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A Review on Effect of Silicon Carbide and Graphene Reinforcement on Aluminium Matrix Composite

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Abstract— In modern day technology composites are the most promising material of interest. In this paper an attempt has been made to consolidate some effect on the properties of the individual and multiple effect of aluminium and reinforcement metal composites are discussed. Each reinforced material has an individual property which when added improves the properties of the base material. The addition of reinforcements in Aluminum matrix improves mechanical properties mainly discussing on Hardness and tensile strength. The results of research show that the hybrid composites possess higher hardness, higher tensile strength, better wear resistance and lower coefficient of friction when compared to pure alloys. Many researchers gone through different experiments with adding different reinforcement materials and results in different property.

Keywords— Aluminium Metal Matrix Composite (AMC), reinforcement, Hardness, tensile strength.

I. INTRODUCTION

These are used to overcome the shortcomings of the conventional monolithic materials having limitations in the structural strength. A metal matrix composite (MMC) is a type of composite material where a metal matrix, typically a light alloy such as aluminium, magnesium, or titanium, is reinforced with another material, such as ceramic or metal fibres, particles, or whiskers. The purpose of incorporating the reinforcement is to enhance the mechanical, thermal, or physical properties of the base metal. The metal matrix provides strength, ductility, and toughness, while the reinforcement improves specific properties like stiffness, wear resistance, thermal conductivity, or dimensional stability. These Aluminium Metal Matrix composites with multiple reinforcements (hybrid MMCs) are finding increased applications in the transport, aerospace, marine, automobile and mineral processing industries, because of improved mechanical and tribological properties and hence are better substitutes for single reinforced composites. The widely used reinforcing materials for these composites are silicon carbide, aluminium oxide and graphite in the form of particles or whiskers. The fabrication of metal matrix composites involves techniques like powder metallurgy, liquid metal infiltration, and stir casting [6]. These methods allow the uniform dispersion of reinforcement within the metal matrix, ensuring good bonding and mechanical properties.

II. COMPOSITES

A composite is a structural material, which consist of combining two or more constituents in order to obtain a combination of properties that cannot be achieved with any of the constituents acting alone.

Composite materials have two phases, the reinforcing and matrix, for the matrix phase, ceramic's metals or polymers utilized, and for reinforcing phase Fibers, Particles utilized [2]

A. *Types of Composite Material*

Classification of composites was mainly into three groups based on matrix material i.e. metal matrix composites (MMCs), polymer matrix composites (PMCs), and ceramic matrix composites (CMCs), as shown in Fig 1.

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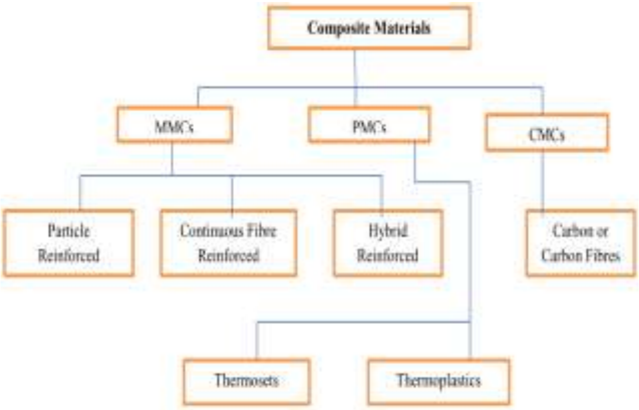

Fig. 1. Types of Composites materials [3]

PMCs are commonly used composite, from available composites. In PMCs, the matrix generally reinforced with ceramic fibers since they have high strength in comparison of the matrix material.

Ceramic Matrix Composites are a mixture of ceramic particulates, fibers and whiskers with a matrix of another ceramic and may be defined as solid materials that normally show highly strong bonding generally ionic, but in a few cases, it may be covalent. The ceramic matrix can be reinforced by ceramics, metals, glasses, and polymers.

These MMCs can be a perfect substitute of costly conventional alloys used for both structural and functional applications. Aluminum matrix composite is recommended for advanced structural applications [5].

B. *Aluminum Matrix Composites SiC Reinforcement*

Aluminium based matrix composites remain the most explored metal matrix material for the development of MMCs. When these composites reinforced with silicon carbide (SiC) particles have up to 20% improvement in yield strength, lower coefficient of thermal expansion, higher modulus of elasticity and more wear resistance than the corresponding non-reinforced matrix alloy systems Among all materials, composite materials have the potential to replace widely used steel and aluminium, and many times with better performance.

