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Experimental Investigation of Microstructure and Mechanical Properties of Aramid Fiber and Basalt Stone Powder Reinforced Metal Matrix Composites

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Abstract*— A wide range of property and performance criteria are needed for composite materials in this era since they are being employed more and more in various applications, including those in aerospace, automotive, electric, and military industries. Composite materials' low density, high specific strength, and stiffness make them ideal for structural applications. In this research paper, an effort has been made to fabricate a composite material using the stir casting technique and assess the fabricated composite's qualities. With different composition ratios of Aramid fibers and Basalt stone powder, pure Aluminum was used as a metal matrix. The microstructure and mechanical characteristics of the nine samples were analyzed.

***Index Terms*— Aramid fibers, Basalt stone powder, composite material, mechanical properties, microstructure, Pure Aluminum.**

I. INTRODUCTION

Composite materials, particularly Metal Matrix Composites (MMCs), have gained significant attention due to their exceptional properties. MMCs are created by embedding reinforcing materials within a metallic matrix, resulting in improved strength, stiffness, and thermal conductivity. They find applications in industries such as aerospace, automotive, electronics, and biomedical engineering. MMCs exhibit high-temperature resistance, and wear and fatigue resistance, and can be enhanced further by adding nanoparticles. This paper aims to fabricate a composite material using pure Aluminium as a metal matrix and Aramid fibers and Basalt stone powder as reinforcements and evaluate the mechanical properties and microstructure of the fabricated composite.

II. MATERIALS AND METHODOLOGY

A. Pure Aluminium

Pure aluminum is a lightweight and corrosion-resistant metal with good electrical conductivity. It has low tensile and yield strengths, high elongation, and low hardness. Pure aluminum is often used as a matrix material in composites due to its low density, excellent thermal conductivity, ductility, and corrosion resistance. Its low density enables the creation of lightweight yet strong composite materials. The high thermal conductivity allows efficient heat transfer, enhancing durability. The ductility of aluminum facilitates shaping and combining with reinforcing materials. Additionally, its corrosion resistance makes it suitable for applications in harsh environments.

B. Aramid Fibers

Aramid fibers, also known as "aromatic polyamides," are a type of synthetic fiber with exceptional strength and heat resistance. These fibers are lightweight, nonconductive, and have a high resistance to abrasion, chemicals, and UV light. Aramid fibers are commonly used in applications that require a high degree of toughness and resistance to wear and tear, such as bulletproof vests, aerospace composites, and protective clothing for firefighters and military personnel. They are also used in various industrial applications, including fiber optic cables, gaskets, and seals, as well as in automotive and sporting goods industries.

C. Basalt Stone Powder

Basalt stone powder can also be used as a reinforcement material in metal matrix composites (MMCs). When basalt fibers are added to a metal matrix, they can significantly improve the mechanical properties of the resulting composite material. Basalt fibers have high strength, stiffness, and thermal stability, which can enhance the tensile, flexural, and fatigue properties of the MMC. Moreover, basalt fibers have good compatibility with various metals, which can result in improved interfacial bonding and wear resistance. These properties make basalt stone powder a promising reinforcement material for MMCs in applications such as aerospace, automotive, and industrial machinery.

D. Methodology of fabrication

The stir-casting method was employed to combine the Aluminium with Aramid and Basalt fibers in the compositions as listed in Table 1. An induction furnace was utilized to perform the casting process.

The following steps were taken to fabricate the MMC:

Firstly, the power of the induction furnace was set to 175 KW, which resulted in a frequency of 600 Hz.

Secondly, the pure Aluminium (PA) rods were inserted in a Graphite crucible. PA was made to melt by heating it to 7200C. Concurrently the Aramid fibers (AF) and the Basalt stone powder (BSP) were heated separately up to 1000C to prevent the formation of slag and to enhance the bonding strength.

Thirdly, the preheated AF and BSF were mixed into the molten PA, and frequency-based stirring was performed equivalent to 1500-3000 rpm of a mechanical stirrer. The stirring took place to die to the building up of Eddy currents, leading to electromagnetic induction. The mixture of materials was heated to an extra 100C to prevent solidification while poring the materials.

