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Original Research

DEVELOPMENT OF ALUMINIUM METAL MATRIX COMPOSITE FOR PRODUCTION OF CENTRIFUGAL PUMP IMPELLER

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Abstract

This study aimed to develop an Aluminum Metal Matrix Composite (AMMC) reinforced with Silicon Carbide particulate (SiC) and Iron oxide (Fe_2O_3) for centrifugal pump impellers and related components. Using a laboratory-scale stir casting process, a composite material denoted as Al-8%SiC+6%Fe_2O_3+Mg+0.5%Cu+0.5%Ni was created. Aluminum formed the continuous phase, while SiC and Fe2O3 served as the primary reinforcements. SiC content remained constant at 8%wt, while Fe2O3 content varied at 0%, 2%, 4%, and 6%wt. The fabricated plate-type samples adhered to ASTM standards for consistent dimensions. The results revealed outstanding mechanical properties in optimal samples: Yield Strength (YS) of 122MPa, Ultimate Tensile Strength (UTS) of 138MPa, Flexural Strength (FS) of 171MPa, Hardness of 55.4HRA, and Density of 0.2482g/cm3. Micro-structural analysis showed a homogeneous dispersion of reinforcements with occasional clusters. The composite with the best properties was chosen for a centrifugal pump impeller, which underwent testing on a Vj300 milling machine and delivered satisfactory performance. This study not only developed and characterized a novel AMMC but also demonstrated its successful use in a functional centrifugal pump impeller. These findings have significant implications for advancing materials science and engineering solutions across various industries.

Keywords: Aluminium Metal Matrix Composite, Silicon Carbide, Centrifugal Pump Impeller, Stir Casting Process, Mechanical Properties.

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1.0 INTRODUCTION

In engineering applications, the burgeoning interest in composite materials has gained substantial global momentum due to their exceptional versatility [1]. Composites, comprising distinct and insoluble phases intricately combined to surpass the individual constituents in both properties and structural performance, have emerged as innovative solutions [2]. This amalgamation, wherein matrices and reinforcements are meticulously bonded or mechanically interlocked, holds immense promise for revolutionizing materials' potential in technological advancements. Extensive research substantiates the advantages of composites over monolithic materials, elucidating the potential for improved properties [3]. These composites span Polymer Matrix Composites (PMCs), Metal Matrix Composites (MMCs), and Ceramics Metal Composites (CMCs), contingent on matrix and reinforcement types. Reinforcements encompass a diverse range of materials – organic, metallic, and ceramic fibers, as well as particles – interwoven with matrices comprising polymers, metals, alloys, glass, and glass ceramics. The matrix's inherent strength often pales in comparison to the reinforcing fibers, driving a quest for effective dispersion mechanisms [4]. In Metal Matrix Composites (MMCs), the past two decades have witnessed their development for bolstering specific metal properties [5]. MMC classifications encompass particulate, short fiber, and continuous fiber-reinforced materials, with the former being more cost-effective than the latter. Although continuous fiber-reinforced metals present processing challenges due to their associated costs, discontinuous reinforced MMCs, particularly aluminum matrices, permit conventional metalworking processes like forging, rolling, and extrusion [6]. Mainly employing matrix materials such as aluminum, titanium, magnesium, and copper, MMCs incorporate major reinforcements like silicon carbide and alumina [7]. By harnessing metal matrices, composites can attain unparalleled strength and stiffness. However, despite superior attributes such as abrasion resistance, dimensional stability, and resistance to degradation, the weight and production costs of metal matrix composites present certain limitations. Particulate composites, exemplified by SiC particle-reinforced aluminum, exhibit remarkable enhancements in modulus without compromising density [8].

Within the domain of engineering applications, the centrifugal pump emerges as a pivotal component. Its ability to harness rotational energy for fluid movement facilitated by impellers underscores its importance [9]. Impeller design, encompassing open, semi-open, or closed variants, profoundly influences pump performance, with the orientation and geometry of vanes significantly dictating efficiency [10]. Traditionally, materials like cast iron, steel, brass, bronze, copper, and plastics have dominated impeller production. Cast iron, while widely used, carries drawbacks including brittleness, corrosion susceptibility, and excessive weight. Recent strides have led to the integration of novel materials and non-ferrous alloys, but the spotlight is now on cost-effective, high-performance materials, with composites emerging as a prominent contender. Particularly in slurry conditions, composite materials like ceramic slurry impellers offer unprecedented advantages over conventional counterparts [11]. This study embarks on the development of an Aluminium Metal Matrix Composite aimed at producing pump impellers through the stir-casting process. The impetus arises from the critical role impellers play in centrifugal pumps, and the subsequent need to address challenges posed by corrosion, cavitation, and material weight. Aluminium Metal Matrix Composites emerge as a promising material with the potential to overcome these hurdles, while simultaneously bolstering efficiency and performance [12]. With the ultimate goal of producing a pump impeller for a Vj300 milling machine, this study strives to contribute to local technology development, economic empowerment, and energy efficiency improvements [13].

2.0 LITERATURE REVIEW

D'Errico et al. [14] evaluated the tensile strength of SiC and Al_2O_3 reinforced AMCs at a temperature range of 300°C–500°C. It was observed that 20% of SiC with Al2618 has a higher tensile strength than 20% of Al_2O_3 with Al.2618. Ductility was improved remarkably at high temperatures, especially with fine particle reinforcement. 20% of Al_2O_3 with Al2618 has a higher tensile strength than 20% of Al_2O_3 with Al6061 within 300°C–350°C, which indicates that the selection of the matrix alloy plays a crucial role in the enhancement of the mechanical property.

