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Investigation of Mechanical Properties and Wear Behavior of Al 2024 Matrix Reinforced with Si_3N_4 and Graphene

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Abstract-The metal matrix composite materials are finding wide applications in industries due to their high strength to low density ratio, wear resistance, fatigue resistance, corrosion resistance. The present research work focuses on the fabrication of Al 2024 matrix composite reinforced with constant weight percentage of Silicon Nitride (Si_3N_4) and various weight percentage of graphene particles by conventional stir casting route and investigation of the mechanical. The percentage of Silicon Nitride in the developed composite is maintained at 6% and graphene is varied from 0.25% to 1% in steps of 0.25%. The mechanical properties such as ultimate tensile strength and hardness are improved at the cost of reduction in ductility with an increase in weight percentage of silicon nitride and graphene particles in the aluminum metal matrix.

Index Terms- Metal matrix composite, Si_3N_4, stircasting, graphene, mechanical properties, aluminum matrix, ductility

1. INTRODUCTION

The composites have introduced an extraordinary fluidity to the design engineering, in conscious society. The properties of the matrix material can be improved by incorporating different types of reinforcements such as fibres, whiskers and particulates[6]. A particle reinforced composite will also be more effective in attaining the isotopic properties for the materials. Therefore, the termcomposite" broadly refers to a material system which is composed of a discrete constituent (reinforcement) distributed in a continuous phase (matrix), and which drives the distinguish characteristics from the properties of its constituents, from the geometry and architecture of the constituents, and from the properties of interfaces between the different constituents.

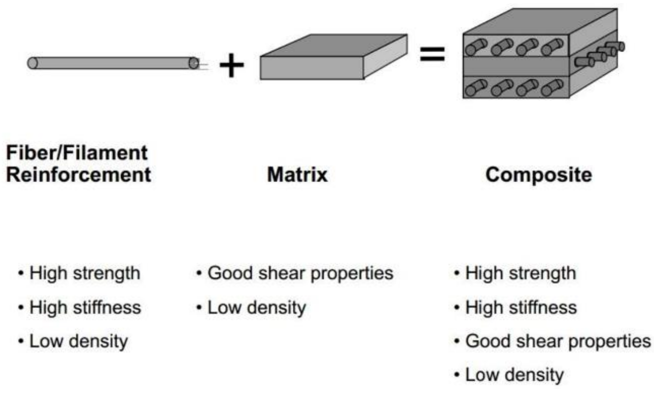

Fig. 1.1 Composite Material

The composite materials are generally classified according to their reinforcement, matrix and processing route. In the case of reinforcements, they can be categorized based on their nature (polymer, ceramic, metal), Shape and the orientation. According to the matrix of the composite, they are categorized as polymer matrix composites (PMCs), metal matrix composites (MMCs) and ceramic matrix composites (CMCs). Few valuable reviews and books have provided detailed discussion on the various composite materials and their properties.

1.1 Metal Matrix Composites (MMCs)

MMCs are distinct from other type of composite materials in many ways. These distinctions mainly arise from the inherent differences among metals, polymers and ceramics and tosome extent from nature of the reinforcements. MMC systems are generally designated according to the matrix or metal alloy designation, type and volume fraction of reinforcement. However, these designations do not cover consolidation process, subsequent heat treatment or specific fibre orientations.These metal matrices are available in the various forms including castings, wrought and powder materials[9]which employed during the manufacturing process of MMCs[9]. The choice of matrix in MMCs is mainly influenced by consideration of the demanded properties of composite in the particular application.The main objectives of reinforcing metal matrices are weight reduction, improvement of corrosionresistance, fatigue resistance and creep resistance at higher temperatures, strength properties coupled with thermal characteristics[5][7].

1.2 Aluminium matrix composites (AMCs):

AMCs have been widely used in structural, automotive and aerospace industries as a light composite material. Due the fact that the desired strength and mechanical properties cannot be achieved by using of aluminum itself or its alloys therefore, they have been replaced by AMCs in these industries [14]. In fact, reinforcing of aluminum alloys gives the possibility of production of parts with optimized mechanical, thermal and physical properties and an accurate chemical composition[1]. Besides, new manufacturing methods have provided more opportunities of production of parts with more enhanced mechanicalproperties[13] and microstructure [12]. These enhancements through reinforcing help the aluminum industry to prevail over new markets for their products.

