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Evaluation of Al-Cu Alloy Hybrid Composites Reinforced with Graphite and Fly Ash

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Abstract

Aim: *In this particular investigation, the Al-Cu alloy serves as the matrix material, and fly ash and graphite are the reinforcements. Composites made of aluminium and copper alloy are particularly popular for a variety of reasons, including their high thermal conductivity and their operability in temperatures that are closer to room temperature. Reinforcing materials used are graphite and fly ash particles in view of their ability to be made into thin layers while yet maintaining their strength. The composite material was produced by a method known as stir casting.* **Methods***: The molten Al-Cu alloy was reinforced with graphite and fly ash particles in proportions of 3 percent, 6 percent, and 9 percent. Following that, an examination of the composite's mechanical properties was carried out. Hardness, tensile strength, and wear were some of these characteristics. The microstructure of the Al-Cu matrix was analysed using SEM to determine how well graphite and fly ash particles were distributed throughout the matrix.* **Results:** *According to the findings, there is a correlation between the weight of graphite and fly ash and an increase in the material's stiffness and hardness. When more reinforcement materials are added to composites, the density of the finished product decreases. Additionally, the presence of the reinforcing particle improves the wear property of the surface. The ASTM requirements were followed in the fabrication of the specimen that was used in the experiment.*

Major Findings: *It is also found that the increase in reinforcement also enhanced the property of hardness in the composites. It is shown that the amount of fly ash and graphite boosts the dry sliding wear resistance, and the microstructure and XRD reveal the presence and fairly uniform distribution of fly ash and graphite particles in the Al-Cu composite.*

Keywords: *Composites, Fly Ash, Graphite, Metal Matrix, Wear*

1.0 Introduction

Metal Matrix Composites, often known as MMCs, are the most promising materials for the aviation and automotive industries in the future. Aluminium and its alloys are becoming increasingly important as a result of the vast array of applications that can be found for them. These applications are made possible by aluminum's low thickness, strength, durability, resistance to wear and exhaustion, and low Coefficient of Thermal Expansion (CTE)[1,2]. It is possible to increase the mechanical and tribological properties of metal by adding ceramic

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particles. Aluminium matrix composites are totally realizable[3] and this is due to significant components such as the matrix and its interface. Metals have many different qualities, including resistance to high temperatures, ductility, high strength with low stiffness, and resilience to high temperatures. Ceramic particles possess a high degree of stiffness, making them more substantial due to their increased weight. Reinforcement and matrix qualities are combined in the production of composite materials to strike a satisfactory balance between the two types of attributes. The qualities that composite materials show change depending on their composition as well as the characteristics of the components that make up the composite. These aspects include the quantity of particles, their shapes and sizes, as well as their distribution.

MMCs can be fortified with a wide variety of additives, the most common of which being silica, aluminium oxide, mica, fly ash, graphite, Cubic Boron Nitrate (CBN), and boron carbide[3]. Hybrid metal matrix composites, or HMMCs for short, are a different category of lightweight materials that are inherently stronger and more resistant to wear than other similar materials. In some circles, these materials are also known as Composite Metal Matrix Composites (CMMCs). Hybrid or dual reinforcement matrices are distinguished by the presence of two different reinforcing components. MMCs are produced by a variety of procedures, some of which include powder metallurgy, squeeze casting, spray deposition, stir casting, and even mechanical alloying. Despite the fact that these processes are not identical, they may all be categorized as powder metallurgy. Stir casting is widely regarded as the most reliable and productive technique of production among these several technologies[1]. The production results from this procedure are highly dependent on the weight fraction, size, type, and distribution of reinforcing particles in the cast matrix[3]. This is since the characteristics of MMC are extremely reliant on those aspects of the matrix's reinforcement particles. Composites made of Al2219 alloy were developed by researcher[4] with the use of B_4C and MoS_2 particle reinforcement. The stir-cast method was used to make the Al2219-B_4C-MoS_2 composites, and then the mechanical properties of the finished products were analysed. Al7020-SiC graphite hybrid metal composites were the subject of research conducted by using the fluid melt technique[5]. With a SiC composition that is held constant at 10 percent and variable levels of graphite in terms of its weight percentage, which ranges from 3 percent to 6 percent to 9 percent. After the new composites were developed, they were put through a series of tests to see how well they would perform under different thermal and mechanical circumstances. The addition of 10 percent SiC increased the material's hardness and elasticity when expanding graphite particles were present[4]. A large number of experiments have been carried out on aluminium amalgam in order to establish whether or not the addition of more additives could improve the wear and mechanical properties of the alloy. In his research, the authors[5,6] discovered that AA8011 alloys could be made by stir casting with Si and Fe particles. The properties of hybrid composites were significantly enhanced, including an improvement in both their strength and their hardness. Therefore, liquid metallurgy was employed in this experiment to develop a hybrid composite consisting of Al-Cu alloy, fly ash, and graphite. This hybrid composite was successfully created. For the purpose of reinforcing the designs, graphite was utilized because of its low density, better physical qualities, and relatively inexpensive cost in comparison to other materials. These particles can be used to make aluminium composites, which, if completed, will result in a composite that is both strong and inexpensive.

