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Investigating the Effect of Adding Fe_2O_3 And SiC on the Mechanical, Electrical and Magnetic Properties of Aluminum Based Hybrid Nano Composites Employing Powder Metallurgy Technique

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ABSTRACT

Fabrication of Al/Fe_2O_3+SiC hybrid nanocomposites using the powder metallurgy method is the focus of this study. Different concentrations of Fe_2O_3 (Hematite) (2, 4, 6, 8 and 10wt%) were incorporated into the materials at the same time as SiC (Silicon Carbide) was maintained at a consistent ratio of 5wt%. The synthesized specimens underwent comprehensive testing such as FESEM (Field Emission Scanning Electron Microscopy) and XRD (X-Ray diffraction) for microstructural analysis; compressive strength, wear resistance and Vickers microhardness for mechanical properties assessment; and electrical conductivity, resistivity, and magnetic hysteresis for evaluation of electrical behavior. Microstructure examinations revealed that SiC and Fe_2O_3 nanoparticles were uniformly distributed throughout the aluminum matrix. In terms of mechanical tests done on this material, there were significant improvements in compressive strength amounting to a 195.20% increase, wear rate which went down by 78.72%, as well as an improvement in microhardness by 44.91% compared with pure aluminum. With the addition of 10wt.% Fe_2O_3, electrical resistivity increased by about 54% whereas conductivity dropped by almost 35.01%. On the other hand, hysteresis loop analysis showed an increase in saturation magnetization (Ms) as well as remanence magnetization (Mr), with increasing amounts of Fe_2O_3 in hybrid nanocomposite. This research signifies transformative progress that can be accomplished when SiC and Fe_2O_3 nanoparticles are strategically infused into aluminum. highlighting their potential for advanced material applications.

1. Introduction

Hybrid nanocomposites are generally composed of a mixture of a base material and two or more additives which usually contain nano-sized particles [1]. These materials are specifically referred to as aluminum matrix nanocomposites (AMNCs) when aluminum serves as the matrix [2,3]. There are specific advantages offered by aluminum such as high strength to weight ratio, good corrosion and wear resistance and it is cost effective [4]. Aluminum Matrix composites with exaggerated wear

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properties have generated Increased Interest in advanced applications over the one last decade [5]. However, the mechanical and physical properties of aluminum are improved by incorporation of reinforcements that give them attributes that cannot be achieved through its use alone [6]. AMNCs find widespread applications in medicine, electronics, telecommunications and renewable energy [7,8]. The main techniques for making hybrid nanomaterials include powder metallurgy and stir casting [9]. Thus, powder metallurgy ensures equal dispersion of additives within the matrix while agglomeration of reinforcing materials may occur in case of stir casting method [10]. Engineering components produced using this method are highly accurate hence it is cost-effective. In this process, the powder materials are mixed well so that the reinforcements will be evenly distributed all over the matrix. Then, they are pressed at a high pressure to form green compacts which are subsequently sintered in an environment free of oxygen at temperatures below that of melting points of materials [11]. To find applicable areas that can employ these new nanocomposites it is important to subject the synthesized samples to complete set of tests to examine their microstructural properties, mechanical behavior and unique properties [12,13]. There are many previous researches on aluminum matrix nanocomposites manufactured by powder metallurgy, which were used for many different industrial engineering applications. Manohar et al. analyzed the microstructure and mechanical properties of Al 7075/ graphite/ SiC hybrid composites synthesized using the powder metallurgy technique [14] produced a hybrid nanocomposite; Al/ Fe_2O_3/ SiC using the powder metallurgy method, then studied the mechanical properties such as wear resistance and hardness [15]. Finally, Maleki *et al*., [16] investigated the effect of magnetic nickel ferrite on aluminum matrix, in that study, NiFe2O4 nanoparticles were added to aluminum matrix composites to improve their mechanical and magnetic properties. The current study investigated the aluminum-based hybrid nanocomposites with low weight percentages of Fe_2O_3 (2-10wt.%), and constant 5wt.% of SiC as reinforcements. It is desired to find out the improvement in microstructure, mechanical, electrical, and magnetic properties with such percentages of reinforcements.

