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Comprehensive study on Mechanical Property of Metal Matrix Composite

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Abstract

Composites materials are materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure. Basically, they can be categorized into two major types, i.e., structural composites with outstanding mechanical properties and functional composites with various outstanding physical, chemical or electrochemical properties. Metal matrix composites are ahead extensive approval for automobile, aerospace, agriculture farm machinery and many other industrial applications because of their essential properties such as high strength, low density, good wear resistance compared to any other metal. Metal matrix composite can be manufactured by various manufacturing techniques such as stir casting, powder metallurgy, pressure infiltration, squeeze casting, chemical vapor deposition etc. Reinforced material has an individual property which when incorporate to improve the properties of the base alloy. The reinforcements being used are whiskers, fibers, and particulates. An effort has been made to review the different combinations of the composites and how they affect the properties of the different alloys of aluminium. A comprehensive knowledge of the properties is provided in order to have an overall study of the composites and the best results can be employed for the further development of the Aluminium reinforced composed. This investigation shows that monolithic materials are highly replaced by metal matrix composites for better performance and longer life.

Key Words: Aluminium; Reinforcement, Stir Casting

INTRODUCTION

Materials are often defined as a mixture of two or more materials that leads to better properties than those of the individual components used alone (Campbell, 2010). It is a combination of two or more materials – often ones that have very different properties. Composites are materials during which two phases are combined, usually with strong interfaces between them. They usually consist of a continuous phase called the matrix and discontinuous phase in the form of fibers, whiskers or particles called the reinforcement. The two materials work together to give the composite unique properties (science, 2016). In another way it is formed from two or more different properties of materials are added in order to improve the properties of the materials for specific and general needs. Composites are the most favorable material of the recent highly improved technology of materials. Nowadays, the concept of mixing two dissimilar materials has gained much attention due to the providing of unique properties. The most commonly used metal matrix is aluminium, magnesium, titanium and their alloys and the reinforced materials are silicon carbide, graphite, fly ash, particulate alumina, red mud, cow dung, rice husk etc. Aluminium matrix composites are the composites in which aluminium is used as the matrix and several reinforced materials are embedded into the matrix (Rohit Sharma, 2017). Aluminium matrix composite are in claim due to their flexible properties like low density, high specific strength, high damping capacity, high thermal conductivity, high specific modulus, and high abrasion and wear resistance, low density, good mechanical properties, low thermal coefficient of expansion, better corrosion resistance, high strength to weight ratio and high temperature resistance etc. also, It provides lesser wear resistance when compared to steel and hence it is widely used as a matrix metal.

Additionally, a hybrid metal matrix composite comprises of three or more composites mixed with the matrix. Stir casting, powder metallurgy, pressure infiltration, squeeze casting, chemical vapor deposition etc. are the manufacturing techniques of metal matrix composites. From all the processes, stir casting is the most common method used by the researchers. In general, the matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix.

Applications of metal matrix composite

Applications of composite materials include aerospace, transportation, construction, marine goods, sports equipment, and more recently infrastructure, with construction and transportation being the largest. In general, high-performance but more costly continuous-carbon-fiber composites are used where high strength and stiffness along with light weight are required, and much lower-cost fiberglass composites are used in less demanding applications where weight is not as critical. Corrosion is a major headache and expense for the marine industry. Composites help minimize these problems, primarily because they are doing not corrode like metals or rot like wood. Using composites to enhance the infrastructure of our roads and bridges may be a relatively new, exciting application. Many of the world's roads and bridges are badly corroded and in need of continual maintenance or replacement. Wind power is the world's fastest-growing energy source. The blades for giant wind turbines are normally made from composites to enhance electricity generation efficiency. Advanced composites are a diversified and growing industry due to their distinct advantages over competing metallic, including lighter weight, higher performance, and corrosion resistance. They are utilized in aerospace, automotive, marine, sporting goods, and, more recently, infrastructure applications. The major disadvantage of composites is their high cost. However, the proper selection of materials (fiber and matrix), product forms, and processes can have a major impact on the cost of the finished part (Campbell, 2010).