In the research that has been done, the benefits of employing fly ash and graphite in composite reinforcement have been discussed. The Al-Cu alloy is a high-strength aluminum alloy that has good performance qualities. The major area of application is aircraft construction. The alloys have medium to high strength and can be age hardened. The alloys are processed by rolling, forging, extrusion and partly by casting.

Extensive study on metal matrix composites and hybrid composites has been carried out by a large number of qualified researchers. The research looked at the effects of increasing the percentage of fly ash and graphite in Al-Cu alloy hybrid composites from 3 percent to 6 percent and 9 percent. Since the metal composites were manufactured, SEM micrographs have been used to investigate the microstructure, mechanical, and wear properties of the composites. This has been done in order to better understand the properties of the synthetic composites.

2.0 Experimental Method

Alloys in which aluminium (Al) is the primary metal is said to be aluminium alloys. Zinc (Zn), manganese

Table 1. Chemical composition of Al4.5% Cu alloy[10]

Cu	Mg	Si	Fe	Mn	Ti	Zn	Al
4.5%	1.00%	0.60%	0.65%	0.10%	0.10%	0.20%	Balance

(Mn), copper (Cu), silicon (Si), and magnesium (Mg) are the alloying elements (Mg). Aluminum was chosen as the foundation material due to its copper content of 4.5 percent because it has strength, hardness, machineability, and heat treatable. The composition of the Al with a 4.5 percent Cu combination is listed in Table 1.

Al-Cu alloys are commonly used in applications requiring high strength and rigidity at high temperatures. Motorcycle, aero plane, diesel, and heavy-duty pistons, as well as aircraft generator housings and air-cooled cylinder heads, are some of the most common uses. As demonstrated in Table 2, the strengthening agent was made of fly ash and graphite particles[7-9]. The average particle size of graphite was determined to be ten millimeters. The density of the fly ash particles was 2.09 g/cm^3.

Graphite is the purest form of carbon and is used to reinforce the experiment. In this scenario, the matrix has two types of reinforcement, one of which is fly ash and the other of which is graphite in variable weight proportions.

Fly ash is a coal combustion byproduct. It is a by-product of recovering flue gas from coal-fired power plants. In addition to silica (amorphous and crystalline), all fly ash contains high levels of lime (calcium carbonate) (calcium oxide, CaO). Fly ash is mostly made up of SiO_2, Al_2O_3, and Fe_2O_3, with tiny amounts of magnesium, calcium, sodium, and potassium oxides. These particles range in size from 1 to 100 microns and have a specific surface area of between 250 and 600 m^2/kg. Fly ash has a specific gravity of 0.6-2.8 g/cc.