Sivachidambaram et al. [15] developed a predictive model to determine the optimum weight percentage of SiC in Al-SiC composites. The Aluminium-silicon was manufactured using different wt % of SiC reinforcement (4%, 8%, and 12%). Microhardness, tensile tests, and bend tests were conducted to analyze the mechanical behavior of SiC wt %. The results indicated that an increase in SiC wt % resulted in higher microhardness and tensile strength while diminishing bend strength and elongation (%) of the material. Employing an empirical model, an optimized SiC wt % in the Al-SiC composite was determined. The optimized outcome, 7.66 wt % of SiC, exhibited favorable characteristics within the range of 4% to 12% SiC reinforcement. Al-SiC with 8% SiC demonstrated excellent microhardness and tensile properties while maintaining ductility, leading to its selection as the optimized SiC wt % for Al-SiC composites.

Akindapo and Bucham [16] developed a hybrid particle-reinforced aluminium alloy metal matrix composite specifically applied in the production of brake discs. The optimal sample exhibited a uniform microstructure with an optimal composition, featuring a density of 3.15 g/cm³, hardness of 68 VHN, Tensile Strength of 221.16 N/mm², Impact Energy of 6.0 J, Wear Rate of 0.0001208 g/m, and Thermal Conductivity of 64.79 W/m·K. The results indicated that the developed composite addressed issues related to weight, offering advantages over As-cast nodular cast iron samples.

An et al. [17] explored the effect of alloying elements (Si, Cu, Ti, and Mg) and their concentrations on the wettability in Al/SiC systems using the dispensed Sessile drop method. Their findings demonstrated that Si weakened or even inhibited the formation of Al4C3, leading to improved wettability due to adsorption. While Magnesium facilitated wettability by disrupting oxide films on Al and SiC surfaces, its effect was limited in clean Al/SiC systems.

Sadashivappa et al. [18] delved into the mechanical properties of Aluminum Matrix Composites. They reinforced Al6061 alloy matrix with weight fractions of 2%, 4%, and 6% of iron oxide (Fe_2O_3) particles (40µm) using stir casting. Standard tests were conducted for tensile, bending, impact, and hardness properties. The results indicated that the mechanical properties of the composite improved with increasing weight percentage of iron oxide up to 4% reinforcement. Improved bonding between the reinforcement and aluminum, along with a well-distributed microstructure, contributed to the enhanced properties. The maximum enhancement was observed at 6wt% Fe_2O_3.

Ghosh et al. [19] explored the microstructural modification and strengthening mechanism of friction stir-casted Aluminum Metal Matrix Composites. Grain refinement played a role in enhancing microhardness, while tensile strength was influenced by grain size, orientation, and defects. AMCs reinforced with 20-30wt% SiCp were fabricated through stir casting and powder metallurgy methods. These composites exhibited superior hardness, radial crushing load, and wear resistance compared to cast iron, suggesting their potential as replacements for poppet valve guides.

In the field of cast MMCs, research has focused on the modeling of particle pushing by solidifying interfaces, considering factors such as thermal properties, solute diffusion, gravity, and microgravity. Daoud et al. [20] proposed models accounting for interface shape and solute presence, showing that the interface shape becomes curved upon interaction. The balance between forces generated during particle rejection and pushing determines the outcome. Parameters such as density difference, particle size, thermal conductivity, and alloy composition influence these forces and the solidification front shape.

3.0 MATERIALS AND METHODS

3.1 Materials

The following materials were used in this research work; Aluminium alloy 6061, Iron Oxide (Fe_2O_3) powder shown in Plate I, Silicon carbide (SiC) particulates shown in Plate II, Magnesium powder, and Sodium hydroxide. The chemical composition of Aluminium type 6061 and the mechanical properties of the materials used are shown in Tables 1 and 2 respectively.

Table 1: Chemical Composition of Al6061 by Weight [21]

Chemical Composition	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Bal
Al6061	0.62	0.23	0.22	0.03	0.84	0.22	0.10	0.1	Al

Table 2: Properties of Materials [21]

Properties	Al6061	SiC	Fe_2O_3
Elastic Modulus (Gpa)	70-80	410	
Density (g/cc)	2.7	3.1	5.74
Poison's Ratio	0.33	014	
Hardness, Vickers	107	2800	520
Tensile Yield Strength (MPa)	276	3900	-
Ultimate Tensile Strength (MPa)	310		

Plate I: Iron Oxide Powder

Plate II: Silicon Carbide Powder

3.2 Equipment

The equipment used in this research work are shown in Table 3;

Table 3: List of Equipment Used

S/N	Name of Equipment	Specification	Model	Brand
1.	Vickers Hardness Testing Machine	For steel, carbide, ceramic, glass, and non-ferrous	HV 50	Shanghai Lianer
2.	Universal Testing Machine	Maximum of 10 KN	Mecmesin-Omnitest-10	Mecmesin-Omnitest
3.	Universal Testing Machine	Maximum 200 KN	Avery Tester	UTM-200
4.	Optical microscope	X1600	Zoom8	Tutoy
5.	SEM Microscope	X1500	Phenom ProX Desktop SEM	Phenom-World
6	Crucible Furnace	Maximum 2000 °C		
7	Charpy Impact Testing Machine	Maximum 100J	Norwood Equipment	

3.3 Methods

3.3.1 Raw Material Processing

The SiC and Fe_2O_3 particles were sieved with appropriate sieves to achieve the desired average particle sizes. The particle size analysis for sample preparation followed the guidelines of BS 1377: 1990 [22].