Stir Casting

Stir casting technique is the most commercial method of production of metal matrix composites. There are several factors that need to be considered in using stir casting techniques, including: Difficulty in uniform distribution of the reinforcement material, Wettability between the two main substances, Porosity in the cast metal matrix composites, and Chemical reactions between the reinforcement material and the matrix alloy (Rohit Sharma1, Feb -2017). In this method, the reinforced particulate is mixed into the aluminium melt by mechanical stirring. After mixing, the molten metal is directly transferred to a shaped mold prior to complete solidification. The big deal is to bring a good wetting between particulate reinforcement and aluminium melt. Distribution of reinforcement depends on the geometry of the stirrer, melt temperature, string time and the position of the stirrer in the melt. An improved conventional stir casting method is two-step or double stir casting process. Here, the matrix material is heated to above its liquids temperature and then cooled down to a temperature to keep in a semi-solid state. And the preheated reinforcement materials are added and mixed with a mechanical stirrer. Again the slurry is heated to a liquids state and mixed carefully. This two-step process gives more uniform microstructure as compared of conventional stirring. A recent development in stir casting is three step stir casting for the fabrication of nanoparticle reinforced composite. In this method, first, the Al particles and reinforcement are mixed using ball milling process to interrupt down the initial clustering of nanoparticles. Then the composite powder is mixed with melt by mechanical stirring.

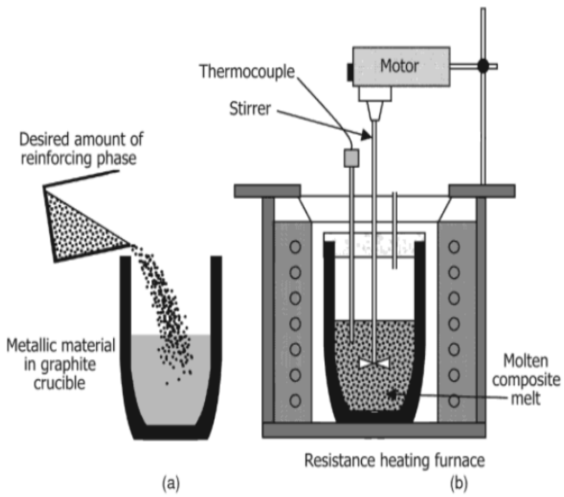

Figure 1: A schematic diagram showing (a) incorporation of reinforcing phase into Matrix metallic material (b) the stir casting setup (Gupta, 2011.)

2. MECHANICAL PROPERTIES

The metal matrix composites have several effects on the mechanical, electrical, thermal and other property of materials. Analysis on those properties tends to make the study of composites in depth. The various mechanical properties that are considered in this study are as follows:

2.1. Hardness

Hardness is resistance of material to plastic deformation caused by indentation.

J. Hasim et al. investigated Aluminium alloy A359 with silicon carbide (SiC) with5-25% vol. SiC, by two step Stir Casting method. The study successfully measures the hardness of the composites and the study had successful fabricate aluminium matrix composite by using the stir casting method (Hashim, 1999.).

Siddique et al had investigated the indentation hardness on Aluminium-Silicon carbide with p-bond composite. The particle size of 74 microns of silicon carbide corresponding to 200 meshes had been taken. It was found from the results that with the increase in silicon carbide, the hardness value of the metal matrix composite increased extremely. The hardness increased by two times with weight fraction of 9% silicon carbide when compared to that of the pure form of aluminium (Ramnath, 2014).

Bindumadhavan *et al.* (2001), experimented Al alloy (356) reinforced with 15% SiC small and large particle sizes they used for study. The study used Stir casting techniques for the formation of the mixtures. The study had measured the Hardness of the composites. From the result, the hardness of the composite increased with the SiC content (Bindumadhavan, 2001). Kok-.K (2005) et al. successfully studied Aluminium alloy reinforced with three different sizes and weight fractions of Al2O3 particles up to 30 wt.%. The methods of studied were stir casting Vortex method and subsequent applied pressure the study successfully measures hardness of the composites. The hardness of the composites increased with decreasing size of the particles and increasing weight fraction of particles (Baradeswaran, 2014). Pathak *et al. in* (2006) had investigated Aluminium- alloy reinforced with 0.6, 1.5 and 2.2% SiC particles using stir casting method. And successfully measures the Hardness of the composites. From the study the increased the hardness of the matrix alloys with the incorporation of silicon carbide (Pawar, 2014.).