Fly ash is preferred as a filler or reinforcement in metal and polymer matrices because of its abundance (80 million tons annually) and low cost. High production costs mean that glass microspheres are utilized in a limited number of applications. Composite material prices can be dramatically reduced by incorporating fly ash into polymer and metallic alloy matrices.

Table 2. Chemical composition of fly ash in weight percentages

Al_2O_3	SiO_2	Fe_2O_3	TiO_2
30.40%	58.41%	8.44%	2.75%

The composite material is produced by a method known as liquid stir casting. A graphite crucible weighing 1 kilogram was filled with globules of an aluminum–4.5 percent copper alloy, and the pot was then heated with an electric furnace. The temperature of the melt was gradually raised all the way up to 650 degrees Celsius. After the alloy had been completely melted and nitrogen had been used to remove any excess gas, a straightforward mechanical stirrer made of alumina-coated stainless steel with four blades was introduced into the molten mixture, and then stirring was begun. The stirrer was rotated at a speed of 600 rpm for twenty-five minutes. After the liquid metal inside the electric heater was stirred vigorously at a rate of roughly 350 to 400 revolutions per minute to create a vortex, reinforced particles were added to the liquid metal[10,11]. After the stirring has begun, a specified amount of graphite and fly ash is added slowly into the molten metal in different percentages[12,13]. It was found that using three, six, and nine weight percentages of fly ash and graphite particles produced the best results. After properly incorporating the particles into the molten material, the liquid mixture was poured at a pouring temperature of 750 degrees Celsius into warmed S.G. iron molds with diameters of 25 and 37 millimeters and a height of 200 millimeters, and then it was allowed to cool at temperatures and pressures that were typical of the environment.

After casting, the specimen is prepared for microstructural analysis using a scanning electron microscope in order to determine the uniform distribution of reinforcing particles in the aluminum-copper alloy. Microstructural images are taken of composites made of aluminium-copper alloy with graphite and fly ash particles. For the microstructural study, the size of the sample is 15 mm in diameter and 5 mm in height. SiC paper with grits of 300, 600, and 1000 is used to grind the surface of the specimen. Next, the surface is polished on a polishing machine with 3 micrometer-thick polishing paper to make it even smoother. After that, the polished surface of the specimens is cleaned with distilled water to get rid of any foreign particles, like dirt or other impurities. Keller's reagent is used to etch the specimens to make the surface stand out.

For the hardness test, the sample was machined so that it meets ASTM standard E6. The Brinell hardness testing machine is used for the hardness test. The surface of the specimen is smooth and polished. A 5 mm ball impression is taken, and a 250 kg load is applied on the specimen. On the surface of the specimen, 5 impressions are made, and the results are evaluated.

To investigate the tensile behavior of aluminium copper alloy with graphite and fly ash particulate reinforced composites, specimens are machined according to ASTM standard E8. The computer-controlled tensile machine is used to determine the tensile strength as well as analyze the influence of uniform distribution and examine the behavior of aluminium copper alloy with graphite and fly ash particle-reinforced hybrid composites subjected to unidirectional strain. The specimen has an overall length of 104 mm, a gauge length of 45 mm, and a gauge diameter of 9 mm. With this tensile test, the mechanical properties of composites can be assessed to determine their ultimate, yield, and elongation strengths. Figure 5 is the tensile test specimen sample.

In analyzing the wear behavior of cast composites utilizing a pin on disc wear machine, circular specimens of 8 mm in diameter and 30 mm in length are subjected to wear tests in accordance with the ASTM G-99 standard. After conducting dry sliding wear tests with varying loads of 4.9, 9.8, 14.7, and 19.6 N at 400 rpm for a distance of 2000 meters, the wear rate is calculated. The weight loss is used to calculate the volumetric wear loss of cast hybrid composites. Finally, the specimens wear has been quantified by the wear rate.