2. Experimental Procedure

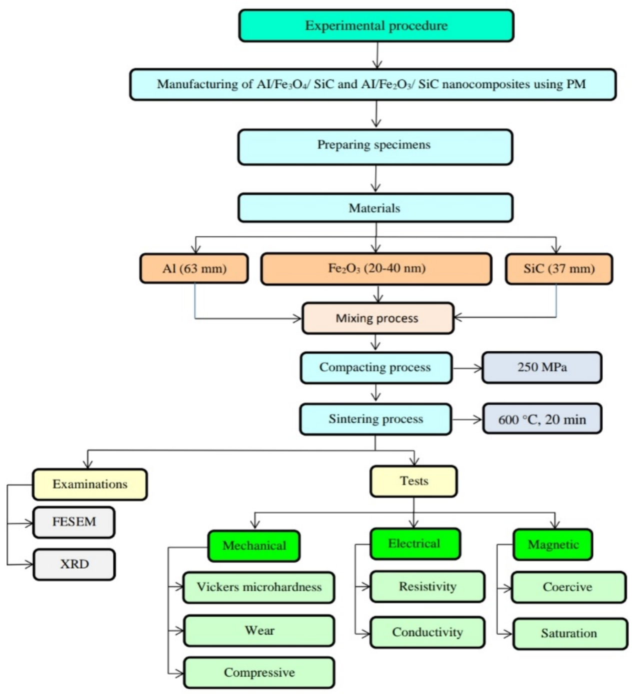


Fig. 1. A schematic diagram of the experimental procedure

2.1 Materials

Aluminum was selected as a matrix with purity of 99% and particle size of 63 µm. The reinforcement materials include hematite (Fe_2O_3) with 98% purity and particle size of 20-40 nm, and silicon carbide SiC with 98% purity and sized at 37 µm. (Fe_2O_3) is a stable oxide, and it is the most attention in advanced technology applications such as sensors, water processing, bio-medical, catalysts, photoanode, electrodes, and pigments. It has exceptional properties, such as low cost, biocompatibility, environment friend, toxicity, and corrosion resistance, enable it to be used in advanced technology. It was applied by (2-10 wt.%) in this study for balanced benefits between mechanical, magnetic, and electrical properties according to previous researches. The main properties of silicon carbides are electrical conductivity owing to their semiconductor characteristics, high resistance to organic and inorganic acids, and high resistance to salts and alkaline in various concentrations. It has many applications such as; high-temperature and high-voltage devices, used in lining work and abrasive resistance with dimensional stability, and electronic appliances such as light-emitting diodes (LEDs) and detectors. It was applied in constant five wt.% to achieve good mechanical properties with moderate impact on electrical and magnetic properties. Table 1. organizes the weigh percentages of added materials for all specimens.

Table 1
The variation of material's weight percentages

Specimen number	Aluminium wt.%	Fe_2O_3 wt.%	SiC wt.%
1	100	0	0
2	95	0	5
3	93	2	5
4	91	4	5
5	89	6	5
6	87	8	5
7	85	10	5

2.2 Specimens Synthesizing

The Powder Metallurgy technique was used to synthesize the samples. This technique has a standard process that involves mixing the powders, compacting the mixture, sintering the green compact, and finishing process [17]. The method of mixing involved using the planetary ball mill (Retsch PM 400). Initially, the powders were measured, and 3 milling balls were added to each one's powder mixture in a little flask. Mixing lasted 2 hours at room temperature with a speed of 150 rpm. The hybrid powders underwent cold compaction by manual pressing to form green compacts. Before compacting, PVA solution was mixed with powders in small amounts. Compaction was carried out at room temperature applying pressure of 250 MPa for five minutes. The upper and lower punches were removed while an extraction rod was pushed into the cavity as a hollow holder supported from the other side gradually releasing green compacts. After that, sintering of the green compacts was done under argon atmosphere in GSL 1600X vacuum furnace to avoid oxidation. The sintering temperature was set at 600°C for twenty minutes with heating and cooling rate being controlled at ten degrees Celsius per minute.

2.3 Microstructural Analysis
2.3.1 Field Emission Scanning Electron Microscopy (FESEM)

The process of manufacturing these specimens was investigated using a FESEM MIRA 3 TESCAN. The reinforcement's distribution and the impact of sintering temperatures and compaction on microstructure were examined on several magnifications' scales. This study included all aluminum matrix nanocomposites with different contents of Fe_2O_3 (2-10 wt.%) and a fixed SiC reinforcement content.

2.3.2 X-Ray Diffraction (XRD)

Phases in the samples were studied by means of X-ray diffraction (XRD). For this purpose, ASENWARE AW-XDM 300 XRD equipment from Shenzhen, China was used. These results show the recorded phases in Al/SiC nanocomposites at different levels of Fe_2O_3 doping, their crystal structure and effect of SiC on pure aluminum.

2.4 Mechanical Properties
2.4.1 Micro hardness test

An HVS-1000 machine was used to determine Vickers microhardness of the Al matrix nanocomposites. It involved carrying out Vickers microhardness measurements on all specimens having different levels of Fe_2O_3 and a constant quantity of SiC. Multiple readings were obtained per sample, then average values computed to reveal properties related to their microhardness.

2.4.2 Wear rate

To assess wear behaviour of Fe_2O_3 containing Al matrix nanocomposites, wear testing was conducted using a dry sliding wear machine. The pin-on-disc technique was used to determine the wear rate according to equation (1) [18]. Cylindrical specimens with 10mm diameter and 10mm height were employed for the wear tests. Precisely, in this study a Microtest pin-on-disk tribometer (MT/60/NI/HT/L) from Spain was used. The specimens were mounted on metal holders during the test and slid against a rotating hard disc at a velocity of 350 rpm for 6 minutes. Different loads (5 N, 10 N and 15 N) were applied to simulate different stress conditions required by each material sample. Thus, by doing this it allowed for evaluation of how different alloys of Fe_2O_3 influenced the wearing characteristics exhibited by the nano-level composite materials containing aluminium under controlled test conditions.

$$Wear\ rate = \Delta W / S.D \qquad 1)$$

$$\Delta W = w1 - w2 \qquad 2)$$

$$S.D = 2\pi\, r.n.t \qquad 3)$$

Where: ΔW is the weight difference before and after each step of the test.
S.D is the sliding distance.
W1 and W2 are weights
r is the radius of the circle mark created on the specimen by the pin.
n is the number of turns.