Sudarshan and Surappa in (2008) studied about A356-Al composites containing 6 and 12 Vol. % fly ash particles, they used stir casting methods for the production of it. And the study had highly measures the mechanical property of the composite. Increased volume percentage of the reinforcement increased the porosity due to the long processing time. So, the study we observed that substantial increase in both the bulk hardness and micro hardness due to addition of fly ash (Surappa, 2008.).

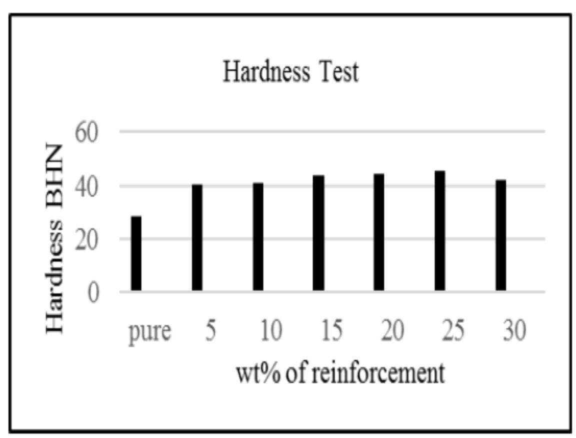

Figure 2: Variation of Hardness with wt. % of SiC (Rohit Sharma, 2017)

The above figure shows the hardness value of the composite from various wt% of silicon carbide in Aluminium matrix. From figure, we observe two things in common. The first is increasing the hardness value up to 25% and the second is decreasing after 25%. It reasons might be due to that when we increase the percentage of reinforced particles, the porosity of the composites also increases. The increasing the reinforcement particles beyond the 15-20% may highly reduce the hardness of the composite because it creates a big spot on the materials. So when we indent the newly invented materials, it indents softly that means hardness value is comparatively less. So in general, it is clear that silicon carbide or any other reinforced materials increasing the hardness of the composite. I.e. the addition of the reinforcements shows an increase in the hardness up to a certain range after which they tend to decrease.

2.2 Tensile strength

Tensile properties indicate how the material will react to forces being applied in tension. Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, reduction in area, tensile strength, yield point, yield strength and other tensile properties. A tensile test is a fundamental mechanical test where a carefully prepared specimen is loaded in a very controlled manner while measuring the applied load and the elongation of the specimen over some distance.

The study conducted by Rhaman (Rahman, 2014.) showed that the 20% weight fraction of silicon carbide in the aluminium matrix has the maximum tensile strength. The reason for the increase in the tensile strength is due to the tensile load transfer to the strongly bonded silicon carbide reinforcement which increases the dislocation density and thus resulting in the grain refining effect. The results of the tensile test on Al6061 reinforcement with silicon carbide and particulates of graphite showed that Al6061-graphite was having higher tensile strength than Al6061-silicon carbide. This is due to the high strength possessed by the filler graphite. Interestingly, at 12% weight fraction, the lastingness remained same thanks to poor wetting of graphite.

Kok-.K et al. in (2005), studies on Aluminium alloy reinforced with three different sizes and weight fractions of Al2O3particles up to 30 wt.%. The study was on stir casting Vortex method and subsequent applied pressure; it was on the improvement of Mechanical properties of Tensile strength, Porosity. The lastingness of the composites increased with decreasing size and increasing weight fraction of particles. When we say this, the increasing of tensile is highly dependent on the porosity of the composite.

Kumar et al. in (2012) studied on Al6061 reinforced with incorporation of 2- 6 wt. % of SiC using Stir casting methods. The studies were about the increasing of tensile strength of the composite. From the result he observed that, when the percentage of the incorporation increases, the tensile strength of the composite also increase up to a certain limit. In general, tensile strength increased with the filler content, the composite with 6 wt. % reinforcement exhibited superior mechanical and tribological properties (Kumar, 2012.).

