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Microstructure and Mechanical Properties of Si_3N_4 and Graphite Reinforced with Aluminium Hybrid Metal Matrix Composites

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Abstract— *Aluminium 2024 is taken as matrix due to its properties like high strength to weight ratio, good fatigue resistance. Silicon Nitride (Si_3N_4) is taken as reinforcement due to its properties like strength and fracture resistance under extreme operating condition and Graphite (Gr) is taken as reinforcement due to its properties like self lubricating and wear resistance. Silicon nitride is kept as constant and varying weight percentage of Graphite (2% and 4%). The composites were prepared using stir casting technique. The prepare composites are characterized by microstructure studies, hardness, density and tensile properties. The result reveals that fairly uniform distribution of reinforcement particles within the Al2024 alloy. The hardness and density of unreinforced alloy is compared with prepared hybrid-1, hybrid-2 and 6%wt of Si_3N_4 composites. The tensile strength and elongation unreinforced alloy is compared with hybrid-1, hybrid-2 and 6% wt of Si_3N_4 composites.*

Keywords*: Silicon nitride (Si_3N_4), Al2024, Graphite, stir casting, hybrid-1 and hybrid-2.*

1. INTRODUCTION

A composite material is a type of material composed with a combination of two or more constituent material work together to form a composite [1]. These constituent materials have significantly different physical, chemical and mechanical properties and remain separate at microscopic or macroscopic scale within finished product [2].Metal matrix composites are one of the important types in composites material due to their modified properties by the addition of reinforcement and their application in automobile and aerospace industries. In recent years particulate reinforced MMCs are widely used as reinforced material because of their specific strength and specific stiffness at elevated or room temperatures [3].In metal matrix composites the properties depends on microstructural parameters of the reinforcement material like shape, size, orientation, distribution and volume fraction within the matrix material [4].

In recent decades aluminium based MMCs have increasing interest as an engineering materials for many applications including automobile and aerospace processing industries because of their strength to weight ratio and excellent thermal conductivity properties [5]. Ceramic materials are introduced into metal matrix produces composite materials will results exceptional combination of physical and mechanical properties which cannot be obtained with monolithic alloys [4]. In recent decades aluminium alloy reinforced with ceramics particles because hardest material, high strength, high melting point and used at high temperature application. Some of ceramic materials are Al_2O_3, SiC, B_4C, Si_3N_4, TiB_2, graphite etc. The addition of reinforcement into the aluminium alloy properties of the composites are improved to certain extent [1-5]. The liquid metallurgy route is used for production of composites and most economical method due to its flexibility, simplicity and applicability for large production of composites. Stirring required for homogeneous distribution of fabricated metal matrix composites as that it is also called stir casting technique [5]. The objective is to learn the hardness and tensile properties of metal matrix composites. Investigated is done on tensile strength and hardness with addition of Al_2O_3 and graphite particles into aluminium alloy. The tensile strength of composites increases and hardness of composites decrease with increase the percentage of reinforcement particles increases [6].The present work an attempt is made to study the mechanical properties of Al2024 alloy and Al-2024/Si_3N_4/graphite composites.

2. EXPERIMENTAL DETAILS

2.1 Material

Aluminium 2024 alloy is used as matrix material and it is a 2xxx series alloy, major alloying element is copper commonly used as an aerospace and automobile material due to its properties such as good fatigue strength, weld ability and machine ability. The alloy was tested for Mechanical property, constituents if Al2024 is given in Table-1. The reinforcing material Silicon Nitride (Si_3N_4) and Graphite is taken for our research work. The properties of Al2024 and reinforcement materials are shown in Table-2.