And t is the sliding time.

2.4.3 Compressive test

Using electric universal testing machine JINAN TEST MACHINE CO, LTD (WDW-200), the compressive strength was calculated for each specimen. The precise dimensions of the specimens were taken and inserted into the computer of the device to draw the load against the deformation graph. Then with the help of equations (4) and (5) the stress and strain could be calculated.

$$\sigma = P/A \quad 4)$$

$$\varepsilon = \Delta L/L \quad 5)$$

Where: (σ) is the stress, (P) is the applied load, (A) is the Area, (ε) is strain, (ΔL) is the length difference before and after deformation, and (L) is the length of the specimen.

2.5 Physical Properties

2.5.1 Density and porosity

The density and porosity of the specimens are calculated before and after sintering to study the effect of sintering as well as different wt.% of additives on these properties. Given the mass of the specimen and its dimensions, equation (6) can be used to calculate density. After measuring the density, the porosity can be calculated depending on the actual and theoretical density by using the following equation (7) [19].

$$\rho = mass/volume \quad 6)$$

$$Porosity\,\% = [1 - Actual\ density/Theoretical\ density] \times 100 \quad 7)$$

2.6 Electrical Properties

Using the Keithley source meter 2100 device for electrical testing, conductivity of each specimen was identified. Using a current density and electric field strength ratio formula, a current is passed through the sample to determine its conductivity. At first resistivity is obtained from physical properties and chemical composition of the material using Expression (8) [20]. Then, expression [21]. followed for obtaining the conductivity.

$$\rho = R \cdot A/L \quad 8)$$

$$A = \pi r^2 \quad 9)$$

σe= 1/ ρ (Ω.m)-1 *10)*

Where: (ρ) is resistivity, (R) is resistance, (A) is specimen's cross section area, (L) is the length of the specimen, (r) is the radius of the specimen, and (σe) is the electrical conductivity.

2.7 Magnetic Properties

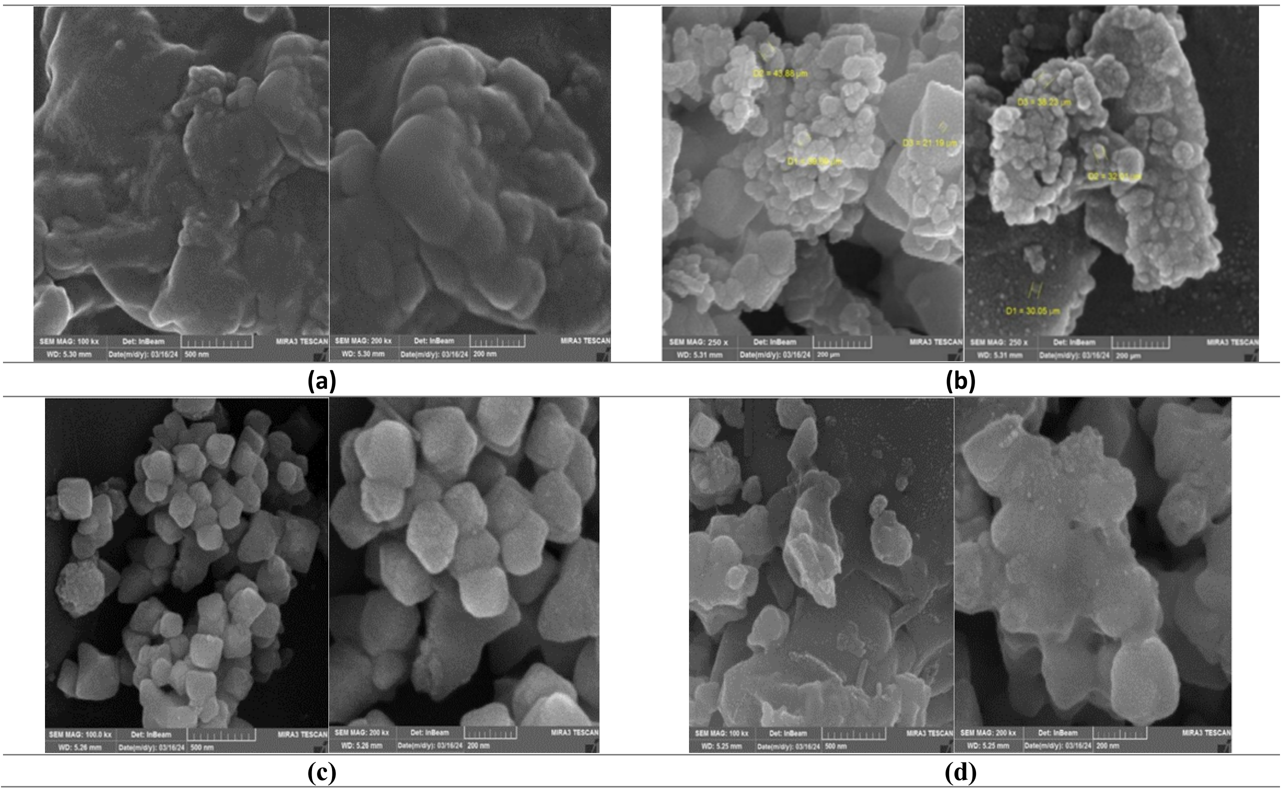
For magnetic testing, a vibrating sample magnetometer (VSM) was used with the Weistron model VSM1100 machine from Taiwan. The method works by measuring induced flux in a resistive detection module due to periodic movement of the sample while it has magnetization M [22]. In this case, the sample is situated at centre of the detection module and vibrates at a frequency f0 with amplitude A. This detection module has four copper coils connected in appositive series which are configured as two coil compensation set ups providing axial and radial compensations, respectively. Samples were placed within the VSM equipment and subjected to a maximum inductor magnetic field of 2T to achieve saturation magnetization before and after any deformation. Under controlled conditions, this provided an opportunity for characterizing various properties such as saturation magnetization for individual samples [23].

