite produced has lower porosity and matrix with homogeneously distributed reinforcement particles. Therefore density regarding composite is been increased.
2. Discontinuously reinforced MMCs are being fabricated by Compo-casting which is one of the most economical methods. Despite, it cannot be used for the fabrication of continuous fiber reinforced composites.
3. The wear property of the composite is enhanced with increase in reinforced ceramic particulate weight percentage.
4. Machinability study reveals that AMMCs with optimal speed, feed rate and depth of cut the machining of composite can be done economically with increased tool life by reducing tool wear and better surface finish. To obtain lower power consumption and increased MMR with less force of cutting advanced tools for cutting is needed.
5. Wettability of reinforcement with matrix is the also the most important factor in fabricating composites.

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