1.3 Silicon Nitride (Si_3N_4):

Silicon nitride (Si_3N_4) constitutes hard ceramic particles with high mechanical strength and good wear resistance, and also can be used as a reinforcement materialin the manufacturing of AMCs [2]. Al/Si_3N_4 AMCs showed high specific strength compared to that of unreinforced alloy[3]. AMCs reinforced with Si_3N_4 particles manufactured by powder metallurgy technique showed high hardness than that of conventional aluminum matrix and hardness Increased by increasing the volume fraction of Si_3N_4 particles[4]. Al2024 matrix composites reinforced with nickel coated Si_3N_4 particles manufactured by liquid metallurgy routeresulted in higher hardness and ultimate tensile strength (MS) of the composites than that of pure Al2024[11].

1.4 Graphene:

Graphene is an allotrope of carbon atom with single atomic layer of graphite organized into a hexagonal lattice (Fig.1)[10]. The stand-out properties are its inherent strength (at all temperatures) and found to be the strongest material ever discovered. Specifically, these materials possess distinctive wear resistance properties and also superior mechanical properties leading to innovative applications. Addition of Graphene at nanoscale range becomes a promising reinforcing material in many engineering applications specifically in ceramics, polymers including metal or its alloys. Research on Graphene metal matrix composites are in infancy stage due to its challenges in homogeneous dispersion and the extensive reaction between metals interfaces during high temperature processing conditions.

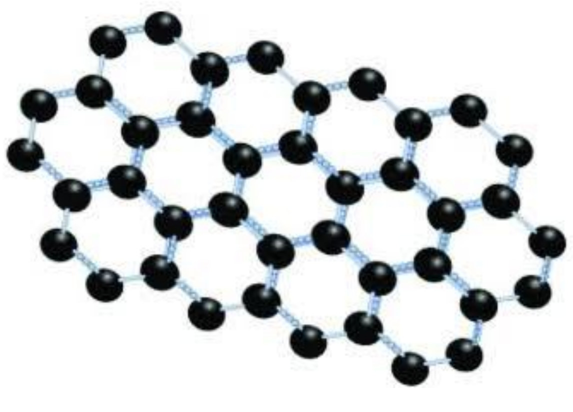

Fig.1.2 Molecular structure (honeycomb) of Graphene

1.5 STIR CASTING METHOD:

Stir casting of metal matrix composites (MMC) was initiated in 1968, when S. Ray introduced alumina particles into aluminum melt by stirring molten aluminum alloys containing the ceramic powders[15].In a stir casting process, the reinforcing phases are distributed into molten matrix by mechanical stirrer. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mould casting, or sand casting. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement. The cast composites are sometimes further extruded to reduce porosity, refine the microstructure, and homogenize the distribution of the reinforcement. The final distribution of the particles in the solid depends on material properties and process parameters such as the wet condition of the particles with the melt, strength of mixing, relative density, and rate of solidification.

2. OBJECTIVES

The objectives of the present study are:

- To develop Al 2024 hybrid metal matrix composite reinforced with Si_3N_4 and Graphene.
- To study the mechanical propertiesof the developed composite like tensile strength, compressive strength, hardness.
- To study the wear behavior of the developed composite.

3. METHODOLOGY

With the use of experimental set-up, we can analyze the data in a real time environment or verify the actual results obtained by other methods. This method is simpler to visualize and understand but is more challenging in terms of manipulation of the input data for finding the sensitivity associated with the output. For our case, the physical experimentation has been carried out under specified input conditions at the foundry; the details of which are given below.

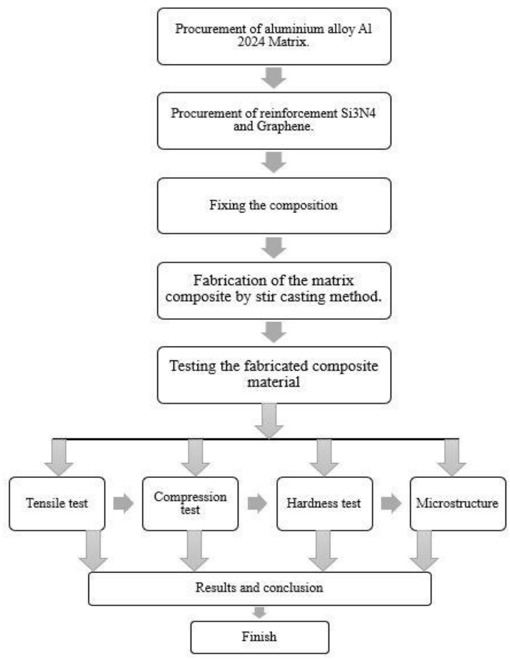

Fig.3.1: Flow Chart

4. MATERIALS AND EXPERIMENTALPROCEDURE:

4.1 Materials

4.1.1 Aluminum 2024 has been procured from Perfect Metal Works as a raw materialextruded rod shown in fig 4.1.The chemical composition of Al 2024 is shown in table 4.1.