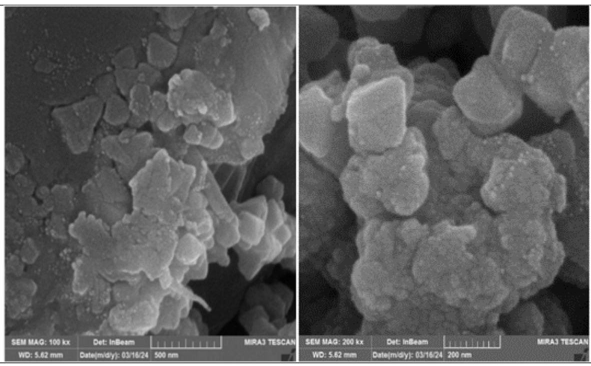
3. Results and Discussion

3.1 Microstructural Observations

3.1.1 Results of FESEM

The FESEM micrographs in Figure 2 highlight the characteristics of pure Al, Al-SiC and hybrid Al-Fe_2O_3-SiC with different amounts of Fe_2O_3 (2,4,6,8,10 wt.%) with constant amount of SiC for all specimens (5Wt.%). These images reveal a uniform dispersion of the reinforcement materials within the aluminium matrix. The sintering process that reached 600 °C has played a crucial role in establishing strong bonds between the additive materials and the aluminium base, facilitated by thermal reactions and diffusion mechanisms. The images of FESEM showed no cracks and minimal porosity due to the homogenous distribution of the additives across the matrix.





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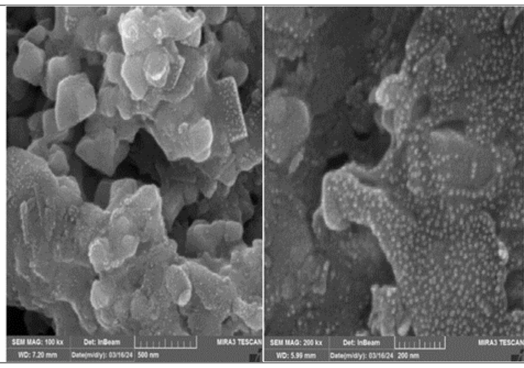

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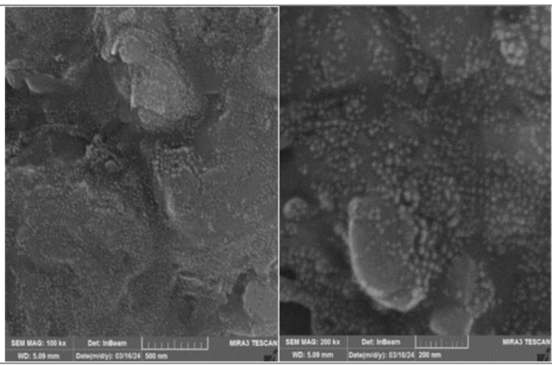

(g)

Fig. 2. FESEM images for (a) pure aluminum, (b) Al-5%SiC, (c) Al-2% Fe_2O_3-SiC, (d) Al-4% Fe_2O_3-SiC, (e) Al-6% Fe_2O_3-SiC, (f) Al-8% Fe_2O_3-SiC, and (g) Al-10% Fe_2O_3-SiC

3.1.2 Analysis of X-Ray diffraction

The XRD report reveals the crystalline structure of Al-Fe_2O_3-SiC hybrid nanocomposites produced by altering the concentration of Fe_2O_3 (2, 4, 6, 8, and 10wt. %) with a constant amount of SiC (5wt.%), which is prepared via powder metallurgy route. The outcome showed that increased content of Fe_2O_3 nanoparticles gave rise to observable distinct Fe_2O_3 peaks that grew with increasing Fe_2O_3 contents. Figure 3 gives an illustration on XRD patterns for Al- Fe_2O_3-5wt.%SiC nanocomposites at various concentrations of Fe_2O_3 with a step size of 0.05 per second. For example, in the XRD spectra; there are peaks that occur at aluminium matrix planes (111), (200), (220) and (311) corresponding to values of 38.45°, 44.70°, 65.05° and 78.15°, respectively. The presence and distribution of SiC within the specimens were indicated by peaks at these angles: 100 (34.05°), 005 (35.65°), 101 (41.50°), 110 (59.95°) and 201 (71.70°). Also, there are other peak positions indicating the existence hematite Fe_2O_3 nanoparticles in the nanocomposites: 220 (30.45°), 400 (43.55°), 511 (57.44°), 440 (63 .25°), 540 (72 .55 °) and 622 (75 .35 °). This extensive XRD analysis provided specific structural data about the dispersion of Fe_2O_3 and Sic into Al matrix which is important for understanding phase composition and crystallographic characteristics of the hybrid nanocomposites.