3.0 Results and Discussion

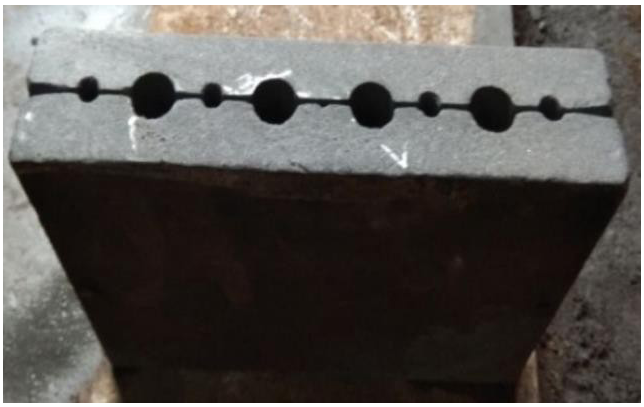
Different testing is performed on machined components of the castings. To determine their hardness, a Brinell Hardness Tester is utilized. Microstructures are analyzed using SEM. The proper distribution of graphite and fly ash particles within the composite was achieved, and reinforcement particles were detected within the matrix. Then, using a computerized pin on disc wear testing equipment, the wear test was completed at room temperature.

3.1 Wear Test

The results for the specimens having a diameter of 25mm and 37mm, respectively, are tabulated in the table for the



(a)



(b)



(c)

Figure 1. Shows the **(a)** stir casting set up, **(b)** S.G. mold, **(c)** prepared composites after molding.

wear condition of the composite on an applied load of 4.9, 9.8, 14.7, and 19.6 N, respectively. The wear assessment is carried out on a pin-on-disc setup[14].

It is observed that the resistance to wear property increases in the composite when the weight percentage of reinforcement increases in the matrix[15-18]. Figures 3 and 4 depict the weight loss of an aluminum-copper

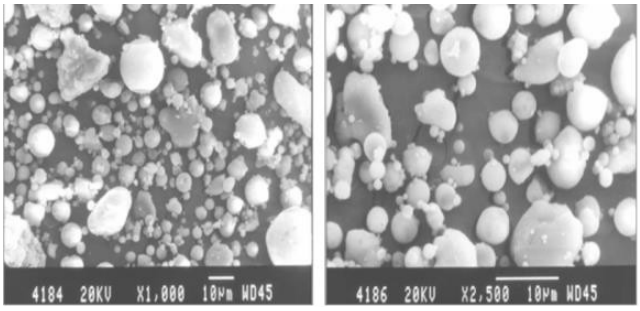


Figure 2. SEM of fly ash particulates.

Table 3. Wear test results of diameter 25mm

Sl No	Composition	Wear (in microns)			
		4.9 N	9.8 N	14.7N	19.6 N
1	3% Flyash & Graphite	125	159	242	263
2	6% Flyash & Graphite	122	202	224	258
3	9% Flyash & Graphite	83	92	164	214

Table 4. Wear test results of diameter 37mm

Sl No	Composition	Wear (in microns)			
		4.9 N	9.8 N	14.7N	19.6 N
1	3% Flyash & Graphite	156	189	300	355
2	6% Flyash & Graphite	152	216	342	415
3	9% Flyash & Graphite	92	96	310	340

composite reinforced with varying amounts of fly ash and graphite. The weight loss of the composites lowers as the fly ash and graphite content in the composite increases. The fly ash and graphite included in the aluminum matrix resist the destructive action of wear testing, hence increasing the composites' wear resistance. The result is as shown in Figures 3 and 4, respectively in the graphical representation and the of wear rate at different loads are tabulated in Tables 3 and 4.