Table 1: Constituent of Al2024 in Weight %

Cr	0.1 max
Cu	3.8- 4.9
Fe	0.5 max
Mg	1.2-1.8
Mn	0.3- 0.9
Si	0.5 max
Zn	0.25 max
Al	Remaining

Table 2: Properties of Al2024, $Si_3N_4$and Graphite

Material/Properties	Al-2024	Si3N4	Graphite
Density gm/cc	2.7	3.21	2.4
Tensile Strength (MPa)	207-220	360-434	4.8
Melting point (0C)	663	1900	1600
Elastic Modulus(GPa)	70-80	317	8-15
Hardness	71 VHN	2200Kg/mm2	----

2.2 Fabrication of composites

A stir casting technique has been used for fabrication of composites material. It is also called as Liquid metallurgy route. This method is most economical compared to other method available for fabrication of metal matrix composites [6].Resistance furnace was used for casting purpose as shown in Fig. 1. The crucible placed in a furnace it contained small piece of Al 2024 alloy. The temperature is raised aluminium alloy melt above its liquidus temperature of aluminum alloy. Preheated Si_3N_4 kept as constant (6%) and Graphite particles by varying weight percentage (2% and 4%) is added into molten Al alloy. Before adding reinforcement into molten Al alloy Hexachloroethane (C_2Cl_6) is added to remove the dissolved gases from liquid and then add cover flux to decrease of contact angle and surface tension forces and wettability of reinforcement increases. Add reinforcement particles separately first add graphite particles into matrix because graphite as less density than alloy and to reduce formation of slag. And then add Silicon nitride particles into alloy. During the addition reinforcement stirring is carried out with a speed of 200 rpm to get uniform distribution of reinforcement throughout matrix. The molten composite is poured into an already preheated circular permanent mould with diameter of 12mm.

Fig. 1: Resistance furnace

3. RESULT AND DISCUSSION

3.1 Microstructure study

The samples are polished by using silicon carbide paper of different grid size 220, 300, 600, 800, 1000 and 1200. Grinding was done in a step on each paper. After polishing the samples then buffing is done by using velvet cloth. The samples were etched with Keller's reagent to expose the grain structure. The polished surface was observed and capturing photograph using NIKON Epiphot 200 optical Metallurgical Microscope. The images are shown in Fig. 2(a)-(d).

In Fig. 2(a) reveals only Al matrix was present and reinforcement particles were absent in optical microscope image. In Fig. 2(b) reveals fairly uniform distribution of Si_3N_4 particles within Al-2024 alloy and also in Fig. 2(c) fine distribution of hybrid-1 reinforcement (Si_3N_4 and Graphite) particles within Al-2024 alloy. Finally in Fig. 2(d) hybrid-2 (Si_3N_4 and Graphite) reinforcement particles are distributed throughout matrix. All images were seen in 60µm magnification in optical microscope.