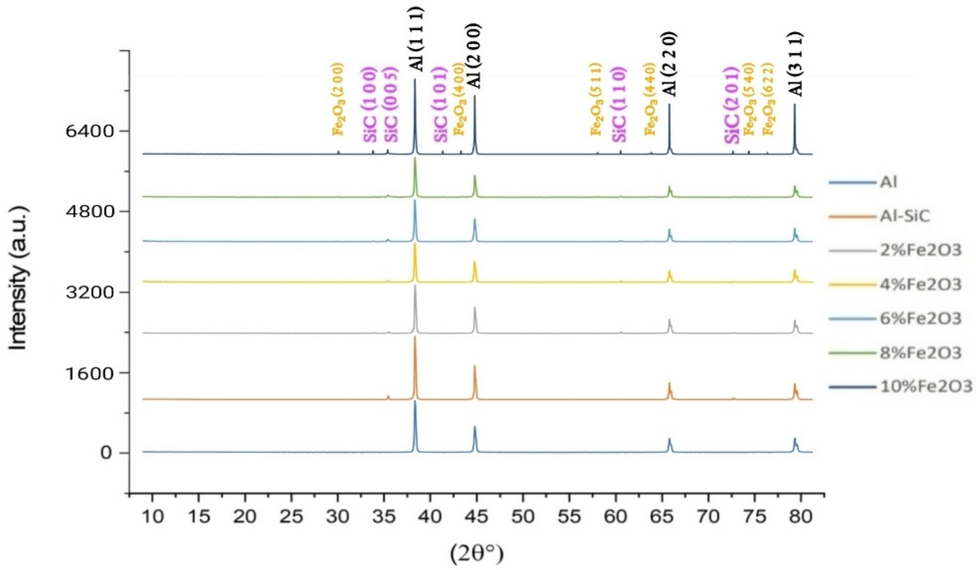

Fig. 3. XRD patterns of Al-Fe_2O_3-SiC

3.2 Mechanical Properties
3.2.1 Microhardness results

The compaction process as well as the weight percentage of the reinforcing nanomaterials influenced the microhardness properties of Al matrix nanocomposites prepared and reinforced with Fe_2O_3-SiC. For this study, different weight percentages of Fe_2O_3 (2, 4, 6, 8 and 10 wt.%) were compared to a fixed composition containing 5wt.% SiC. These values are given in Table 2 where interestingly it can be seen that there is a clear trend in which an increase in the weight percent of Fe_2O_3 results to higher microhardness values. This confirms that the additive's hardness is higher than that of aluminium alone. On increasing their presence in nanocomposites porosity decreases while microhardness changes significantly due to some sort of cooperation between them. That is a high improvement over other reinforcements materials added to aluminium matrix [24].

Table 2
The micro hardness results for Al-Fe_2O_3-SiC

Specimen number	Wt.%	Microhardness (HV)
1	Pure Al	58.898
2	Al-5%SiC	65.569
3	2	69.133
4	4	71.631
5	6	76.881
6	8	80.188
7	10	85.348

3.2.2 Results of wear rate

A rotational speed of 350 rpm and a duration of six minutes were used to evaluate the wear rate for Al-Fe_2O_3-SiC nanocomposites with different Fe_2O_3 contents. Figure 4 below shows the impact on wear rate improvement of Al- Fe_2O_3-SiC nanocomposites containing different weight percentages of Fe_2O_3 (2, 4, 6, 8 and 10wt.%) at fixed SiC content of 5wt.%. It is evident from the findings that addition of SiC and increasing Fe_2O_3 content reduced wear rate more effectively than use of pure aluminium.

Importantly, the most significant drop in wear rate was noticed in specimens with 10 wt.% Fe_2O_3 regardless of applied loads. Table 3 is a comprehensive summary of data regarding hybrid nanocomposite materials which was acquired by means of tribology testing techniques. Ali Sadooghi and seyed Jalal Hashem [25] studied the effect of Al2O3, ZnO, and CuO nanoparticles as reinforcement material on the wear rate. According to their results, the current study improved to have lower wear rates with such additives.

Table 3
Wear test data of Al-Fe_2O_3-SiC

	Wear rate (g/cm) x10^{-6}						
Load (N)	**Al**	**Al-5%SiC**	**2wt.%**	**4wt.%**	**6wt.%**	**8wt.%**	**10wt.%**
5	1.305	1.119	0.916	0.806	0.655	0.578	0.273
10	2.316	1.854	1.689	1.512	1.104	0.823	0.490
15	4.863	3.553	2.672	2.241	1.993	1.156	1.059