3.2 Tensile Properties

Tensile testing in UTM revealed that increasing the ash and graphite concentrations in the Al-Cu alloy

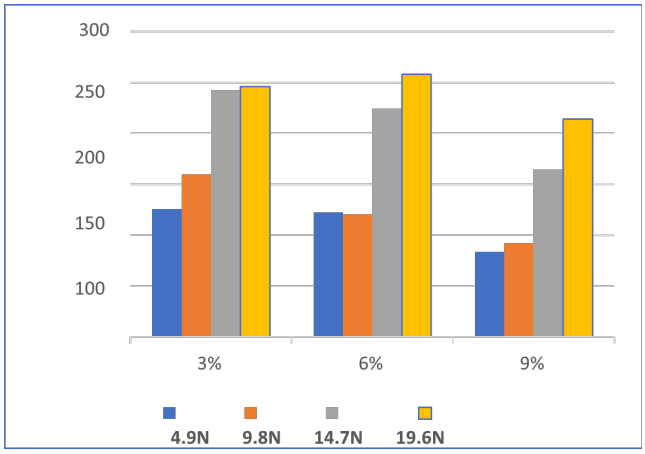


Figure 3. The wear result of the specimen having a diameter 25mm.

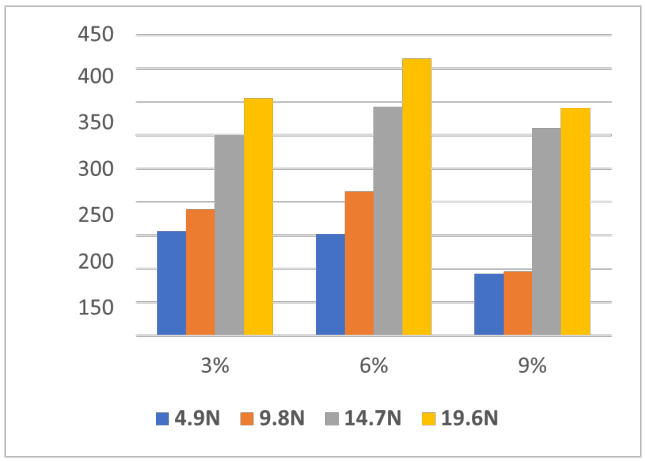


Figure 4. The wear result of the specimen having a diameter 25mm.



Figure 5. Tensile test specimen.

increased the material's tensile strength. Tensile strength is significantly increased when fly ash is added at various weight percentages. Graphite, too, makes a significant contribution to the material's properties. The presence of fly ash contributes to the composite's low density and lightweight.

Tensile values in MPa for the 25mm and 37mm diameter testing rods are shown in Table 5.

Table 5. Tensile test results

Sl No.	Composition	Tensile Strength (MPa)	
		(Diameter 25mm)	(Diameter 37mm)
1.	3% Flyash & Graphite	100.49	119.33
2.	6% Flyash & Graphite	149.92	183.4
3.	9% Flyash & Graphite	181.98	260.30

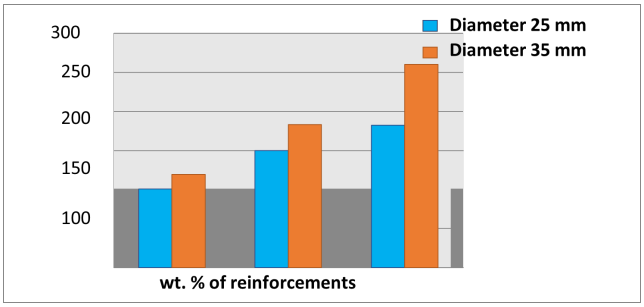


Figure 6. Tensile strength results of specimens having a diameter of 25mm and 35 mm.

3.3 Hardness

A Brinell hardness tester was used to discover the hardness of the composite material. The outcome achieved by the experiment improved the hardness of the composite by adding a reinforcing ingredient. The composition of the specimen also plays an essential part in improving the composite hardness. The data in Table 6 indicate the hardness number values in N/mm^2 for the samples having a diameter 25 mm and 37mm, respectively. As there is a percent increment in the reinforcing agent, there is an increment in the hardness of the hybrid composite. The hardness increased up to 1039.86 N/mm^2 with the addition of the fly ash and graphite in the aluminium copper alloy matrix.

Figure 8 illustrates the hardness value of the specimens with diameters 25 and 37 mm, and the specimen for the hardness test is shown in Figure 7.