Muruganandan et al. studies on the combination of Al7075 with fly ash and titanium carbide. From his study, he get that the reinforced aluminium alloy had 32% more tensile strength than the pure form of aluminium. And we observed that the increasing of the reinforced materials also the increasing of the tensile strength of the composite materials (P. Muruganandhan, 2015)

Aigbodian et al (Aigbodion, 2007) successfully studied about the composite of Al-Si-Fe/Rice husk. From his study he observed that, at 10% of rice, maximum tensile strength value had recorded and it comes to decreases after 10wt% of flyash.

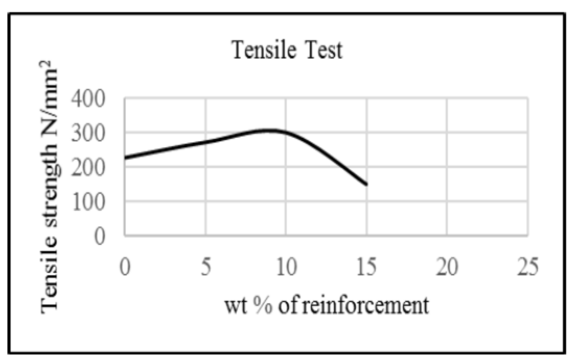

Figure 3.Tensile strength variation with wt. % of fly ash (Sharma, 2017)

From above figure, figure 2, shows the hybrid composite aluminium alloy (Al7075), fly ash and titanium bromide. So from the figure we observed that, the tensile strength of the composite is increased with increase in the wt. % of fly ash and TiB2 in the case of Al7075 reinforced hybrid composites. The highest tensile strength value obtained 301 N/mm2 at 10 wt. % of reinforcement. Actually here, it is possible to observe more than this value. But due to so many causes, the highest tensile strength value is recorded in this point. The ultimate tensile strength of a composite is affected not only by the particle and matrix fraction but also the micro geometry of the composite components.

2.3 Compression Test

Compression test is performed on Universal Testing Machine. A compression test may be a method for determining the behavior of materials under a compressive load. it is conducted by loading the test specimen between two plates and then apply a force to the specimen by moving the crossheads together. This test determines elastic limit, proportionality limit, yield strength and compressive strength, yield point. It is the utmost compressive stress that a cloth is capable of withstanding without fracture.

Table 1: Compression strength of hybrid composite material

No	Designation of specimen	Compressive load (KN)	Compressive strength (MPa)
1	Pure Al356	53.4	679.91
2	Al356 + 2%fly ash + 2%Al_2O_3	50	636.62
3	Al356 + 4%fly ash + 4%Al_2O_3	57.95	737.84
4	Al356 + 6%fly ash + 6%Al_2O_3	59.6	758.85
5	Al356 + 8%fly ash + 8%Al_2O_3	60.23	766.56
6	Al356 + 10%fly ash + 10% Al_2O_3	62.56	761.98

The table shows the compressive strength of hybrid composite materials. From the table, When we increase the incorporation of Al2O3 (alumina) in to the comparative aluminium (Al356), the compressive strength of composite materials is increases. The increasing of the compressive strength is depends on how match the compressive load is applied on the materials. Again the result of the newly invented composite materials shows, the increasing of the compressive strength of the composite materials is up to limited points. From the table, the compressive strength of the materials is increasing up to 8% the incorporation of alumina. But at 10% incorporation of alumina, the compressive strength is comes to decreasing. As a result, when we increase the alumina above 8%, the compression strength is comes to lower and lower. So the above data, we conclude that, the increasing of the reinforcement of the materials in to the matrix especially in metal matrix composite, it lowers the compressive strength of the materials.

The following graph shows the compressive result of matrix composite of the combined one and the pure aluminium.