Finally, the mixture was poured into a split-type cast iron die of 20mm diameter and 150 mm length. After solidification, a total of 18 rods, two from each sample were fabricated. These rods were machined for performing hardness, wear, and impact test along with microstructure analysis. After machining, the tests were performed, and the results were evaluated.

The composition of the nine samples of composite materials is specified in table-1. Four tests- Hardness test, Wear resistance test, Izod impact test, and Microstructure analysis were performed on the composite material.

Table I: Composition of each sample of composite material

S. No.	Weight (%)		
	Metal Matrix	Basalt stone powder	Aramid Fibers
1	92	4	4
2	89	4	7
3	86	4	10
4	89	7	4
5	86	7	7
6	83	7	10
7	86	10	4
8	83	10	7
9	80	10	10

III. EXPERIMENTATION

A. Hardness Test

The Brinell hardness test is a non-destructive method used to determine the hardness of metallic materials. The test measures the permanent impression made on the surface of the material by an indenter, which is usually a spherical ball made of hardened steel or tungsten carbide. The Brinell hardness number (BHN) is calculated by dividing the applied load by the surface area of the indentation.

The Brinell Hardness test was performed on the Brinell Hardness Tester machine and the specimens are shown in Fig 1.

B. Wear Test

Wear test results provide insights into durability, material quality, product performance, and comparisons between materials or products. They help evaluate wear resistance, estimate service life, and guide improvements or material selection. Interpretation should consider test conditions, intended use, and industry standards. The specimens are shown in Fig 2.

C. Izod Impact Test

The Izod impact test was performed on a pendulum impact tester machine, it is a device used to measure the impact resistance of materials. It works by releasing a pendulum from a fixed height, allowing it to strike a sample material, and measuring the energy absorbed by the material during impact. The machine consists of several components, including a pendulum, a release mechanism, and a testing area.

The specimen after the Izod impact test is shown in Fig 3.

Fig 1: Hardness Test Specimen

Fig 2: Wear Test Specimen

Fig 3: Izod Impact Test Specimen

D. Microstructure Analysis

In order to analyze the microstructure of the test pieces, specimens were prepared following the standard metallographic process. The first step involved cutting and preparing the specimens using grit sheets to achieve smooth surfaces. These prepared specimens were then subjected to microstructure analysis using an intercept approach at a magnification of 100X.

To reveal the grain boundaries and obtain a refined surface finish, Keller's reagent was applied as an etchant to the specimens. Keller's reagent is a mixture of hydrochloric acid (HCl), hydrofluoric acid (HF), and nitric acid (HNO3), specifically formulated for this purpose. The application of Keller's reagent played a crucial role in highlighting the grain boundaries, allowing for a detailed examination of the microstructures.

After the application of Keller's reagent, the specimens were carefully examined using an optical microscope in the controlled environment of a laboratory. The microscope utilized a magnification factor of 100X, enabling the observation of fine details within the microstructures. This level of magnification was deemed appropriate for the analysis, as it provided sufficient resolution to observe the grain boundaries and other important features of interest.

During the examination, particular attention was given to the revealed microstructures. The grain boundaries, which were made more apparent by the etching process, were examined for their size, shape, and distribution. Additionally, other microstructural characteristics such as the presence of inclusions, phases, and any potential defects were also observed and documented.

The thorough examination of the microstructures provided valuable insights into the material's properties and behavior. By understanding the grain structure, it becomes possible to assess the material's mechanical properties, such as strength, ductility, and fracture resistance. Furthermore, the examination of any defects or inclusions can aid in determining the material's overall quality and potential performance issues.

Fig 4: Microstructure analysis specimens

IV. RESULTS

A. Hardness Test

The Brinell hardness test is a method used to determine the hardness of a material by measuring the indentation it produces on the surface under a specific load. The result of a Brinell hardness test is typically reported as the Brinell hardness number (BHN).