3.4 Microstructure

The microstructure of the composite presentation is critical to the entire functionality of the presentation as a whole. Particle microstructure, size, shape, and dispersion of the particles in the amalgam are all important factors in determining its essential features. The specimens were examined, and it was discovered that they included fly ash and graphite particles in the matrix. These observations were carried out using SEM, and the results are depicted in Figures 9 (a) and 9 (b).

Table 6. Hardness test results of 25 and 37mm diameter, respectively

Sl No.	Composition %	Brinell hardness number (N/mm^2)	
		Diameter (25mm)	Diameter (37 mm)
1.	3% Flyash & Graphite	578.79	970.79.
2	6% Flyash & Graphite	931.95	1009.73
3	9% Flyash & Graphite	1039.86	1181.09

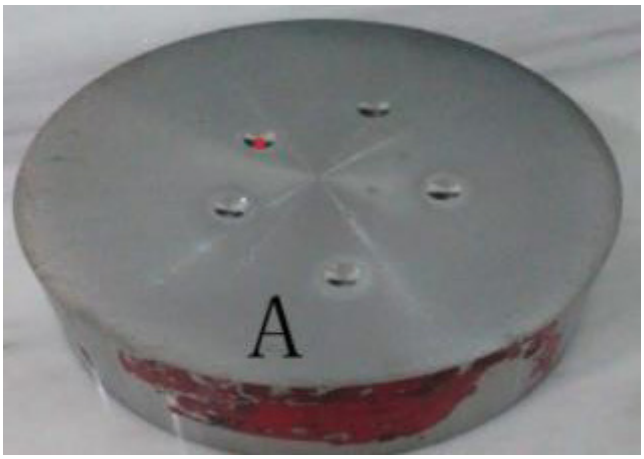


Figure 7. Hardness test specimen with indentation.

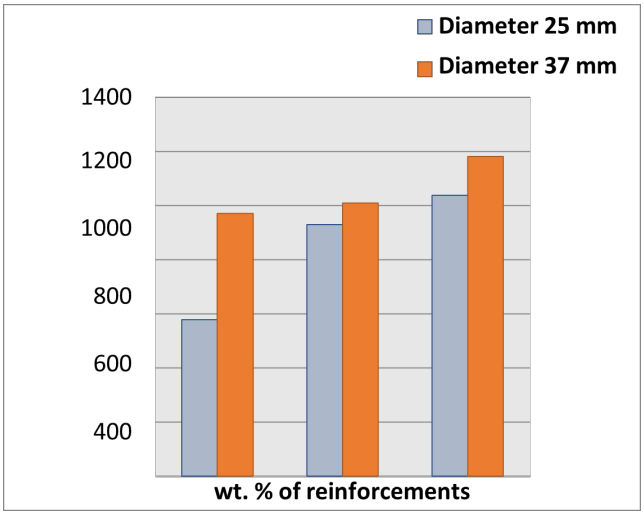


Figure 8. The hardness result of the composite.

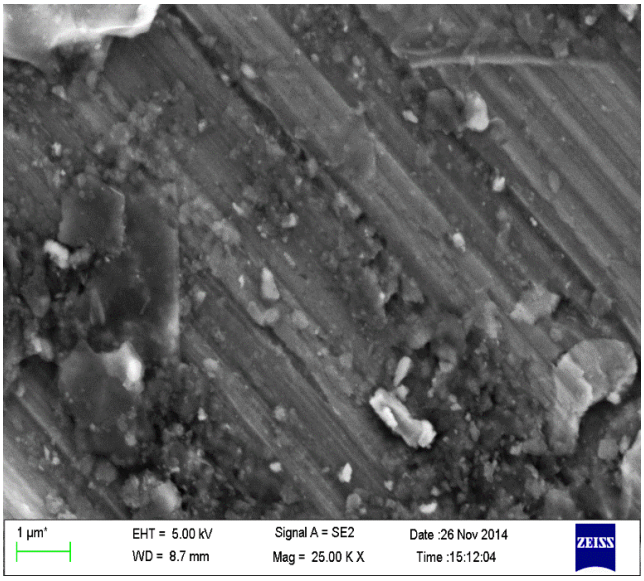


Figure 9 **(a).** SEM micrographs.