3.3.2 Sample Preparation and Stir Casting Process

Stir-casting, a widely used liquid metallurgy method for composite development was employed as the primary production process for the centrifugal pump impeller [22]. The commercially available cast aluminium alloy Al6061 was meticulously cleaned and preheated below the aluminium melting temperature for 30 minutes to eliminate moisture. Magnesium powder was also preheated for 45 minutes to remove moisture and gases from the particle surfaces. Similarly, SiC particulates and Fe_2O_3 were preheated for 45 minutes to remove impurities and moisture. The SiC particulates were sieved to achieve uniform particle sizes. The chosen reinforcement was black silicon carbide grains (average particle size 30 µm or 600 grits) [23]. The preheated aluminium was charged into the furnace and heated to 750°C to form molten aluminium before adding sodium hydroxide to degas the melt, based on previous study findings [24]. Considering production costs and material properties, a SiC reinforcement fraction of 8 vol % was selected to fabricate the composite impeller [24]. Stirring of the melt was conducted using a steel shaft with three equally spaced blades at its base. Stirring was carried out at 300 rpm and 700°C. The preheated reinforcement was introduced into the melt and the stirring speed was reduced to 100 rpm due to the increased viscosity of the mixture.

To enhance wetting conditions in the ceramic-metal system, the matrix alloy composition was modified by adding a small amount (< 1%) of Mg as a wetting agent to reduce surface tension of the molten melt [25]. Iron oxide particles were individually added at 0, 2, 4, and 6wt% to the superheated liquid aluminium at 720°C. The appropriate quantity of reinforcement was added while stirring. Continuous stirring of the molten aluminium occurred for the next 15 minutes to ensure a homogeneous mixture before pouring it into moulds, shown in Plate III, to create test samples [26]. The liquid Al6061-SiC+Fe_2O_3 composite was then poured into sand moulds and allowed to solidify. This process was repeated by varying the weight percentage of iron oxide while keeping silicon carbide constant at 8wt% before casting the impeller. Subsequent machining of the parts from the moulds was performed to prepare specimens for various experimental tests. The sample with the most favorable combination of mechanical properties was chosen for producing the prototype centrifugal pump impeller.

Plate III: Sand Mould Preparation for the Samples

3.4 Experimentation

The following mechanical tests were carried out:

i. Tensile test: The tensile tests were performed using the Universal Testing Machine (UTM). The specimens were prepared according to ASTM E08-8 standards using BAOMA EDM machine. The specimen was fitted in a UTM of capacity 200kN. During testing the load applied and the displacements reading were recorded to calculate the stress and strain. From the experiments, Yield Strength, and Ultimate Tensile Strength were determined. The results were based on the average of three samples.

ii. Flexural test: The bending test experiment was conducted on Mecmesin-Omnitest-10, a Universal Testing Machine for all four compositions. The specimen prepared was as per the ASTM E290 and ISO-178 standards. The specimen was prepared with the following dimensions to study the flexural behavior of the composite. The three-point bending specimen was used to characterize the flexural strength. Flexural strength is the stress at failure of the material under the flexural load. Compositions of the composites were tested as per the standard testing procedures to find the bending properties.

iii. Impact test: The Charpy impact test was conducted for all four different compositions to absorb the required energy to initiate the crack and continue till the specimen fractured. Test specimens were machined from the cast samples and prepared as per ASTM standard of the square bar (55mmX10mmX10mm) with 45-degree V notch cutting at the middle of the specimen, and the impact test was carried out at room temperature by blowing the pendulum. The specimen was prepared as per ASTM E23 standards.

iv. Hardness test: All four compositions of the composites were tested for their hardness using the Vickers hardness testing machine at room temperature. The specimen dimensions used were Ø30x 15mm. The measurement was done at different locations on the surface of the specimen.

To characterize the hardness, which is resistance to the deformation of the solid material. The test was conducted based on the depth of penetration under the application of the external uniform load. For the hardness test, ASTM E23 standards were prescribed for the specimen preparation. The hardness tests were carried out for all four compositions using the diamond indenter in the Vickers Hardness Testing Machine with a force of 5kgf. Vickers micro hardness measurements were evaluated by applying an indentation load of 5kgf allowing for a dwell time period of 15s. The test was performed by indenting the indenter in 10 places on the surface of the testing samples; the readings were taken and average mean values were tabulated for the composites.

v. Microstructural Examination: Microstructural examination was conducted using a Tutoy 1600X Zoom 8 USB Microscope. A 10x10mm sample was prepared to fit the microscope's field of view. The sample was carefully cleaned with methanol to eliminate surface dirt. The digital microscope was powered on, and its software was launched on the computer. The microscope was set to a specific magnification of 80µm for clarity. The sample was placed in the designated slot, and the lens was adjusted to focus on it. The transmission light was set to the appropriate brightness. The magnification settings were fine-tuned to ensure that a clear image was captured. Once done, the sample was removed, and the microscope and software were turned off.

vi. Scanning Electron Microscope (SEM): SEM/EDS studies were performed to analyze the microstructural characteristics of the optimized samples. To be examined under SEM, the sample had to be suitably sized for the specimen chamber when securely mounted on a specimen holder. Conductivity was essential for effective imaging, and grounding was necessary to prevent electrostatic charge accumulation during electron irradiation. The samples underwent the polishing and cleaning procedures outlined in the protocol [27].

3.5 Production of Prototype Composite Centrifugal Pump Impeller

The production process for the composite centrifugal pump impeller involved the following sequential steps;

(i) Pattern Preparation: A wooden pattern was meticulously crafted based on standardized dimensions of conventional centrifugal impellers. This pattern was divided into two sections, the cope, and the drag, and its size was adjusted to accommodate anticipated shrinkage during cooling, solidification, and subsequent finishing operations [28].