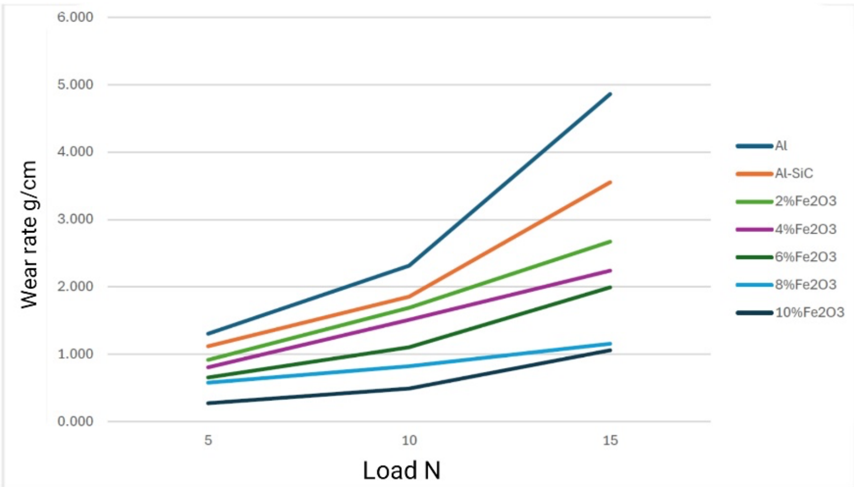

Fig. 4. Wear rate results of Al-Fe2O3-SiC

3.2.3 Compressive results

The mechanical behaviour of the nanocomposites is represented by stress-strain curves which depend on different weight percentages of reinforcement nanomaterials as shown in Figure 5. This figure depicts the stress–strain response for pure Al, Al-SiC and Al-Fe_2O_3-SiC nanocomposites with various Fe_2O_3 contents (2,4,6,8 and 10 wt.%) and a constant SiC content of 5 wt.%. The compressive strength of the nanocomposites increases with increasing concentration of additives to reach maximum value at 10wt.% Fe_2O_3 that reads132.90 MPa. This was enhanced by nanoparticles which hindered dislocation motion thus strengthening the matrix. Also, Fe_2O_3 incorporation led to brittleness because more nanoparticles were present. Moreover, since SiC is inherently strong as it serves as reinforcement element in these composites; its inclusion significantly increased their compressive strengths. For full details about compressive testing results read Table 4 below. V. S. S Venkatesh [26] investigations showed higher overall compression strength values, but the maximum increase of compression strength over the pure aluminium matrix was 29.24% compared to 195.2% obtained by this study.

Table 4
Compressive test data for Al-Fe_2O_3-SiC

Specimen number	Wt.%	Load (KN)	Compressive (MPa)
1	Pure Al	5.59	45.02
2	Al-5%SiC	7.2	58.44
3	2	8.57	69.03
4	4	9.72	78.29
5	6	11.41	91.8
6	8	14.01	112.72
7	10	16.52	132.90

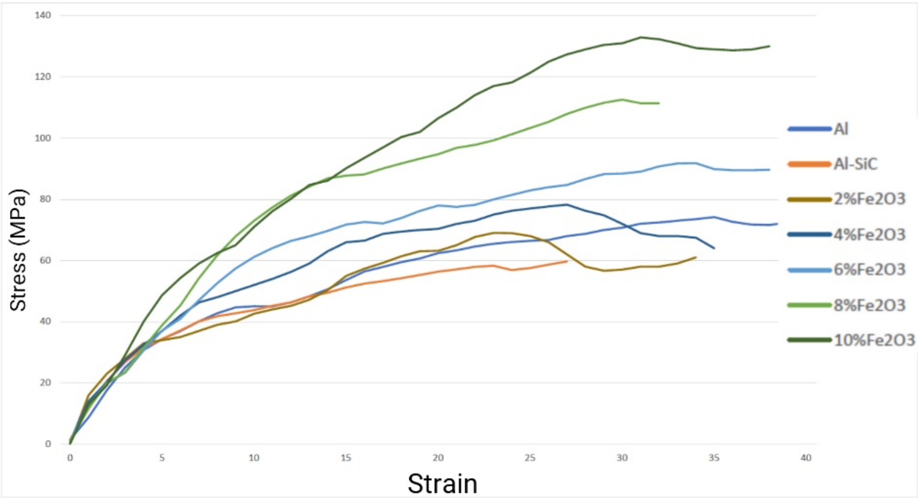

Fig. 5. Compressive test results graph for Al-Fe_2O_3-SiC

3.3 Physical Properties
3.3.1 Density and porosity results

Different amounts of Fe_2O_3 were added in and the effect of their weight percentages on sintering of the composites at constant 5wt.% SiC content was assessed by observing the variations in density before and after sintering in Al- Fe_2O_3-SiC nanocomposites. It can be seen from the results that presence of SiC as well as addition of more weight fractions of Fe_2O_3 nanoparticles led to higher densities at both stages, affected by compaction and sintering conditions. Results for density and porosity prior to sintering and afterwards are listed in Table 5. For instance, the increased yield strength with increasing concentrations is primarily due to the higher mass volume densities of SiC and Fe_2O_3 over Al. On the other hand, during sintering, gaps between particles are shut down as they come closer together moving towards fusing, this leads to an overall elimination or reduction of porosity. Figure 6 shows how density changes with respect to additive concentration during both compaction and sintering stages. Such a graphic representation gives an idea about how different loading levels of Fe_2O_3 influence density parameters in nanocomposites emphasizing effects caused by process of densification throughout sintering operations.