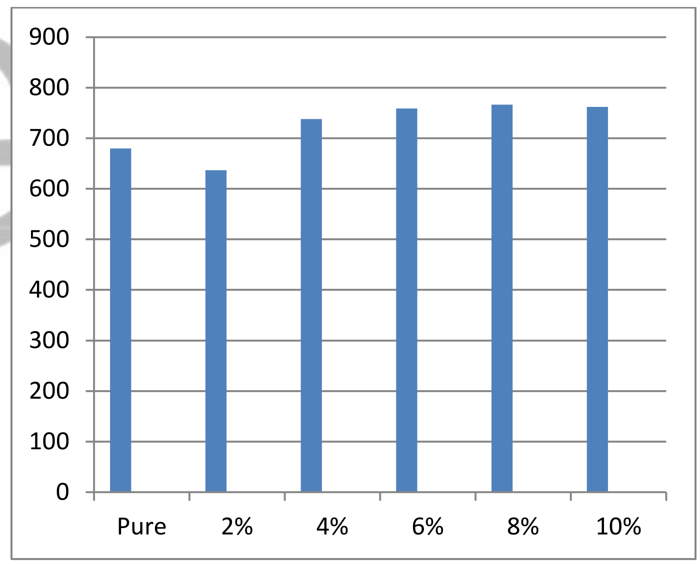

Figure 4 compressive result of pure aluminium and the combined one.

Microstructure Analysis

Microstructure is the structure of a prepared surface or thin foil of fabric as revealed by a microscope above 25× magnification. it is strongly influence physical properties like strength, toughness, ductility, hardness, corrosion resistance, high /low temperature behavior, wear resistance, and so on. Han Jian-min et al in. (2006) studied on Aluminium alloy (Al356) with 10% and 20% SiC vol. particles the study was used improved Stir Casting method. The study was about the finding of Microstructures of the cast composites. In the study, Microstructure of the cast composites revealed three phases of the composites e.g. α-Al, eutectic structures and SiC particles are located predominantly in the inter-dendritic regions. The growth of α-Al nuclei led to enrichment of SiC in the melt around the particles. The interface formation between SiC and the matrix was confirmed by the interface reaction products such as Al4C3 which was also detected experimentally. An improved stir casting process is established for fabricating SiCp/A356 composites with good mechanical properties and fewer defects (Han J. W., 2006.)

Mondal et al. in (2006) Al–Si alloy (ADC- 12) with SiC the study was used Stir casting methods. In the study they used to see the Microstructural structural of the newly invented materials. He get the Transition in wear mechanism from microcutting/ ploughing dominated to micro-cracking and -fracturing dominated wear happened when abrasive size increased from 100 to 120 mm (Mondal, 2006.).

Sreenivasan et al. in (2011) Al 6061 alloy reinforced with 5, 10, 15%TiB2. The methods of production were using the Stir casting methods. The study was about on Microstructure and Wear behavior at different loads and speeds of the composite. The microstructure revealed the segregation of TiB2 particles in the interdendritic region as rejected by the α-aluminium dendrites. (Sreenivasan, 2011.)

Toptan et al. in (2012) successfully study Al alloy reinforced with 15 and 19% B4C using Squeeze casting route at low vacuum. The finding was with help of Micro-structural features. The homogeneous distribution of the B4C particle with decreased porosity was attributed to the addition of Titanium containing flux which promoted the wetting between B4C and liquid aluminium metal was observed from the microstructural evaluation of it (Toptan, 2012).

The following images show the incorporation of alumina in aluminium alloy (Al6063). From the image we observed clearly that, there is an interaction between the alumina and aluminium composites. The SEM images shows formation of grain boundaries and the structures show loosely formed grains with Unmodified Vermicular. The white grains show the silicon segregation in arranged manner of dendrites leading to "shrinkage prone site". Sometimes, from SEM image we may observe defects. Casting has all the following defects like shrinkage, gas holes & inclusions. Those defects come from different factors like, mixing speed, time and condition are some of the basic causes. Porosity and its effects on mechanical properties of composite have been the matter of several studies results. So, in general tensile properties decrease with an increase in porosity content. The following figure (figure 5, 6 and 7) SEM images show the incorporation of alumina in aluminium alloys.