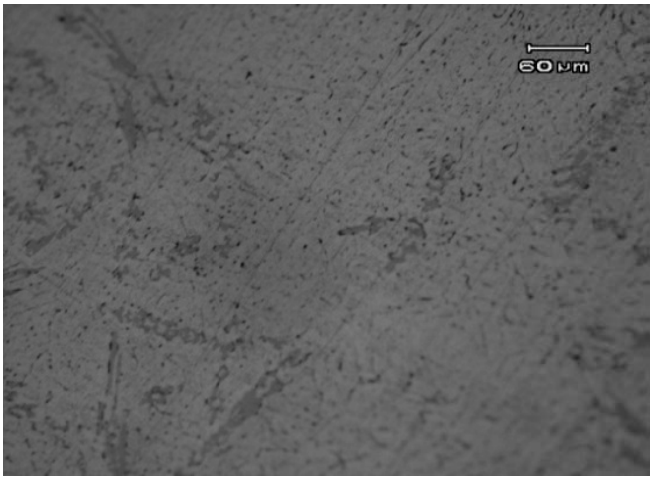

Fig. 2: (a) Al base alloy

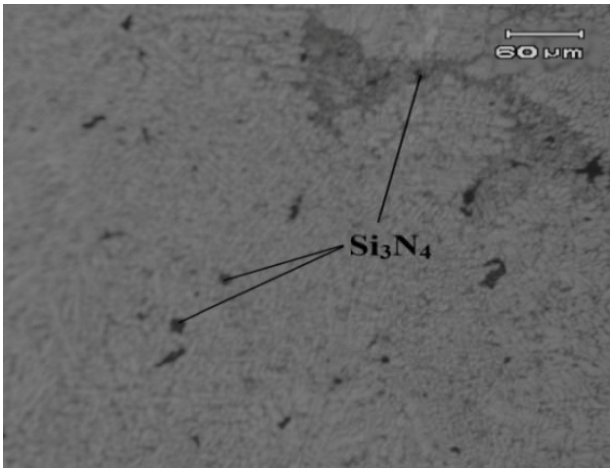

Fig. 2: (b) Al alloy + 6% Si_3N_4

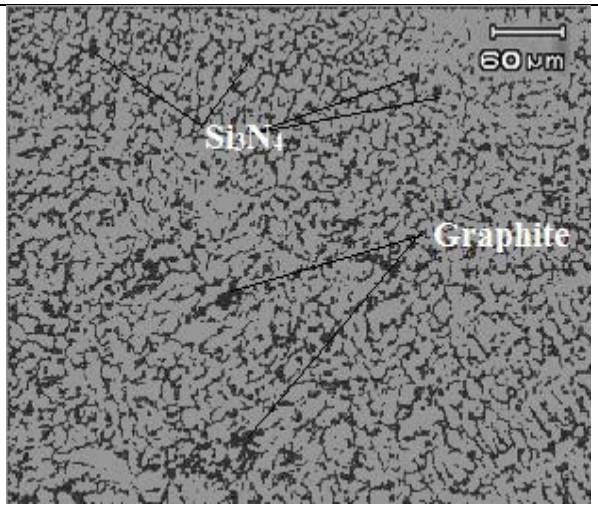

Fig. 2: (c) Al alloy + 6% Si_3N_4+2%Gr

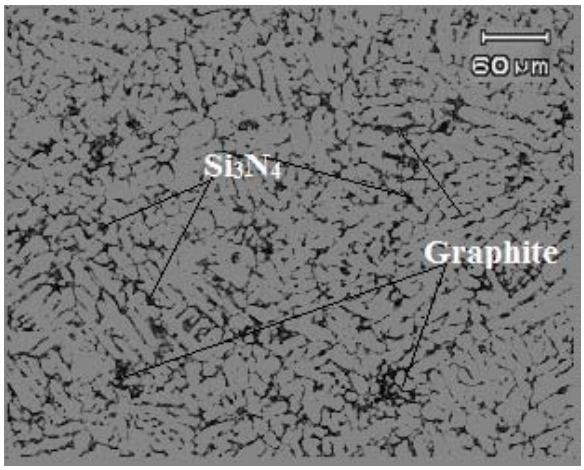

Fig. 2: (d) Al alloy + 6% Si_3N_4+4%Gr

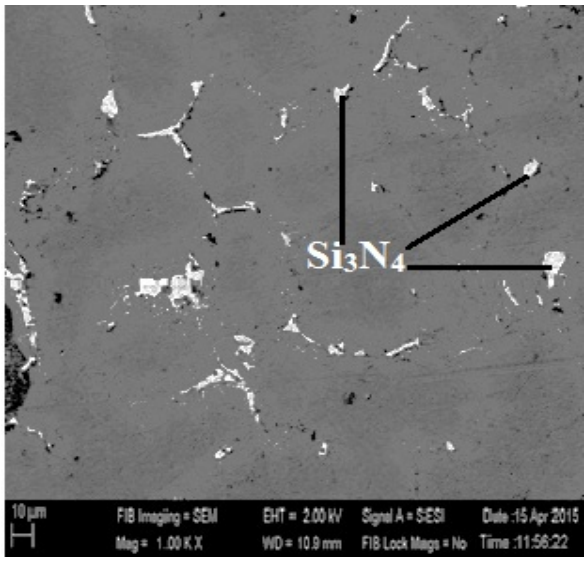

Fig. 3: (a) Al alloy + 6% Si_3N_4

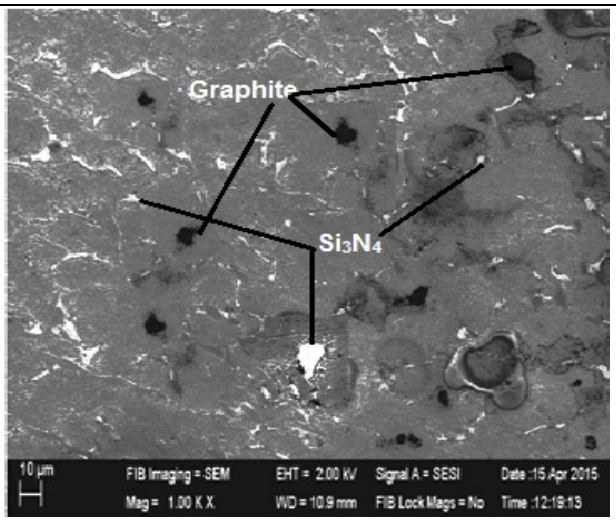

Fig. 3: (b) Al alloy + 6% Si_3N_4+2%Gr

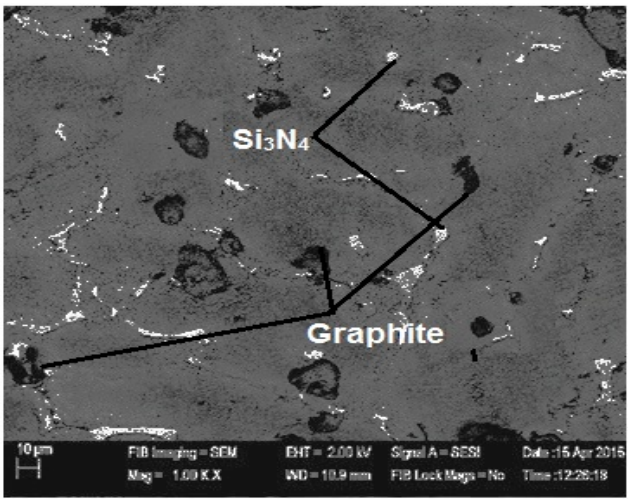

Fig. 3: (c) Al alloy + 6% Si_3N_4+4%Gr

The SEM is conducted in Central Manufacturing Technology Institute in Bangalore. In SEM images reveal that sensible amount of distribution takes place in matrix. Silicon Nitride particles are distributed throughout matrix is as shown inFig. 3(a).In Fig. 3(b) and Fig. 3 (c) reveal that Silicon Nitride and Graphite particles are distributed throughout matrix.

3.2 X-ray diffraction analysis

The XRD analysis was conducted in Department of chemistry, Bangalore University, and it confirms that Silicon Nitride particles is present within Al2024 alloy is as shown in Fig. 4(a).In Fig. 4(b) confirms Silicon Nitride and Graphite particles are present within the matrix material and also confirms there is no interfacial product is present within Al2024 alloy in both the XRD analysis pattern.