(ii) Core Formation: A core, essential for creating the impeller's internal surface, was crafted from foundry sand fortified with resin for enhanced strength. Core boxes were employed in this process.

(iii) Mould Creation: The mould was constructed using specially prepared foundry sand, pattern, and core. The formation of a sprue allowed the molten composite to be poured into the mould cavity, and a riser was established to supply the casting as it underwent the cooling and solidification process.

(iv) Composite Pouring: The optimized composite formulation, in molten form, was introduced into the mould via the sprue. Over a period, the composite solidified within the mould to yield the composite centrifugal pump impeller.

(v) Demoulding and Inspection: The mould was disassembled, revealing the newly formed impeller. A thorough inspection ensured the impeller's quality and integrity.

(vi) Finishing Touches: To enhance both aesthetics and functionality, machining, fettling, and deburring processes were executed. These final operations contributed to refining the impeller's appearance.

4.0 RESULTS AND DISCUSSION

4.1 Results

4.1.1 Tensile Test Result

The result for the tensile properties is shown in Table 4;

Table 4: Tensile properties of Aluminium - Silicon Carbide + Iron oxide Composites

Sample	Material Composition	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Percentage Elongation (mm)	Young's Modulus N/mm^2
1	Al6061-8%SiC	95	119	10	63.33
2	Al6061-8%SiC+2%Fe_2O_3	102	122	13	72.85
3	Al6061-8%SiC+4%Fe_2O_3	51	71	6	42.50
4	Al6061-8%SiC+6%Fe_2O_3	95	138	6	75.00

4.1.2 Flexural Test Result

The flexural test result is shown in Table 5;

Table 5: Flexural properties of AA6061-SiC+ Fe_2O_3 Composites

Samples	Material Composition	Max Force (N) at 5% (N)	Max (MPa) at 5% Strain	Percentage Elongation	Calculated Flexural Strength (MPa)
1	Al6061-8%SiC	460.476	325	16.4	165.78
2	Al6061-8%SiC+2%Fe_2O_3	472.86	264	15.3	170.24
3	Al6061-8%SiC+4%Fe_2O_3	357.93	279	17.2	128.84
4	Al6061-8%SiC+6%Fe_2O_3	448.88	318	17.2	161.60

4.1.3 Impact Test Result

The Charpy impact test result is shown in Table 6;

Table 6: Results of Impact Testing

Samples	Material Composition	1st test (J)	2nd test (J)	3rd test (J)	Average Value (J)
1	Al6061-8%SiC	5.32	5.24	5.40	5.32
2	Al6061-8%SiC+2%Fe_2O_3	4.71	4.70	4.71	4.72
3	Al6061-8%SiC+4%Fe_2O_3	5.94	5.91	5.97	5.94
4	Al6061-8%SiC+6%Fe_2O_3	3.49	3.48	3.49	3.49

4.1.4 Hardness Test Result

The result for the Vickers hardness test is shown in Table 7;

Table 7: Result of Hardness of Composite.

Samples	Material Composition	Test 1(HRA)	Test 2(HRA)	Test3(HRA)	Average (HRA)
1	Al6061-8%SiC	54.2	54.1	54.1	54.1
2	Al6061-8%SiC+2%Fe_2O_3	55.0	54.6	54.8	54.8
3	Al6061-8%SiC+4%Fe_2O_3	54.4	54.4	54.4	54.4
4	Al6061-8%SiC+6%Fe_2O_3	55.8	55.8	55.8	55.8

4.1.5 Result of Density Analysis

The result of the density analysis is shown in Table 8;

Samples	Material Composition	Weight (g)	Volume (cm^3)	Density (g/cm^3)
1	Al6061-8%SiC	17.950	70.695	0.2539
2	Al6061-8%SiC+2%Fe_2O_3	17.656	70.695	0.2497
3	Al6061-8%SiC+4%Fe_2O_3	17.719	70.695	0.2506

4.1.6 Result of the Microstructural Studies

The optical micrographs of Al6061-SiC+ Fe_2O_3 composite for the various iron oxide are shown in Plates IV through VII;

Plate IV: Microstructure of Al6061-8%SiC (X1600)

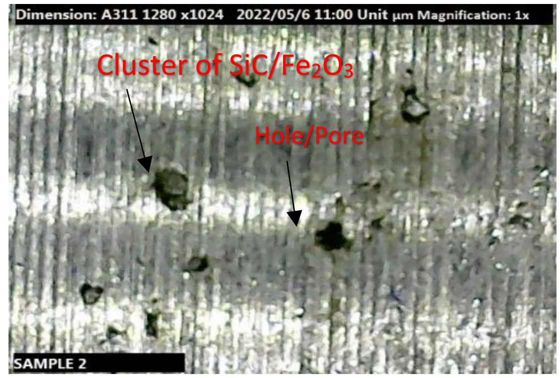

Plate V: Microstructure of Al6061-8%SiC+2%Fe_2O_3 (X1600)

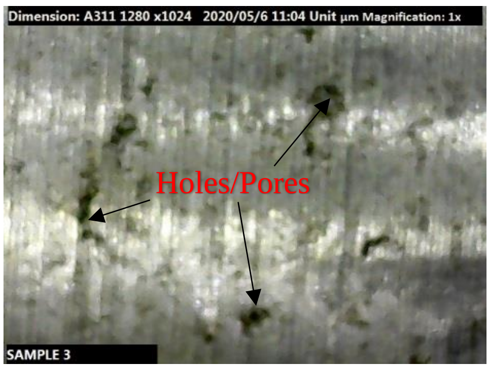

Plate VI: Microstructure of Al6061-8%SiC+4%Fe_2O_3 (X1600)