Table 4.1: Chemical composition of Al 2024

Element (%)	Alloy
	2024
Cu	3.80-4.90
Mg	1.20-1.80
Mn	0.30-0.90
Si	0.50 (Max.)
Fe	0.50 (Max.)
Zn	0.25 (Max.)
Ti	0.15 (Max.)
Cr	0.10 (Max.)
Others	0.05 (Max.) each 0.15 (Max.) total

4.1.2 Procured Silicon Nitride from Parshwamani materials in powder form as shown in fig 4.1.The chemical composition of Al 2024 is shown in table 4.2.

Table 4.2: Chemical composition of Si_3N_4

Properties	Silicon Nitride
Chemical Formula	Si_3N_4
Density	3.17 g/cm3
Melting Point	1900°C (3,452°F)
Solubility in Water	Insoluble
Average Molar Mass	140.283 g/mol
Purity	99.10%
Particle size	40 Microns
Form	Powder

4.1.3 Procured Graphene from BTcorp Generique nano private limited in powder form as shown in fig 4.1.The chemical composition of Technical Graphene is stated in the table4.3.

Fig 4.1 Raw Materials

Table 4.3: Chemical composition of Graphene

Sl. No.	Parameters	Technical Grade [G2]
1.	Thickness	10-20 nm
2.	Lateral Dimension	10µ
3.	Layers	20-40
4.	Bet Surface Area	52 m2/g
5.	Bulk Density	0.41/cc
6.	Product Purity	>98%
7.	Porosity Over Surfaces	>10 nm
8.	Sulphur	<1%
9.	Atomic Oxygen Content	<1%

4.2 Fabrication Process

Fixing the composition ratio of Al 2024, Si_3N_4 and Graphene as shown in table 4.4.

Table 4.4: composition Ratio

Sl. No.	Specimen No.	Al 2024	Si_3N_4	Graphene
1	A	100	0	0
2	B	93.75	6%	0.25
3	C	93.50	6%	0.5
4	D	93.25	6%	0.75
5	E	93	6%	1

4.3 Experimental Procedure

The proposed AMC was produced using Al 2024 having chemical composition as shown in table 4.1. The reinforcement particles were Si_3N_4 and graphene powder. Table 4.2 and table 4.3 provide the details of reinforcements used respectively. Aluminum 2024 was melted in a graphite crucible by heating it in a muffle furnace at 800°C for four hours by using electric furnace shown in Fig 4.3. The silicon nitride (Si_3N_4) and Graphene particles were mixed together and preheated at 400°C with the help of preheat equipment as shown in Fig 4.3 for three hours to make their surfaces oxidized. Proper stirring is required in order to achieve uniform spreading of reinforcement in the aluminum melt. Degassing tablet is provided into the molten mixture during the whole process to escape the gasses. After stirring of molten metal, it was poured into a preheated permanent mould. The manufactured composite material was allowed to solidify in atmosphere air and was taken out from the permanent mould after complete solidification. The AMC's have different weight percentage of Graphene. Table 4.5 shows the process parameters employed in the process of stir casting in the present work. The fabricated typical composite materials are shown in Fig 4.4.

Table 4.5: Process parameters of stir casting

Sl. No.	Process Parameters	Value
1.	Stirring Temperature	800°C
2.	Stirring Speed	250

		rpm
3.	Stirring Time	5 min
4.	Preheat temperature of reinforcement particles	400°C
5.	Preheat temperature of permanent mould	400°C
6.	Final temperature of Al 2024	800°C
7.	Blade Angle	60°


Fig4.3: Stir casting and reinforcement preheat set-up


Fig. 4.4: Manufactured Composite material

4.4 Specimen preparation:

Specimen preparation or sample making is a first and necessary step in performing destructive testing service on metal materials. The test specimen or sample is prepared to confirm to the requirements stated in the standard or specification called out for the testing that will be performed. After machining, a dimensional inspection is prepared to ensure the specimen complies with design specifications. All tests are to be carried out by competent personnel. Testing machines are to be maintained in a satisfactory and accurate condition and are to be recalibrated at approximately annual intervals.

5. RESULTS AND DISCUSSION

5.1 Results

5.1.1 Tensile Test

The tensile tests are conducted in UTM (MECH-002, UTE-60, 60T) having load capacity 600KN and also have an accuracy of ±1%. Specimens were prepared according to ASTM E-8 (flat standard) for testing. Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contract. Table 5.1 shows the Tensile Test Results.