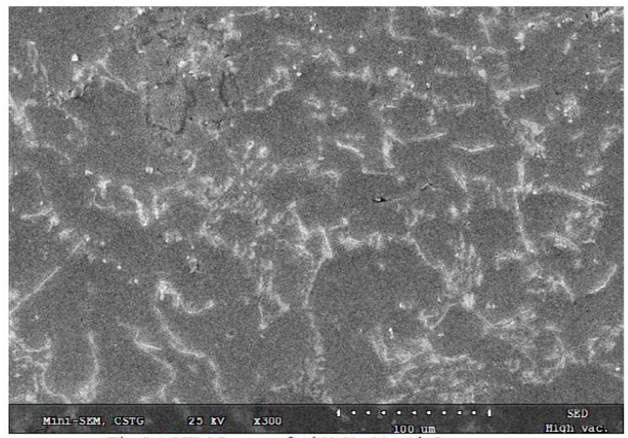

Fig.5 SEM Image of Al6063+9% Al_2O_3

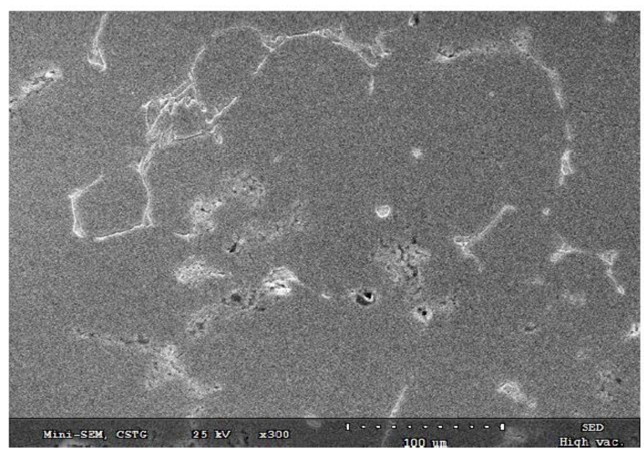

Fig. 6 SEM Image of Al6063+3% Al_2O_3

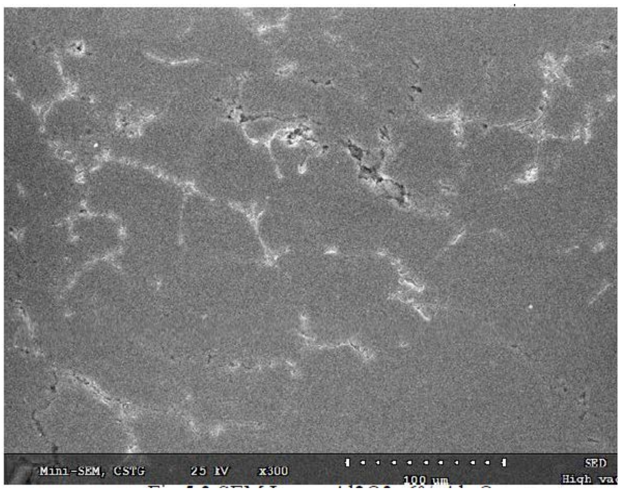

Fig 7 SEM Image Al_2O_3+6% Al_2O_3

Figure 5, 6 and 7 are shows the incorporation of alumina in aluminium (K.Hemalatha, 2013)

CONCLUSION

The study of this paper is to have a wider view of the production and result of newly invented composite materials from diverse levels of aluminum and its incorporation. The selection criteria for necessary properties depend on the properties of the selection of materials such as low density, good fatigue performance, and high wear and corrosion resistance are seen as general necessities for efficient performance in the industry. So, this paper makes a case for metal matrix composite and its application in numerous methods of production by exploring its properties. The papers also tell about the different results from the combination of aluminum with diver's weight percentage of incorporation of reinforcement materials.

The following points are addressed from the study: Hardness shows the best results when silicon carbide is employed at 25% weight percent. Hardness increases with the increasing of the incorporated of silicon carbide but decreases beyond 25 weight percent of silicon carbide. To obtain an optimum hardness of the desired number, both the reinforced and the matrix material can be used in proper proportions. Similarly, the highest tensile strength value obtained is 301 N/mm^2 at 10 wt. %. And it comes to decreases above 10% of the incorporation. Also for the improvement of compressive strength, fly ash particles are the most appropriate ones as it indurates the base alloy. The compressive strength of hybrid composite materials is drawn in the figure and it shows the compressive strength of the materials is decreasing after the limited points after 8% of alumina. In general, Uniform distribution of the reinforced materials in the base materials plays a great roll in the structure and properties of composite materials.

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