Table 5
Data table for the physical properties of Al-Fe_2O_3-SiC

Wt.%	Theoretical density	Actual density			
		Before sintering	Porosity %	After sintering	Porosity %
Pure Al	2.7	2.173	19.52	2.222	17.70
Al-SiC	2.725	2.203	19.16	2.257	17.17
2	2.776	2.247	19.06	2.315	16.61
4	2.827	2.299	18.68	2.374	16.02
6	2.878	2.354	18.21	2.487	13.59
8	2.929	2.412	17.65	2.507	14.41
10	2.981	2.463	17.38	2.643	11.34

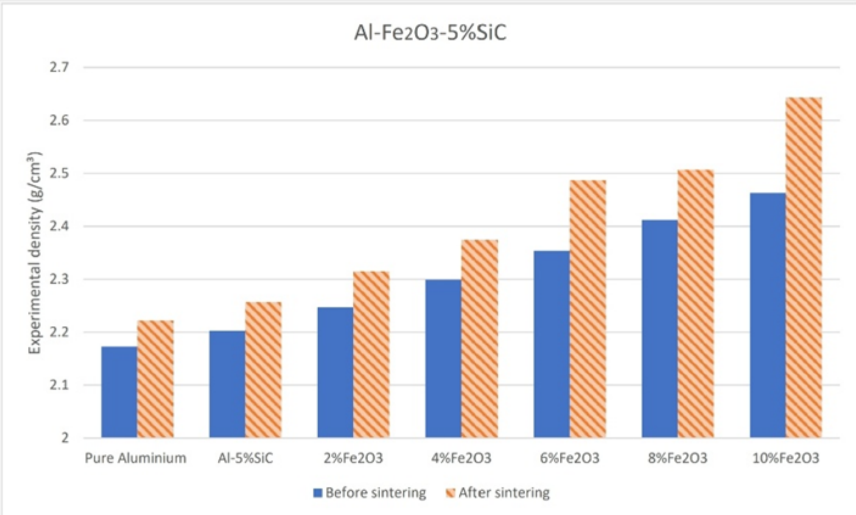

Fig. 6. Relationship between the wt. % and the density for Al-Fe_2O_3-SiC

3.4 Electrical Properties

The hybrid nanocomposites' electrical features were assessed to determine the electrical resistivity (ρ) and conductivity (σ_e) at different nano additive concentrations. Keithley source meter 2100 was employed in measuring resistance of specimens; then, their dimensions were used to calculate the values of resistivity and conductivity. While holding SiC constant at 5 wt.% for all samples, Table 6 shows results of ρ and σ_e for Fe_2O_3-SiC-Al matrix nanocomposites with changing Fe_2O_3 content. The introduction of SiC largely increased the resistivity for the hybrid nanocomposites because this material has lower conductivity compared to aluminium which is based on semiconductors such as SiC. With each further addition of Fe_2O_3, resistivity rose gradually until it reached its maximum value at a concentration of 10 wt.% Fe_2O_3, which was equal to 64.79×10^{-6} Ω·m. Conversely, there is an inverse relationship between conductivity and resistivity where the former decreases with increasing weight percentages of additives while the latter increases proportionally. This correlation demonstrates how nano additives affect electrical properties in these composite materials by influencing both conductance and resistance changes resulting from variations in composition. Khodabakhshi and Simchi [27] studied the effect of adding SiC to aluminium matrix on the electrical resistivity. The resistivity increased by 40% with 6 vol.% of SiC over the pure aluminium matrix. While the resistivity increased by 51% in the current study due to higher percentage of the additives. This comes with other benefits to the nanocomposites such as better mechanical and magnetic properties.

Table 6
The results of electrical resistivity and conductivity of Al-Fe_2O_3-SiC

Specimen number	Wt.%	ρ (Ω.m) ×10^{-6}	$σ_e$ $(Ω.m)^{-1}$ ×10^3
1	Pure Al	42.07	23.770
2	Al-5%SiC	49.22	20.317
3	2	50.85	19.666
4	4	53.14	18.818
5	6	57.47	17.400
6	8	59.61	16.776
7	10	64.79	15.434

3.5 Magnetic Properties

Al-Fe_2O_3-SiC nanocomposites' magnetic hysteresis loop is shown in Figure 7. This experiment was conducted to investigate saturation magnetization (Ms), residual magnetization (Mr) and coercive field (Hc) for each sample through their respective curves. The results indicate that the effect of SiC on magnetic properties is minimal, thereby justifying its role in improving mechanical features. However, increasing the amount of Fe_2O_3 in hybrid nanocomposites resulted in a notable improvement of both Ms and Mr. These enhancements can be connected to the changes in distribution of magnetic domains and moments induced by Fe_2O_3 content variations within specimens. At room temperature Fe_2O_3 becomes paramagnetic hence it increases its strength when put into a magnetic field. Table 7 shows that specimen with 10wt.% Fe_2O_3 had the highest saturation magnetization of 0.956 emu/g with an Ms/Mr ratio of 0.284. This result showed how much impact can be revealed through change in Fe_2O_3 content on magnetic characteristics of nanocomposites. Manal Hadi Jaber *et al.*, [28] investigated the effect of adding magnetic TiO_2 to the aluminium matrix . By comparing the results obtained from Fe_2O_3, the current study showed lower magnetization than that of TiO_2.