To conduct a Brinell hardness test, a hardened steel ball or tungsten carbide ball is pressed into the material's surface using a specified load. The diameter of the indentation is measured using a microscope, and the Brinell hardness number is calculated based on the applied load and the diameter of the impression.

The Brinell hardness number provides an indication of the material's resistance to indentation and deformation. Higher Brinell hardness numbers generally indicate harder materials, while lower numbers indicate softer materials.

Table II: Brinell Hardness Number

Sample No.	Diameter of indentation (mm)	Brinell Hardness number
1	7	56.79
2	6.9	65.27
3	7.2	53.05
4	6.5	67.62
5	6.8	60.85
6	7.1	54.88
7	6.9	58.78
8	7.8	43.38
9	7.5	47.95

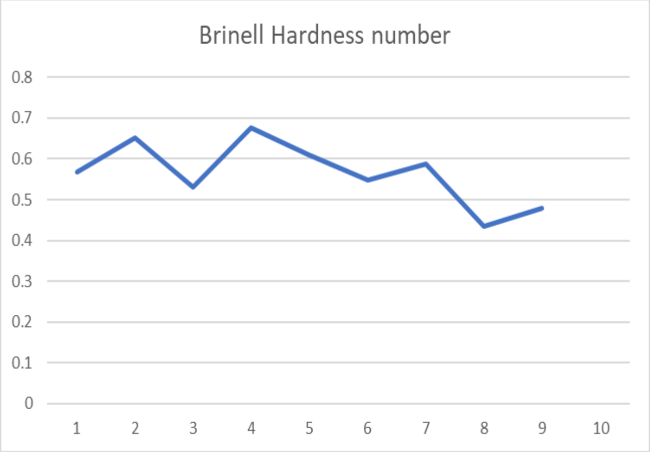

Fig 5: X-axis denotes the sample number and Y-axis denotes BHN x 10-2

B. Wear Test

Table III: Wear Test Results for 20 KN Load

Sample No.	Wear Rate (g/min)
1	9.54 x 10^{-6}
2	1.43 x 10^{-5}
3	3.08 x 10^{-4}
4	4.77 x 10^{-6}
5	2.22 x 10^{-5}
6	2.70 x 10^{-5}
7	3.81 x 10^{-5}
8	1.27 x 10^{-5}
9	2.54 x 10^{-5}

The results of a wear test can imply several things depending on the context in which the test was conducted. Generally, a wear test is performed to evaluate the durability and performance of a product or material over a period of time or under specific conditions.

To study the wear characteristics of the composite, a pin-on-disc test device was used, and the specimens were machined to a pin diameter of 8 mm and a length of 35 mm. Using a Linear Variable Differential Transducer, the wear loss was directly detected as the weight loss of the specimen. The specimen was pressed against the rotating disc with hardness by applying the load during the test. During each test, the frictional force was also recorded. The friction coefficient was calculated by dividing the friction force by the normal load. The test was carried out with a load of 20N, a 250-rpm disc rotation speed, and a 10 mm track radius. The time was set to 4 minutes per specimen to wear.