C. *Role of Additional Fillers*

The end properties of the AMCs depend upon the manufacturing process, matrix and reinforcing particles selected. The properties of AMCs are also dependent on parameters like the size of the fillers reinforced, morphology and the volume of fillers reinforced in the matrix [8].

1. Graphene Fillers:

Graphene (Gr) is an allotrope of carbon atom and a two-dimensional crystalline material. It is a basic single layer of a two-dimensional lattice assembly from sp2-hybridized (two-dimensional honeycomb structure) carbon atoms and has attracted considerable attention from past few years because of its unique thermal and mechanical properties [9]. Graphene has fracture strength of 130 GPa of Young's modulus of 1 TPa a low density of 1 g/cm3 and a large specific surface area which could make it an excellent reinforcement for metal matrix composites [10].

III. Fabrication of Composite

Composites are prepared by different processing techniques as shown in Fig 2.

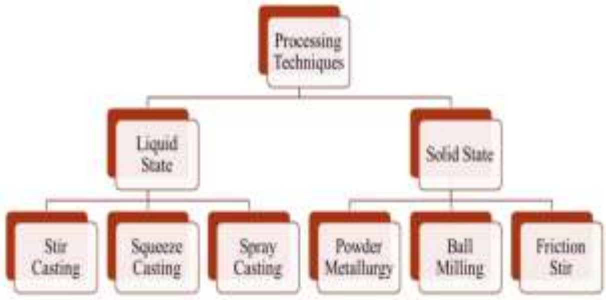

Fig. 2. Processing of Composites materials [2]

Metal matrix composites are generally produced either by Liquid State (LS) or Solid State (SS) like powder metallurgy etc. In LS the particulate phases are mechanically dispersed in the liquid phase before solidification of the melt. Stir casting technique is one of popular LS method and also known as a very promising route for manufacturing near net shape hybrid metal matrix composite components at economical cost [6].

Stir casting technique is simple and the most commercial method of production of metal matrix composites. In conventional stir casting method, reinforced particulate is mixed into the aluminium melt by mechanical stirring. Mechanical stirring is the most important element of this process. After the mechanical mixing, the molten metal is directly transferred to a shaped mould prior to complete solidification. The essential thing is to create the good wetting between particulate reinforcement and aluminium melt. The metal matrix was a grade aluminium alloy, with silicon carbide and graphene particles as reinforcement. Samples are made using a reinforcement ratio of wt. %. Later, distinct castings of fixed wt. % silicon carbide and wt. % graphene particles were introduced to molten aluminium alloy. To achieve a homogeneous dispersion of particles, the semiliquid mixture was agitated for around 10 minutes at a 450-rpm constant speed. After that, the semi-liquid mixture was put into a casting mould. The distribution of the reinforcement in the final solid depends on the wetting condition of the reinforcement with the melt, relative density, rate of solidification etc. Distribution of reinforcement depends on the geometry of the stirrer, melt temperature and the position of the stirrer in the melt. Fig. 3 shows a schematic diagram of stir casting process.

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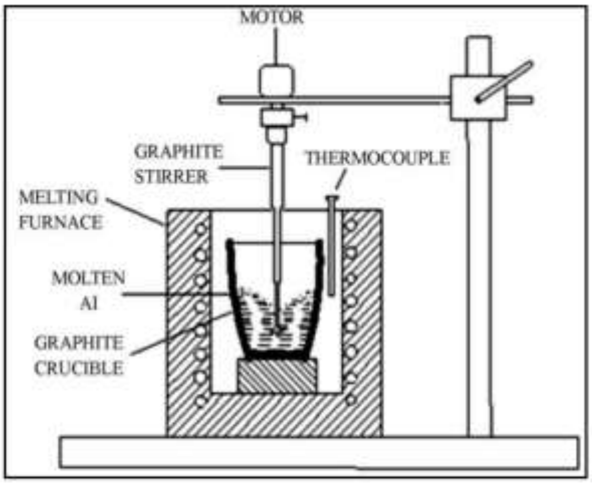

Fig. 3. Stir Casting Process [2]

The present study deals with the stir cast aluminium matrix composite regarding their enhanced properties such as mechanical and tribological.

IV. Effect of Reinforcement on Composite Properties

The aluminium metal matrix composites have various effects on the physical and mechanical properties with the addition of reinforcement, that impart many modern-day applications. Investigation on mechanical properties like hardness and strength tends to make the study of composites in depth. Some of the mechanical properties like hardness, compressive strength is considered in the present study.