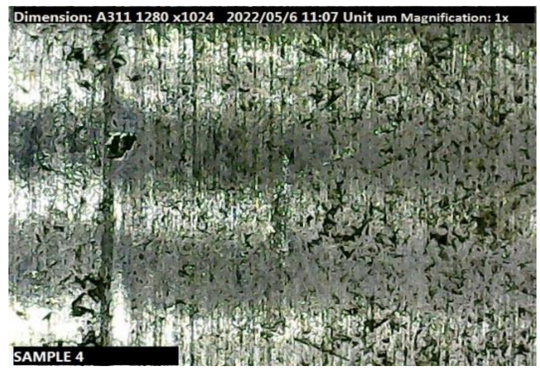

Plate VII: Microstructure of Al6061-8%SiC+6%Fe_2O_3 (X1600)

4.1.6.1 SEM/EDX Results

The optical and SEM morphologies of the optimized fabricated aluminium matrix composites are shown in Plates VIII through XI;

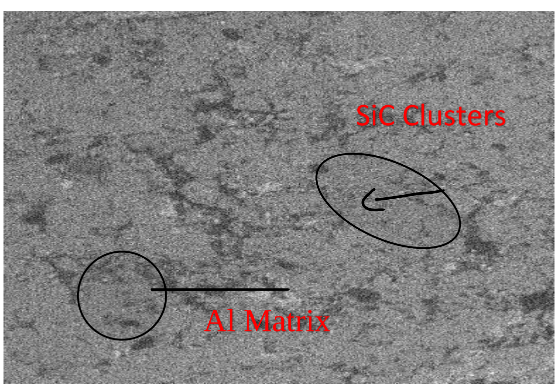

Plate VIII: Morphology of Al6061(X300)

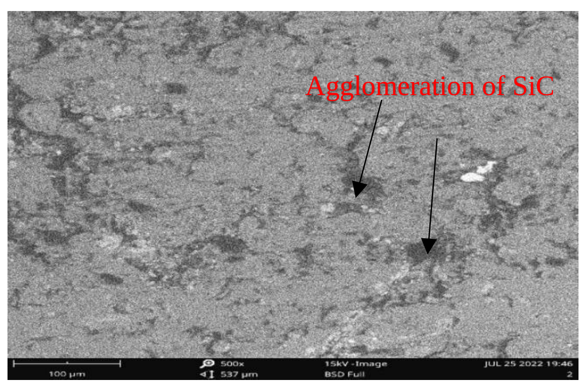

Plate IX: Morphology of Al6061 (X300)

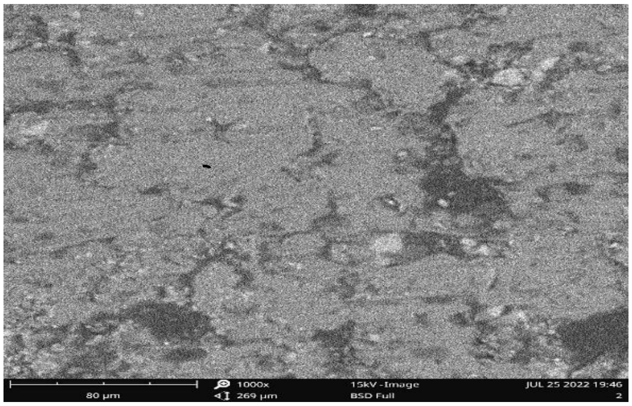

Plate X: Morphology of Al6061 (X1000)

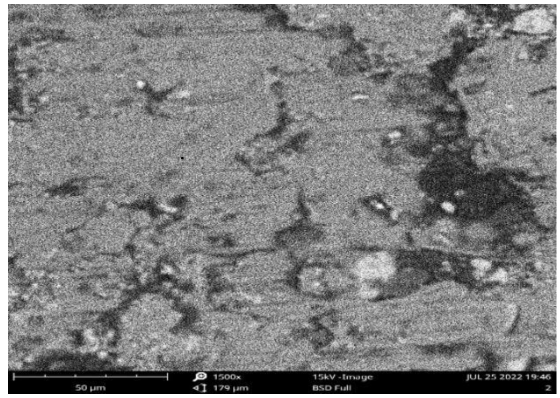

Plate XI: Morphology of Al6061 (X1500)

4.2 Discussion of Results

4.2.1 Discussion of Tensile Test Result

The result obtained from the tensile test conducted is presented in Figure 1.