Table 7
Magnetic loop parameters of Al-Fe_2O_3-SiC

Specimen number	Wt.%	Ms (emu/g)	Mr (emu/g)	Hc (Oe)	Mr/Ms
1	Pure Al	0.006	0.000	79.26	0.023
2	Al-5%SiC	0.014	0.001	219.00	0.105
3	2	0.367	0.106	118.49	0.290
4	4	0.546	0.124	130.11	0.227
5	6	0.767	0.157	131.44	0.205
6	8	0.911	0.230	131.10	0.253
7	10	0.956	0.271	164.60	0.284

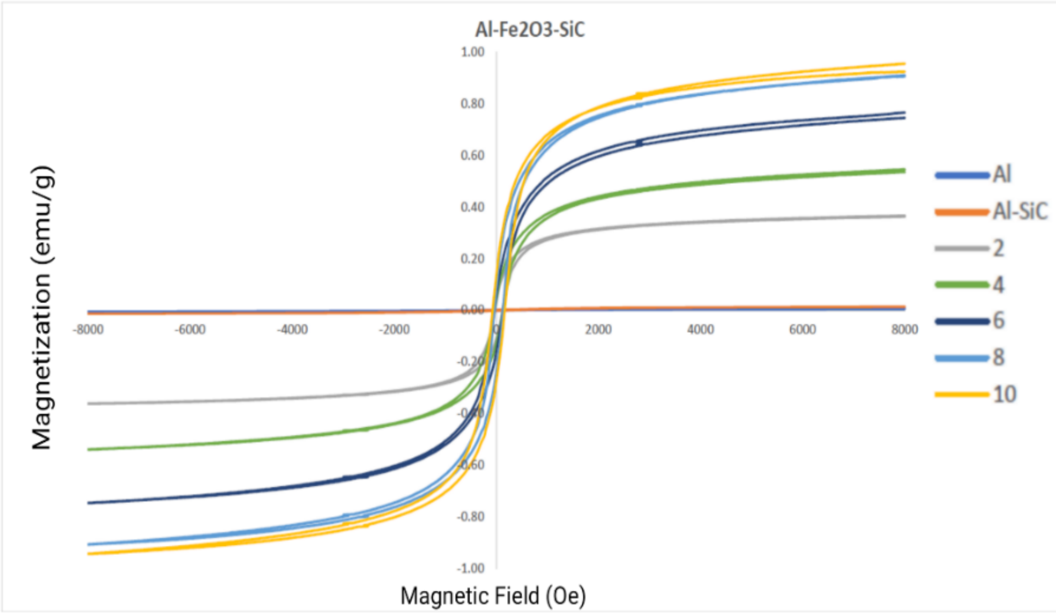

Fig. 7. Relationship between magnetization and magnetic field for Al-Fe_3O_4-SiC

13. Conclusion

This research investigated the impact of incorporating different amounts of Fe_2O_3 with 5 wt.% of SiC nanomaterials as reinforcement into an aluminum matrix. The study focused on examining the resulting changes in microstructure, mechanical, electrical and magnetic properties through experimental methods. The goals of the current research were accomplished, and the conclusions derived from the analysis of the results are summarized as follows:

1. FESEM images of Al-Fe_2O_3-SiC hybrid nanocomposites showed a uniform distribution of the reinforcing elements within the aluminum matrix, exhibiting minimal porosity and no cracks.
2. XRD analysis indicated that increasing the weight percentage of Fe_2O_3 led to more pronounced phase peaks for these nanoparticles, suggesting a uniform dispersion within the Al matrix.
3. The microhardness results revealed that increasing wt.% of Fe_2O_3 led to higher values of microhardness in the hybrid nanocomposites. The highest value of microhardness was 85.348 HV for Al-(10wt.%) Fe_2O_3-SiC which is 44.91% increase over pure aluminium matrix.
4. Wear rate results showed lower rates with the increasing of Fe_2O_3 amounts. The wear rate has been reduced by 78.72% of the pure aluminium matrix with 10wt.% of Fe_2O_3.
5. The compressive test results illustrated that the higher the amount of Fe_2O_3 is imbedded in the nanocomposites, the higher the compressive strength will get. Compressive strength reached its peak of 195.2% increase over pure aluminum with 10wt.% of Fe_2O_3.
6. Density and porosity calculations pointed out the increasing of density with the increasing of Fe_2O_3 addition to the hybrid nanocomposites. On the contrary, Porosity got less and less with higher amounts of the additive. The density increased by 13.35% with 17.38% porosity before sintering and by 18.95% with 11.34% porosity after sintering for 10wt.% of Fe_2O_3.
7. The electrical resistivity and conductivity results showed increment in resistivity with higher amounts of additives and obviously lower conductivity. For Al-Fe_2O_3-SiC, the resistivity increased by 54% with 10wt.% addition of Fe_2O_3, while the conductivity got reduced by 35.01%.

8. The results for magnetic test demonstrated that increasing the wt.% of Fe_2O_3 nanoparticle increased the saturation magnetization (Ms) from 0.006 to 0.956 (emu/g) and remanence magnetization (Mr) from 0 to 0.271 (emu/g) with 10wt.% of Fe_2O_3.

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