A. Effect of SiC Reinforcement Materials on Microstructure of Aluminium Matrix Composites

Veeresh Kumar et al. (2010) observed a uniform distribution of reinforcing particles in Al 6063-SiC and Al7075-Al2O3 composites, processed through liquid metallurgy route (Fig. 4). A uniform distribution of SiC particles was observed in AA 7075/SiC composite, fabricated using stir casting method, at a stirring speed of 650 rpm and stirring time of 10 min (Bhushan and Kumar 2011). Vanarotti et al. (2012) observed a homogeneous distribution of SiC particles in the cast Al 356/SiC (5 and 10 wt.%) composites, fabricated by stir casting technique, under a metallurgical microscope.

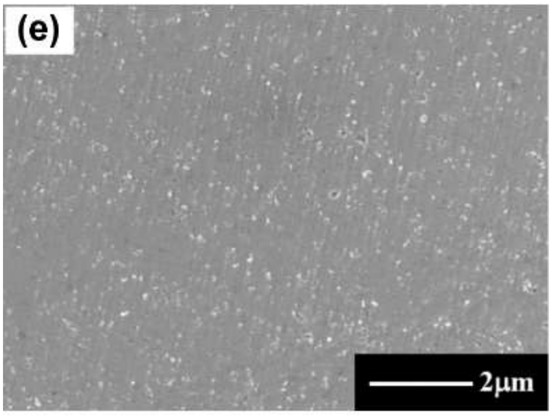

Fig. 4. SEM micrographs of composite Al-5 wt.% Sic (70- nm) [4]

Microstructural features of bamboo leaf ash (BLA)- and SiC-reinforced Al-Mg-Si alloy hybrid composites, fabricated by a two-step stir casting process, revealed good distribution of the reinforcing particles in the matrix with minimal particle clusters (Alaneme et al.2013). Boopathi et al. (2013) observed non-uniformity in the distribution of reinforced particles in the case of Al-SiC and Al-fly ash composites; however, their uniform distributions were observed in the micrographs of Al-SiC-fly ash hybrid composite, fabricated by stir casting technique. Umanath et al. (2013) observed a uniform distribution of ceramic reinforcements in Al 6061/SiC/Al2O3-T6 heat-treated hybrid metal matrix composites, processed by stir casting method.

B. Effect of Percentage Weight Fraction of SiC Reinforcement Materials on Hardness

Sahin and Murphy (1996) measured the Brinell hardness of Al 2014 alloy and that of SiC-coated unidirectional boron fibre-reinforced Al 2014 matrix composites and reported that the hardness increased linearly with increased volume percentage of reinforcements [7]. Jayaram and Biswas (1999) reported that porosity was the major influencing factor for the hardness of Al2O3 and SiC-reinforced Al composites. The hardness of the composite was observed to be decreased with the increase in porosity [7]. (Bhushan and Kumar 2011) reported that hardness increased by 10.48% with the increase in percentage of SiC reinforcement from 5 to 15 wt.% in AA 7075/SiC composite. Purohit et al [7]. observed that the Rockwell hardness of Al-SiCp composites increased with the increase in weight fraction of SiCp from 5 to 30 wt.% of SiCp. Vanarotti et al. observed that the Brinell hardness number of Al 356/SiC composite increased with the increasing weight fraction of SiC reinforcement in the matrix alloy. The BHN was observed to be 70 and 78 for 5 and 10 wt.% of SiC reinforcement, respectively.

From the above discussion, it is evident that weight fraction of silicon carbide plays an important role in increasing the hardness of the composite.

C. Effect of SiC Reinforcement Particle Size on Hardness of Aluminium Matrix Composites

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Figure 5. shows the effect of the SiC particle size and amount on the composite hardness. Considering this figure, by increasing the amount of SiC, composite hardness increases since its hardness is much higher than that of pure aluminium [8]. This fact can be easily analyzed through the rule of mixtures.

$$Hc = Hm*fm + Hr*fr \quad (1)$$

Hr, Hm and HC are the hardness of reinforcement, matrix and composite, where fr and fm are volume fraction of reinforcement and matrix, respectively. It was observed from this study that by increasing the amount of SiC from 0% to 10%, hardness increased from 40.3 to 52.8 HV. Apparently, the hardness of aluminum improves considerably with the additions of SiC particles at the expense of its ductility that can be attributed to higher hardness of SiC. This result was consistent with another research [8]. It is thought that higher quantity of ceramic particles in the matrix would result in more dislocations that increases the hardness of the composite [8]. Considering this figure also, it shows that decreasing the particle size will increase the composite hardness. Therefore, the average hardness of Al–SiC composite specimens with 70 nm SiC particles is higher than that of the Al–SiC composite specimens with 10 and 40 nm SiC particles. The reason for this increase can be examined from two perspectives. One is due to greater interfacial area between the hard and soft phases [5]. Secondly, the defects in the coarse-grained particles are more than the fine-grained ones which results in its easy fracture under tension.