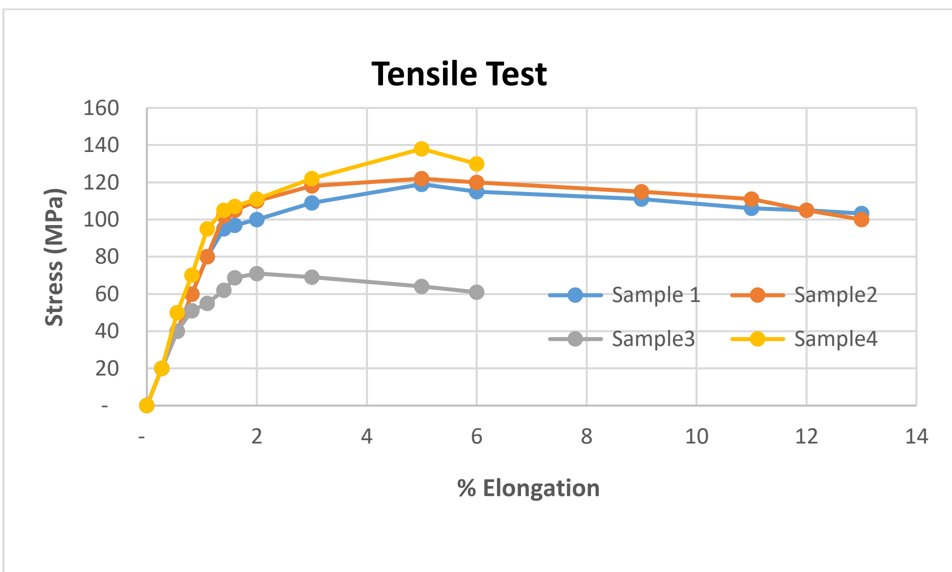

Figure 1: Tensile Test Curve Diagram

Figure 1 indicates the obtained tensile test curve of the sample specimens investigated. The figure reveals the effect of reinforcement on AA6061-SiC-Fe_2O_3 composite's tensile properties was evident. Results were consistent with findings by [29, 30], except for sample 3. A composition increase of 2wt% led to a UTS of 122MPa, while an increase from 2wt% to 4wt% caused UTS to drop to 71MPa. Subsequently, a composition increment from 4wt% to 6wt% yielded UTS of 138MPa. This aligns with the 3 to 5wt% composition range observed in literature as optimal for MMCs' mechanical properties [31]. Table 4 summarizes AA6061-SiC+Fe2O3 composite's tensile properties.

Sample 2 boasts both high Young's Modulus and ductility, whereas Sample 4 is stiffer with less ductility. Reinforcement addition improves tensile strength through better microstructure distribution, stirring, and reduced porosity [30]. Sample 3 and Sample 4 show reduced percentage elongation in reinforced composites. AA6061-SiC+2%Fe2O3 composite maintains ductility after yielding, enhancing tensile strength, yield, and elongation. Copper reinforcement presence decreases aluminium composite's strain to failure, potentially due to agglomeration at higher concentrations, leading to strength reduction [32].

4.2.2 Discussion of Flexural Test Result

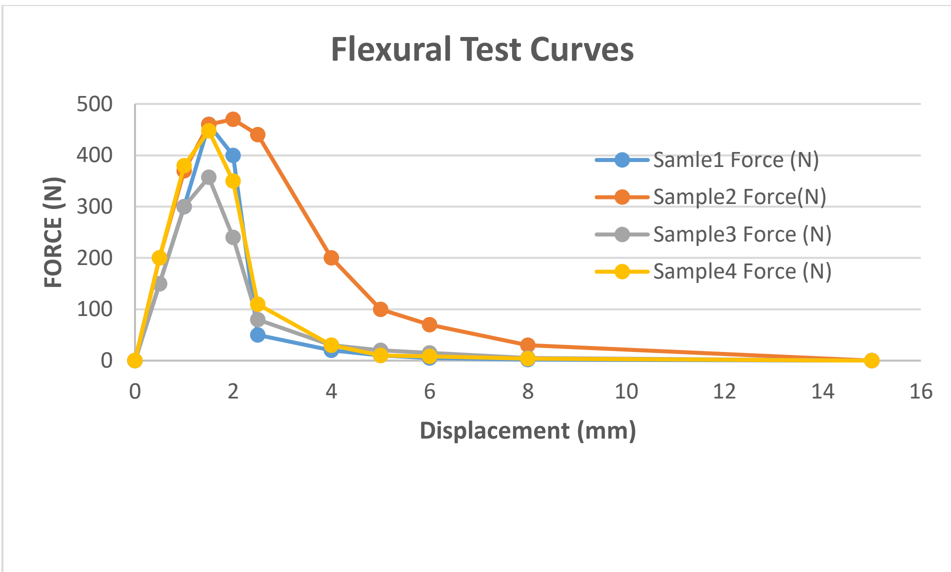

Figure 2: Bending Curve of Composite for Various Percentages of Iron Oxide

The bending behavior of AA6061-SiC+Fe2O3 composite at different weight percentages (2wt%, 4wt%, and 6wt%) of iron oxide reinforcement is illustrated in Figure 2. The plots revealed a trend where bending resistance initially increases from 165.75 MPa to 170.24 MPa with a rise in iron oxide content, then decreases to 128.84 MPa, followed by a subsequent increase to 161.60 MPa for 0wt%, 2wt%, 4wt%, and 6wt% respectively. Notably, the bending properties of the composite exhibit a decline up to 4wt% of reinforcement, beyond which the addition of iron oxide leads to an increase in bending properties. The calculated flexural strength and percentage elongation are summarized in Table 5. The results highlight the influence of iron oxide on the flexural strength of the composites. The observed decrease in flexural strength at a certain point may be attributed to a sudden brittle behavior that limits gradual plastic deformation. It is worth noting that the introduction of nickel beyond 0.4wt% in aluminum matrix composites has been shown to substantially reduce percentage elongation, yield strength, ultimate tensile strength, hardness, and impact strength [33].