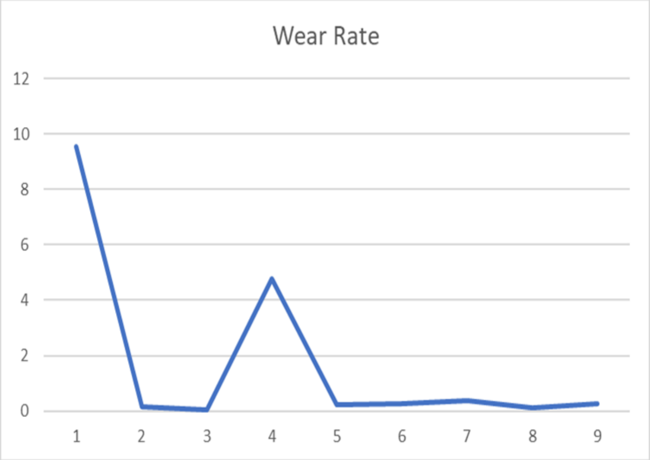

Fig: 6: X-axis Represents the Sample Number, and Y-axis Represents the Wear Rate

C. Izod Impact Test

Table IV: Izod impact test results

Sample No.	Impact Force (Joules)
1	154
2	155
3	155
4	152
6	152
7	156
8	157
9	155

The Izod impact test is a mechanical test used to determine the impact strength or toughness of a material. It involves striking a standardized notched specimen with a pendulum, and measuring the amount of energy absorbed during the fracture. The test provides a measure of a material's ability to withstand sudden impact loads and is commonly used in quality control and material selection for applications where impact resistance is critical, such as in engineering, construction, and automotive industries.

The Izod impact test is particularly valuable in assessing the behavior of materials under dynamic loading conditions. It helps engineers and manufacturers understand how a material will perform when subjected to sudden impacts or shocks, which may occur during accidents, collisions, or other high-velocity events. By measuring the energy absorbed and the extent of fracture, the test enables the identification of weak points or potential failure areas in a material.

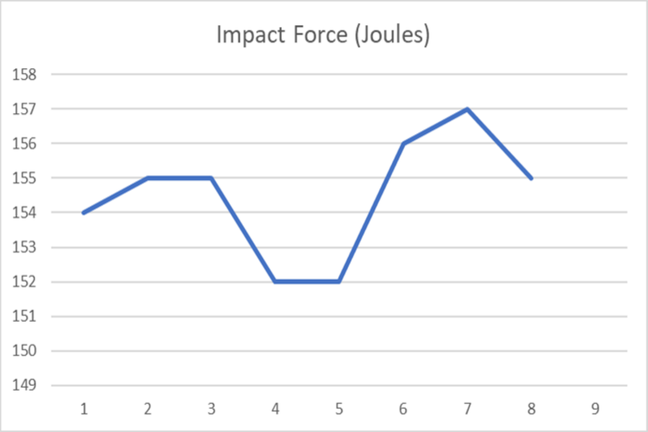

Fig 7: X-axis represents the impact force and Y-axis

D. Microstructure of Samples 2, 3, 5, 7, and 8

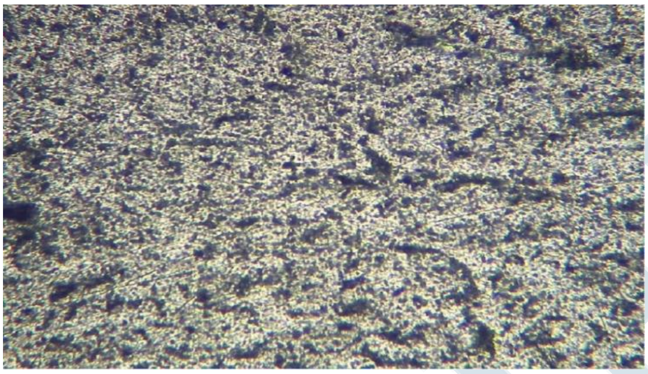

Fig 8: 89% PA, 4% BSP, 7% AF (Sample- 2)

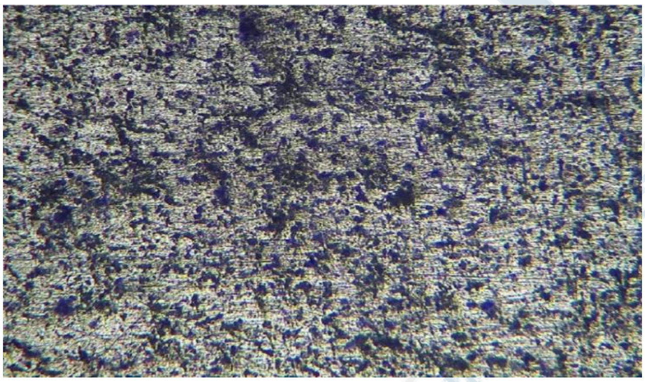

Fig 9: 86% PA, 4% BSP, 10% AF (Sample- 3)