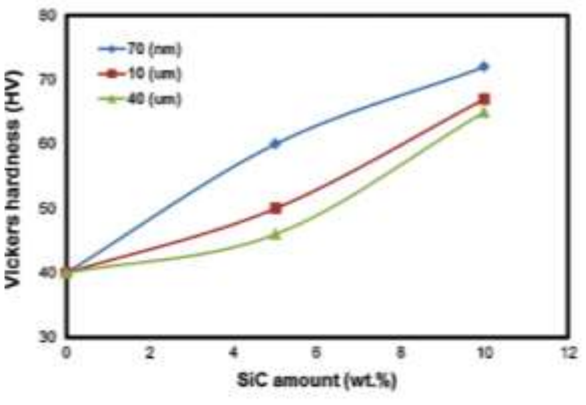

Fig. 5. The effect of SiC particle size and amount on AMC composite Hardness [8]

D. Effect of SiC Reinforcement Particle Size on Tensile Strength of Aluminium Matrix Composites

Young's modulus, yield stress, ultimate tensile strength and fracture stress of heat-treated SiCp-reinforced Al 2080 matrix composites were improved; however, percent elongation, percent reduction of area and tensile ductility were reduced with increasing reinforcement content, as reported by Srivatsan and Prakash (1995) [7]. Fractography analysis revealed that the presence of the hard and brittle SiC particles in the soft and ductile metal matrix caused initiation of fine microcracks at low values of applied stress. The microcracks had grown rapidly, resulting in macroscopic failure and low tensile ductility. Manoharan and Gupta (1999) reported that the ultimate tensile stress was increased and fracture strain was reduced with the increase in reinforcement content in the as-processed and extruded SiC-reinforced AA 1050 matrix composites. The yield strength first improved and then reduced with the increase in SiC content in the composite. However, all the properties tend to increase with decrease in the size of particles.

E. Effect of Percentage Weight Fraction of Graphene Reinforcement on Hardness

Fig. 6 shows that the Vickers hardness increases from Hv 131.5 (7055 aluminum alloy) to Hv 151.2 after the addition of 1 wt. % graphene plates. However, further addition of graphene is detrimental to the Vickers hardness. Obviously, the hardness of composite with 3 wt.% graphene (Hv 128.3) is lower than that of the pure alloy and reaches the lowest value at 5 wt. % graphene (Hv 98.6) [9].

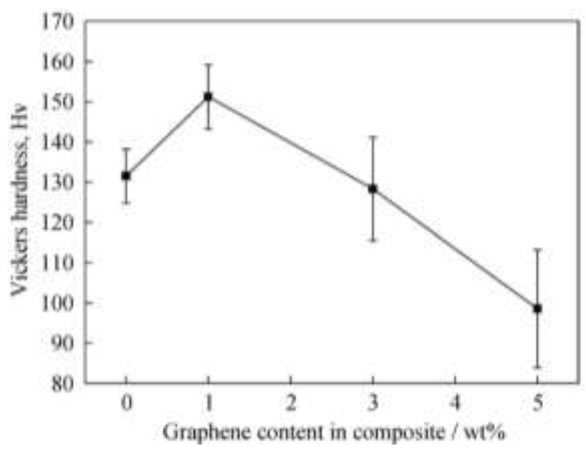

Fig. 6. The effect of Graphene weight percentage on sintered AMC composite on Hardness [9]

Hence, initially, the strength of Al increased with an increase in graphene content. However, the material properties started to deteriorate once they reached a critical level of graphene content because of the agglomeration issue

F. Effect of Percentage Weight of Graphene Reinforcement on Compressive Strength of Aluminum Matrix Composites

Typical compressive strength curves and the correlative results of the sintered composites are shown in Fig. 7. The composite with an addition of 1wt% graphene significantly improves the mechanical properties. The yield strength and compressive strength increase by 34.9% and 22.1%, respectively, compared to pure 7055 aluminum alloy [9].

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Graphene plates with such thicknesses would turn into graphite and lose their excellent mechanical properties, reducing the hardness of the composites significantly. The optimal addition amount of graphene depended on the processing technique, powder size, and metal type. Tang et al. [9] fabricated a 0.94 wt.% graphene-reinforced copper-nickel composite, the tensile strength of composites increased significantly and the ductility decreased compared to pure copper. Again, the further addition of graphene resulted in gaps between plates and reduced both of the strength and ductility.