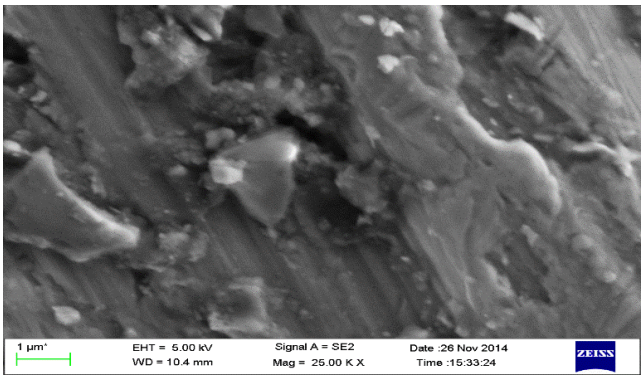


Figure 9(b). SEM micrographs.

3.5 X-Ray Diffraction

Peak width (FWHM), peak position (and wavelength) can be used to determine crystalline size once instrument effects have been removed. The genuine diffraction profile can be obtained by deconvolving the reported peaks and the broadening caused by the instrument[19]. Both the crystalline size distribution and the lattice microstrain can be obtained through the use of this technique. Crystallographic structure, physical properties and chemical composition can be determined using XRD. In the XRD experiment, the voltage was set at 40 kV, and the current was maintained at 30 mA. The following graphs illustrate the XRD patterns of composites containing graphite, fly ash, and aluminium. The test is conducted to show the presence of fly ash and graphite particles in the aluminium-copper alloy. The presence of all the particles in the composite is shown in Figure 10.

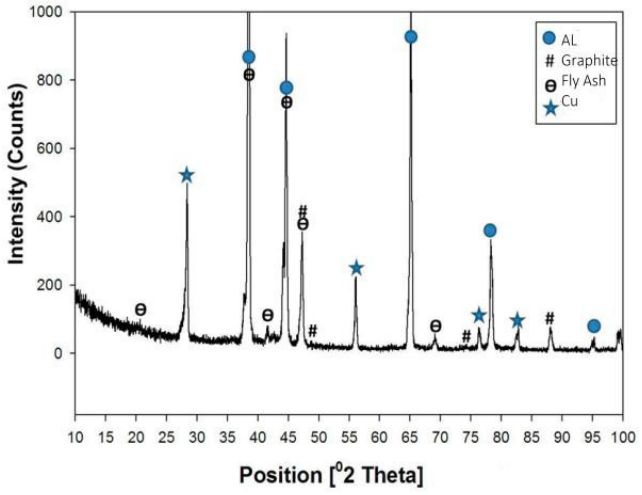


Figure 10. XRD test for the Al-Cu alloy, fly ash, and graphite composite.

4.0 Conclusions

MMCs with 3, 6, and 9 percent fly ash and graphite particles were easily formed. The microstructure showed a consistent blend of fly ash and graphite. The thickness of the composites diminishes, while the hardness increases with an expanding level of fly ash and graphite particulates. As there is a percentage increment of graphite and fly ash in the matrix, there is a particular increase in the tensile strength up to 260 MPa. It is also found that the increase in reinforcement also enhanced the property of hardness up to 1181 N/mm^2. It is shown that the amount of fly ash and graphite boosts the dry sliding wear resistance. The microstructure and XRD reveal the presence of fly ash and graphite particles in the Al-Cu composite. The MMC formed can be utilized for the applications of bearings on account of its excellent wear resistance. Further studies can be done by changing the materials used for either reinforcement or base metal.

5.0 Author's Contribution

Writing-review and editing, Girish; Writing-original draft preparation, Satish; methodology, Jayasheel; formal analysis, Shubha. All authors have read the manuscript and agreed to the published version of the manuscript.

6.0 References

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