4.2.3 Discussion of Impact Test Result

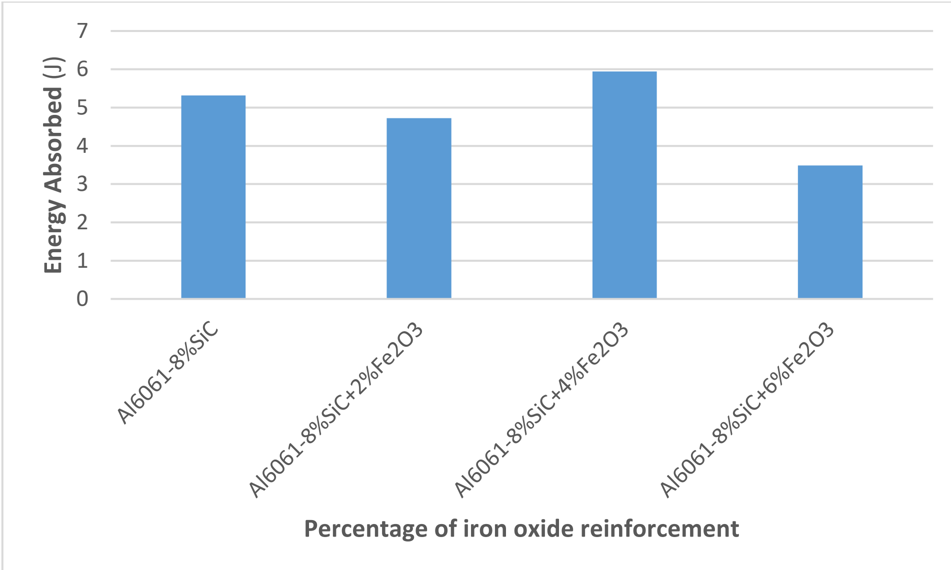

Figure 3: Variation of Impact Strength with Percentages of Iron Oxide Reinforcement

Aluminum 6061 is renowned for its toughness, resulting in a high energy absorption capacity. Furthermore, due to the utilization of the liquid phase method in the preparation of these composites, they exhibit elevated impact toughness compared to alternative techniques. As depicted in Figure 3 from Table 6, the impact strength of the composite demonstrates a discernible trend: an increase up to 4%wt of iron oxide content, followed by a subsequent decrease. This increment in impact strength can be attributed to the material's ability to retain its ductility, consequently enabling greater energy absorption during fracture. The highest impact energy absorption is achieved at 4%wt of iron oxide, with values of 4.7J and 5.94J for compositions with 2%wt and 4%wt of iron oxide, respectively, before decreasing to 3.48J. This decline might be attributed to the brittle nature observed at 6%wt. Additionally, the outcomes diverge from the linear trend reported by [29] with SiC addition. The heightened impact energy is credited to the robust presence of SiC and Fe_2O_3 particulate reinforcements, enhancing resistance to fracture and overall toughness [29].

4.2.4 Discussion of Hardness Test Result

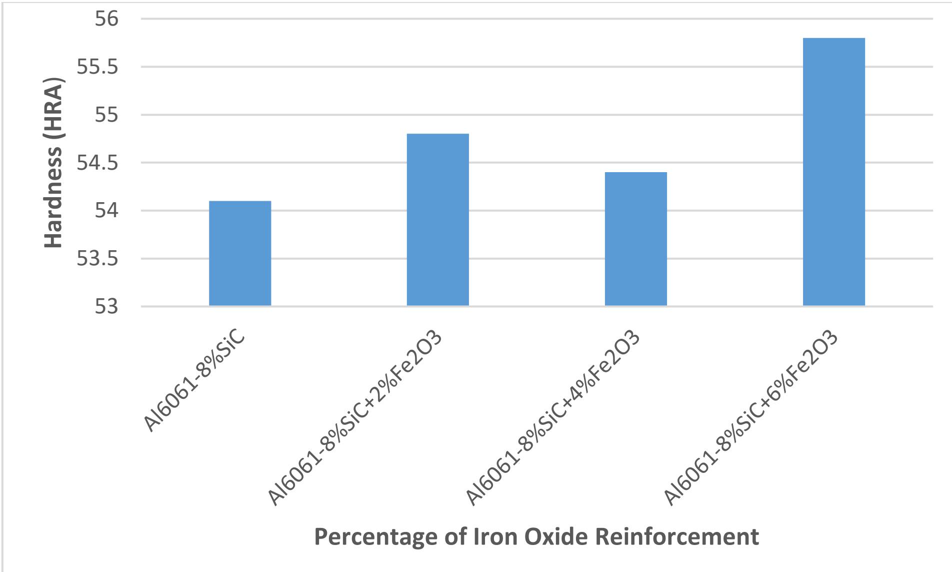

Figure 3: Variation of Impact Strength with Percentages of Iron Oxide Reinforcement

Aluminum 6061 is renowned for its toughness, resulting in a high energy absorption capacity. Furthermore, due to the utilization of the liquid phase method in the preparation of these composites, they exhibit elevated impact toughness compared to alternative techniques. As depicted in Figure 3 from Table 6, the impact strength of the composite demonstrates a discernible trend: an increase up to 4%wt of iron oxide content, followed by a subsequent decrease. This increment in impact strength can be attributed to the material's ability to retain its ductility, consequently enabling greater energy absorption during fracture. The highest impact energy absorption is achieved at 4%wt of iron oxide, with values of 4.7J and 5.94J for compositions with 2%wt and 4%wt of iron oxide, respectively, before decreasing to 3.48J. This decline might be attributed to the brittle nature observed at 6%wt. Additionally, the outcomes diverge from the linear trend reported by [29] with SiC addition. The heightened impact energy is credited to the robust presence of SiC and Fe_2O_3 particulate reinforcements, enhancing resistance to fracture and overall toughness [29].