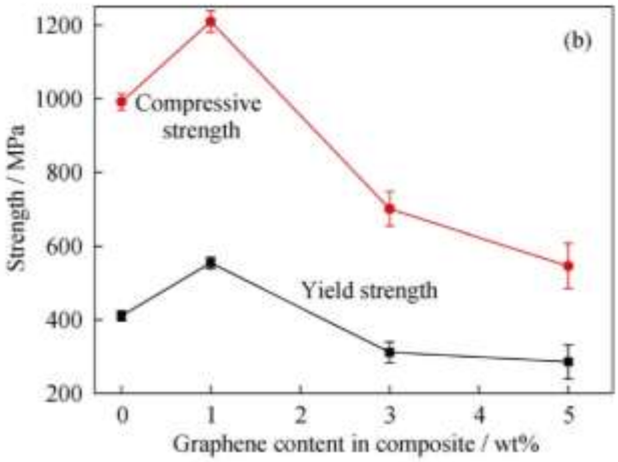

Fig. 7. The effect of Graphene weight percentage of sintered AMC composite on Strength [10]

G. Effect of SiC and Graphene Multiple Reinforcement on the Hardness of Aluminium Metal Matrix

Suresha and Sridhara (2012) observed that the Brinell hardness of LM 25-SiC-Gr hybrid composites increased up to 2.5% of combined equal percentage of reinforcement and then decreased (Fig. 8). The increase was due to the addition of SiC particulates, overriding the effect of Graphene particulates, and the decrease was due to the overriding effect of Graphene particulates, the addition of which reduced hardness as a consequence of the increase of porosity. However, Uvaraja and Natarajan (2012) reported that the Rockwell hardness of Al 7075/SiCp/B4C hybrid metal matrix composite (MMC) increased with the volume fraction of the particle reinforcement. Ravesh and Garg (2012) reported that the hardness of fly ash-SiC-reinforced hybrid aluminium composites increased with increasing volume fraction reinforcements. The Rockwell hardness on the C scale was observed to be 61, 70, 81 and 93 for 2.5%, 5%, 7.5% and 10% of SiC, respectively, with a constant 5% fly ash-reinforced hybrid Al 6061-T6-treated hybrid matrix composites. The hardness of the Al 7075-SiC composite was found to be increased with the increased volume percentage of ceramic particles (Veeresh Kumar et al. 2012)

Boopathi et al. (2013) evaluated the Brinell harness number of Al-SiC, Al-fly ash and Al-SiC-fly ash metal matrix composites and reported that aluminium in the presence of 10% of SiC and 10% of fly ash was the hardest instead of Al-SiC and Al-fly ash composites.

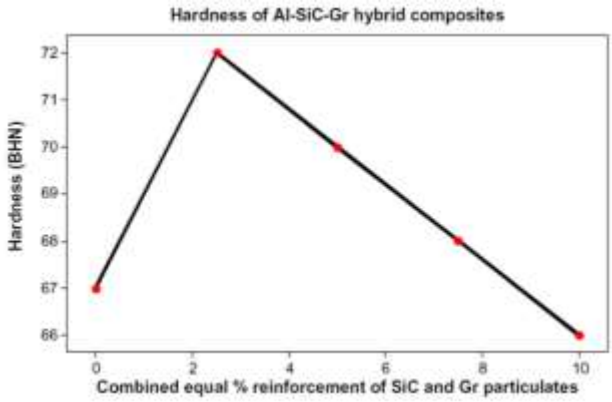

Fig. 8. Effect of percentage of reinforcement on the hardness of Al-SiC-Gr hybrid composites [7]

IV. CONCLUSIONS

In this paper, various composites and manufacturing process has been listed to strengthen different usage of AMMC's such as effect of reinforcement and manufacturing technique on mechanical properties. The effects of particle size and amount of reinforcement component on some properties of AMC were discussed. The following findings can be summarized:

1. The presence of Al and SiC were verified and according to SEM micrographs, as the SiC particles size decreases, the grain size and the distribution of reinforcement decreases.

2. As the amount of SiC particles increase, the composite's densification declines. Also, as the SiC particle size increases in the composite samples, densification increases.

3. Increasing the amount and reducing the size of SiC promote high hardness in the composite. The highest hardness of 72 HV is attributed to the sample containing 10 wt.% of SiC with 70 nm particle size.

4. The finer particle size of SiC presents greater compressive strength. By increasing the amount of SiC, compressive strength increases. The highest strength was 601 MPa, for the composite containing 10 wt.% SiC with 70 nm.

5. Apart from mechanical and tribological properties, thermal is one such area where the further research can be concentrated upon.

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