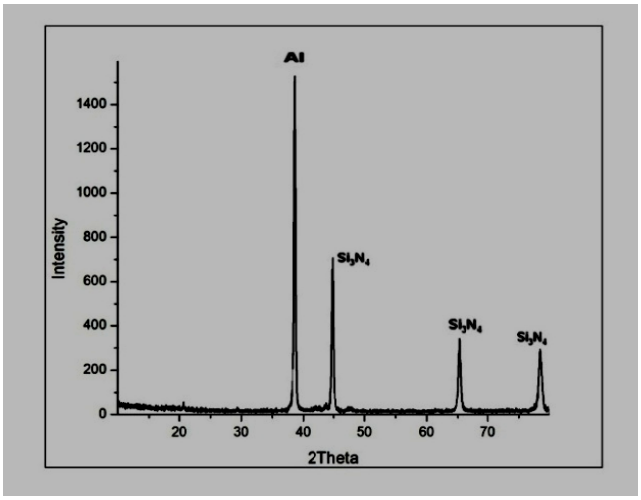

Fig. 4: (a) XRD Pattern of Al2024 and Silicon Nitride Composites

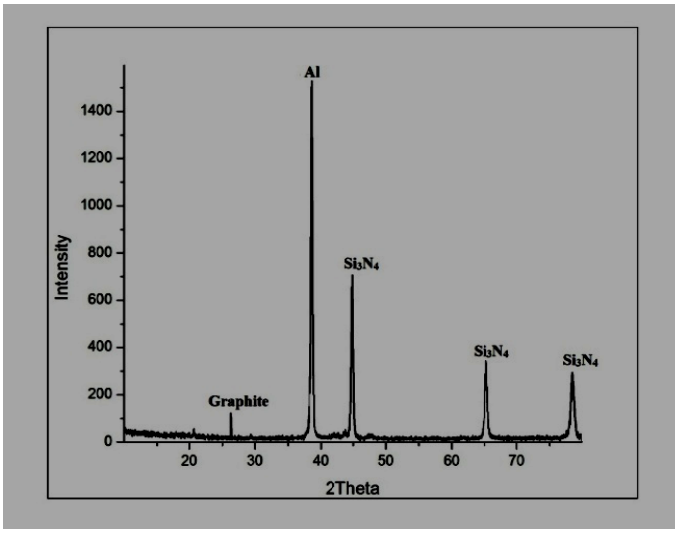

Fig. 4: (b) XRD Pattern of Al2024- Silicon Nitride-Graphite Composites

3.3 Density

The Theoretical density is conducted by simple rule of mixture and Experimental density is conducted by Archimedes principle. In Fig. 5 shows that the density of unreinforced alloy is quite low compared to addition of reinforcement into alloy. Density increases with addition 6% of Si_3N_4 into matrix, as the percentage of graphite increases density of composite decreases because density of graphite lower compared to base alloy and Si_3N_4. Hence graphite content increases density of the composite decreases marginally compared to density of base alloy and Al+6% Si_3N_4. From the Fig. 5, clearly reveals that experimental and theoretical density values are not much difference due to suitability of the liquid metallurgy technique for preparation of composites. In Siddesh Kumar N G et al and Dharma lingam et al similar result was achieved.

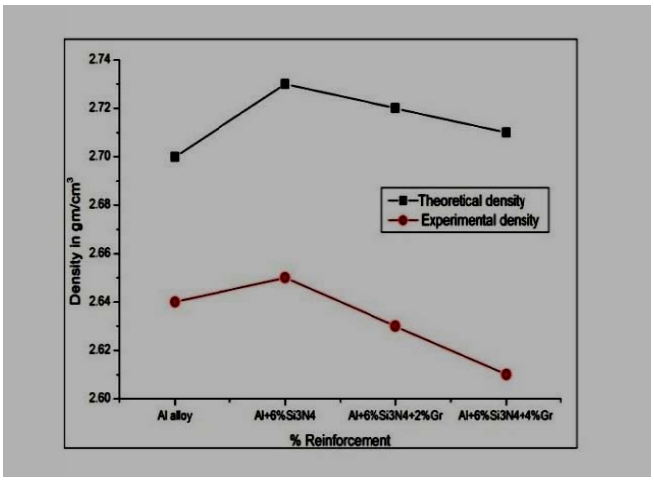

Fig. 5: Comparision of Theoretial density and Experimental density

3.4 Hardness

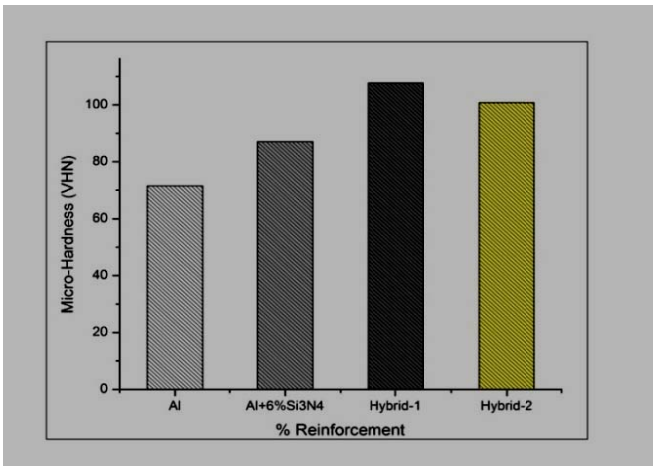

Fig. 6: Variation of hardness with addition of Si_3N_4 and Graphite into Al2024 alloy

The hardness is conducted by micro vickers hardness tester and result reveals that hardness of composites is increases compare to unreinforced alloy. Hardness is higher due to the addition of Si_3N_4 and Graphite particles, reinforcement acts as obstacles to the motion of dislocation and good bonding between matrix and reinforcement[]. Fig. 6 shows that hardness increases up to hybrid-1 than hardness of hybrid-2 (Al+6%Si3N4+4%Gr) little less compared to hybrid-1(Al+6%Si3N4+2%Gr).