4.2.4 Discussion of Hardness Test Result

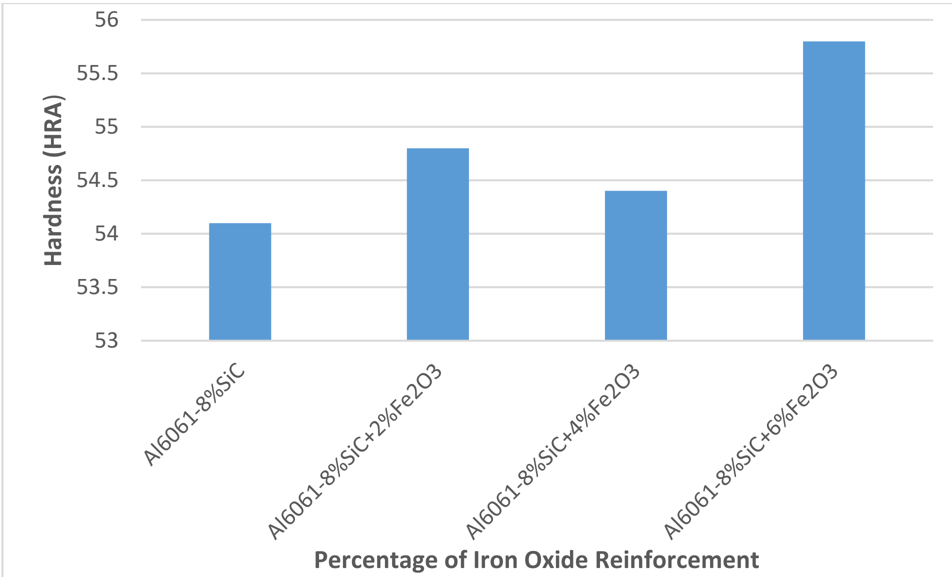

Figure 4: Variation in Hardness of Composite with Percentage of Iron Oxide Reinforcements

Vickers hardness testing yielded average hardness values shown in Table 7, subsequently converted to HRA. It is assumed that uniform distribution of silicon carbide and iron oxide particles within the aluminum 6061 matrix results in consistent hardness values throughout the specimen. Figure 4 displays the average hardness values for all compositions. It is evident that an increase in iron oxide content affects the hardness of the AA6061-SiC+Fe_2O_3 composite. The highest hardness value of 55 HRA was achieved with 6wt% reinforcement. Research indicates that higher hardness correlates with reduced porosity [34].

4.2.5 Discussion of Density Analysis

From the density analysis in Table 8, it was observed that there is slight reduction of density of the composite with sample 4 and sample 2 having the least densities of 0.2482 and 0.2497g/cm^3 respectively. This is lower than the density of aluminium 6061 which is 0.27g/cm^3.

4.2.6 Discussion of Micro-structural Analysis

The micro-structural analysis of the specimens shown in Plate IV through VII, revealed that SiC particulates were uniformly distributed in the matrix, but the presence of porosity around the SiC was noted. This observation aligns with the findings of [35]. The micro-graph displayed a uniform distribution of SiC and Fe_2O_3 reinforcements. Fine grain refinement was evenly and consistently observed within the matrix due to the addition of Fe_2O_3. Clusters of reinforcement were also observed, and these could be attributed to certain process parameters that have not been fully optimized, such as stirring speed, preheating temperature, and the type of furnace used, among others. The solidification process played a critical role in the quality of the grain and in the occurrence of an in-homogeneous distribution, which could manifest as defects [36, 37].

4.2.6.1 Discussion of SEM Analysis

The optical and SEM morphologies of the optimized fabricated aluminum matrix composites are presented in Plate VIII through XI. The micro-structure was examined based on the weight fraction of reinforcement. The observations indicate that the morphology results in a uniform distribution, with some instances of clustering or agglomeration. The micro-graph provides insight into the phase distribution and the features of Al/SiC inter-facial bonding, as the properties of this matrix composite depend on these attributes [38]. Additionally, it was noted that there exists good bonding between the matrix and the reinforcement particulates, especially with SiC, leading to enhanced load transfer from the matrix to the reinforcement material [34].

4.3 Production of the Pump Impeller

The pump impeller shown in Plate XII, was designed specifically for the Vj300 Series milling machine, using the dimensions of the existing sample as a reference. The composite cast impeller underwent precision machining to ensure its dimensions matched the original sample accurately. To guarantee smooth operation, a thorough balancing procedure was carried out on the impeller, ensuring that it did not exhibit any wobbling or vibration when put into use. This step aimed to prevent any potential disruptions or inefficiencies during the milling machine's operation. Following the balancing process and other necessary adjustments, the impeller was securely attached to the milling machine. A comprehensive functional test was conducted to assess the impeller's performance under basic operating conditions. The results of this test indicated that the impeller performed optimally, confirming its suitability for its intended function in the Vj300 Series milling machine.

Plate XII: Produced Pump Impeller

5.0 Conclusion and Recommendation

5.1 Conclusion

The research endeavor successfully created a centrifugal pump impeller by formulating a composite material consisting of silicon carbide and iron oxide particulates as reinforcements, combined with aluminum as the matrix. The stir-casting technique was employed for both the formulation and fabrication processes. The key findings and implications of this work are summarized as follows:

The investigation led to the development of an alternative aluminum metal matrix composite (AMMC), labeled as Al6061-8%SiC+6%Fe_2O_3, which emerged as the most promising choice among the various compositions tested. This composite demonstrated significantly improved mechanical and machining properties due to the addition of iron oxide alongside the SiC reinforcement. The reinforcing effect on the material was clearly evident.

The specimen with a composition of 8% SiC and 6% Fe2O3 particulates exhibited superior mechanical characteristics compared to all other samples produced. This particular specimen achieved remarkable Ultimate Tensile Strength, Flexural Strength, Impact Strength, and hardness, making it the standout choice. Its higher Young Modulus further reinforced its position as the best sample.

A significant achievement of this work was the successful production and testing of the centrifugal pump impeller designed for Vj300 milling machines. The impeller exhibited excellent basic functional performance during testing.

5.2 Recommendation

Looking ahead, several recommendations are made for future research endeavors in this field. These include exploring the use of various reinforcements at the nanoscale level, optimizing process parameters in composite fabrication through liquid processing techniques, and utilizing software tools to review, refine, and potentially validate existing findings.

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