Table: 5.1 Tensile Test Results

Specimen	Ultimate stress σ_u σ_u(MPa)	Breaking stress σ_f (MPa)
A	233.21	220.65
B	238.72	195.21
C	252,46	207.93
D	264.83	252.83
E	278.36	278.36

Graph

The values from the above table are shown in the graph.

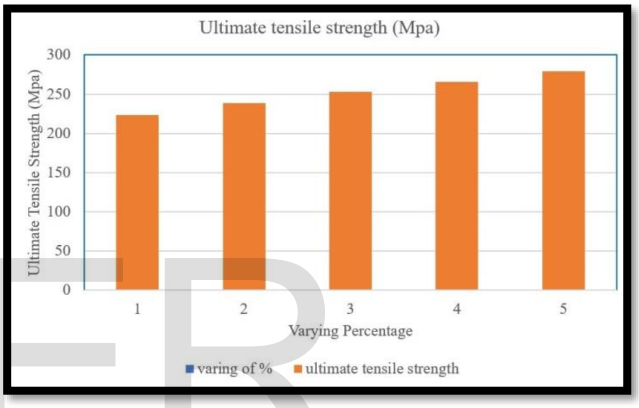

Fig: 5.1 Ultimate Tensile Strength V/s varying % of Si_3N_4 and Graphene

Figure 5.1 shows the effect of Si3N4 and Graphene on the tensile strength of Al 2024. It is inferred from the test results that, the tensile strength of hybrid MMC increases with increasing percentage of Si_3N_4 and Graphene content. The level up to it increases is the 6% of Si_3N_4 as constant and varying Graphene from 0.25%to 1% gradually, the maximum peak tensile stress achieved is 278.36MPafor 6% Si3N4 and 1% of Graphene (sample E). However, the tensile strength is gradually increasing with the Si3N4 and Graphene content exceeds 6% Si_3N_4 due to increase in ductility. The tensile strength for 6% Si_3N_4 and 0.75% Graphene is 264.83MPa. As we added Si3N4 and Graphene in the Al 2024 both having different atomic size which increases the stress required to move the dislocation through the crystal but these phenomena occur up to some level.

5.1.2 Hardness

Vickers hardness test is conducted to know the hardness of composites. Here load of 100 Kgf is applied for about 10 seconds and the Vickers hardness number was measured using the Dial indicator.

The below table 5.2 shows the details of the specimen andVickers hardness number being carried out on the Vickers hardness setup.

Table: 5.2 Hardness Number Results

Sample	Vickers Hardness
A	78
B	89
C	97
D	105
E	116

Graph

The values from the above table are shown in the graph.

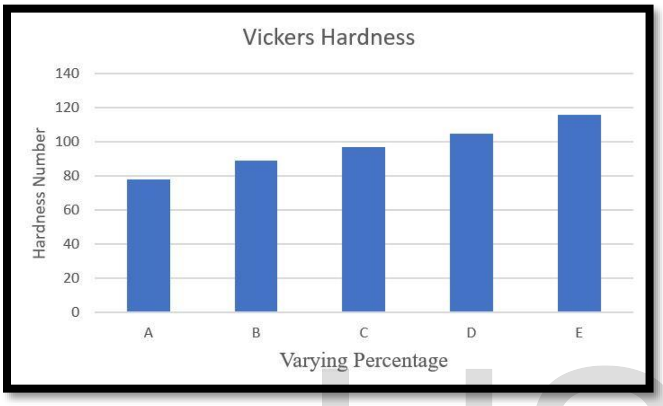

Fig: 5.2 Hardness Vs varying % Si_3N_4 and Graphene

6. CONCLUSIONS

We successfully fabricated the Composites where Al 2024 as matrix material, Si_3N_4 and Graphene as reinforcement material by using Stir Casting arrangement with proper distribution of Si_3N_4 and Graphene particles all over the specimen. `

We have drawn various conclusions from the various calculations based on the different experimental tests:

1. The tensile strength improves for 6% addition of Si_3N_4 and 1% of Graphene in aluminium with Si_3N_4 and graphene, whereas in no decrease in tensile strength compared to addition of Si_3N_4 and Graphene.

2. The hardness of the material increases with the increase in the percentage of Si_3N_4 and Graphene content and it is 78HRB, 89HRB, 97HRB, 105HRB & 116HRB for specimen of pure Al 2024, with constant 6% of Si_3N_4 and 0.25%, 0.5%, 0.75 & 1% Graphene content respectively.

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