3.4 Tensile Properties

Universal testing machine is used for determining the percentage of elongation and tensile strength of prepared specimen as per ASTM E8M-04 standards.

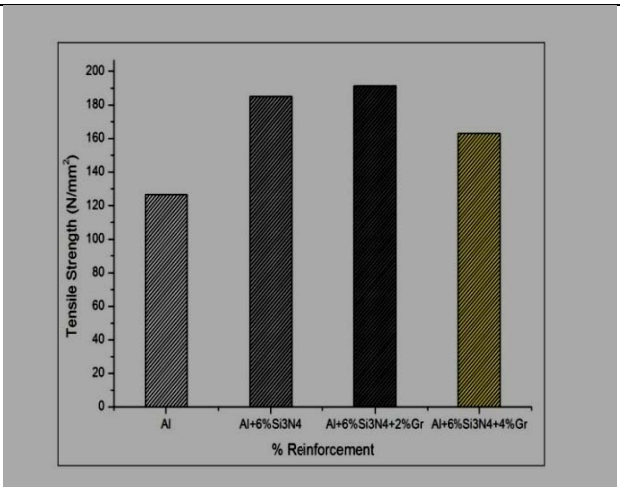

Fig. 7: (a) Variation of tensile strength with addition of reinforcement into alloy

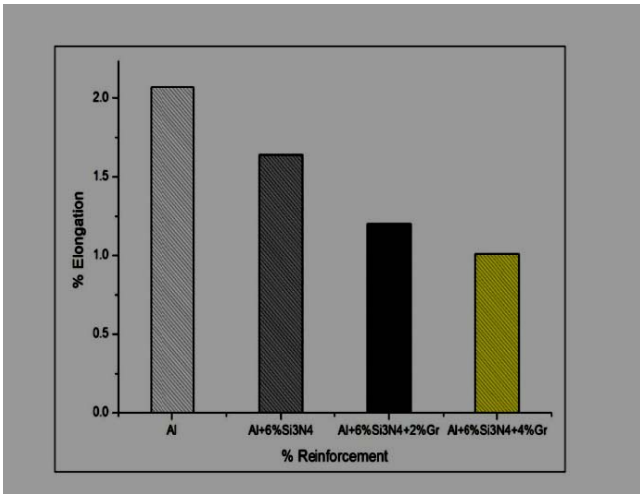

Fig. 8: Variation of % elongation with addition of reinforcement into alloy

Tensile strength of composites is more compared to unreinforced alloy. The tensile strength increases percentage of elongation of composites decreases. The percentage of graphite increases 2% to 4% the tensile strength of composites decreases to smaller amount but percentage of elongation decreases considerably. The tensile properties of composites increases because reinforcement particles present matrix induces strength of Al2024 alloy therefore increase in resistance to tensile stress. The tensile strength increases considerably due to the addition of 6% Si_3N_4, 2% and 4% of graphite by 46%, 51% and 33% respectively then that of Al2024 alloy. The tensile strength and percentage of elongation is as shown in Fig. 7 and Fig. 8 respectively. The increase in weight percentage of reinforcement reduces the percentage of elongation of composites. The ductility of prepared composites is less compared to Al2024 alloy.

4. CONCLUSION

In the present work, Si_3N_4 and graphite reinforced with Al2024 alloy. The composite is prepared by using Stir casting technique and fairly uniform distribution can be achieved is as shown in optical microscope and SEM images. The microstructure contains that fine dendrites of Al solid solution, Al+6%Si_3N_4, Al+6%Si_3N_4+2%Graphite and Al+6%Si_3N_4+4%Graphite erratically dispersion of reinforcement particles are seen in optical microscope. The XRD analysis confirms that presence of Si_3N_4 and graphite particles within Al2024 alloy. The theoretical density is lesser than experimental density. Theoretical and experimental density increases to addition of Si_3N_4 particles to 6% and then decreases. The hardness and tensile strength of composites increase up to Addition of 2% of graphite and then decreases to smaller amount in addition of 4% of graphite particles. The percentage of elongation decreases gradually. Hardness increases than unreinforced alloy by 22%, 47% and 41% for Al+6%Si_3N_4, hybrid-1 and hybrid-2.

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