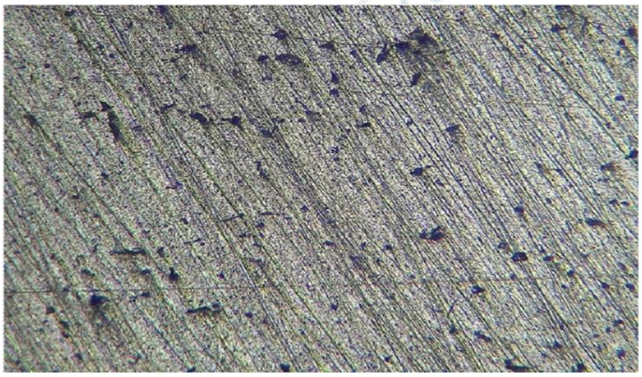

Fig 10: 86% PA, 7% BSP, 7% AF (Sample- 5)

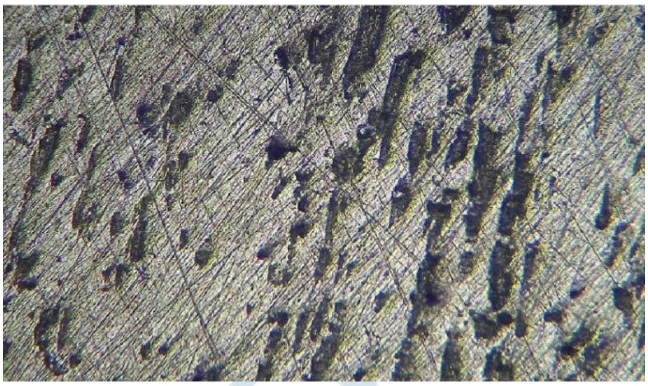

Fig 11: 86% PA, 10% BSP, 4% AF (Sample- 7)

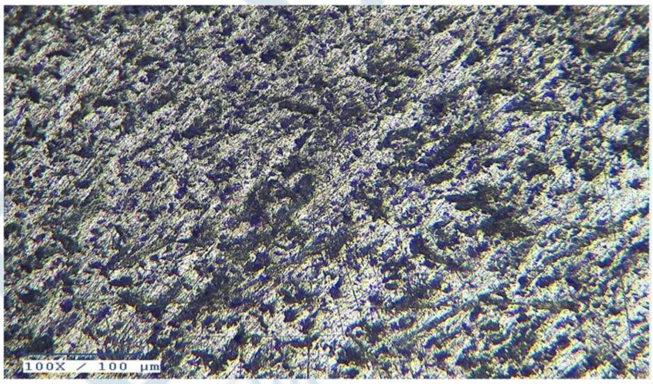

Fig 12: 83% PA, 10% BSP, 7% AF (Sample- 8)

V. CONCLUSION

In this work, pure Aluminium metal matrix composite was fabricated through the medium frequency induction furnace. Three tests namely, hardness, wear, and Izod impact test were conducted on the specimen along with microstructure analysis.

From the results of the Brinell hardness test, it is concluded that sample- 4 (89% PA, 7% BSP, 4% AF) has exhibited the highest hardness number, and sample- 8 (83% PA, 10% BSP, 7% AF) has shown the least hardness number.

From the results of the wear test, sample- 1 (92% PA, 4% BSP, 4% AF) has exhibited the highest wear rate, and sample- 8 (83% PA, 10% BSP, 7% AF) has exhibited the lowest. This means that sample- 8 (83% PA, 10% BSP, 7% AF) has the highest wear resistance among the nine samples.

From the results of the Izod- impact test, sample- 8 (83% PA, 10% BSP, 7% AF) has exhibited the highest resistance to impact force, and sample- 4 (89% PA, 7% BSP, 4% AF) and sample- 2 (89% PA, 4% BSP, 7%AF) the lowest.

From the corresponding results of the microstructure, sample- 2 (89% PA, 4% BSP, 7%AF) has a homogeneous distribution of PA, BSP, and AF.

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