International Journal of Frontiers in
Engineering and Technology Research
Journal homepage: https://frontiersrj.com/journals/ijfetr/
ISSN: 2783-0497 (Online)

(Research Article)

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Investigating the effects of SiC particles addition and thermal treatment on 90% Al-10% Cu alloy

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International Journal of Frontiers in Engineering and Technology Research, 2023, 04(02), 016–032

Publication history: Received on 18 March 2023; revised on 15 May 2023; accepted on 18 May 2023

Article DOI: https://doi.org/10.53294/ijfetr.2023.4.2.0015

Abstract

Investigation of the effects of SiC particles addition and thermal treatment on 90Al-10Cu alloy has been undertaken. The work produced 90Al-10Cu Alloy and further produced test castings to which particle additions of SiC were added in the order 0.5%SiC, 1%SiC, 2%SiC and 4%SiC to see the effects of a wider variation in particle addition. These additions were made using stir-cast method to produce the test sample bars. The test sample bars were then taken to the University of Uyo, Faculty of Engineering workshop to prepare the test specimens into standard specifications for various tests. Some of the prepared test specimens were then given thermal treatment called age hardening. The specimens were first solutionised in the furnace at 500 °C (500 C) and quenched in warm water at 60C. It was then aged at 170C for three hours before cooling in air. It was after this treatment that the test specimens were subjected to hardness test, wear resistance test, strength test, and microstructure analysis. The result of the work showed that the thermal treatment had effect on the microstructure of all the samples. The result also showed that the SiC particle addition also affected the mechanical properties of the specimens. For the untreated compositions the alloy and 90Al-10Cu/2%SiC particulate composite had the lowest wear rate value of 0.0212mm³/N/m. 90Al-10Cu/1% SiC had the highest hardness value of 67.38 BHN. 90Al-10Cu/0.5%SiC particulate composite outperformed other compositions with the following mechanical properties: hardness value of 64.28BHN; ultimate compression strength of 217.18N/mm²; % reduction at failure of 3.01; and wear rate value of 0.0633 mm³/N/m. For the thermally treated compositions; the lowest wear rate of 0.0246mm³/N/m is with the alloy composition and 90Al-10Cu/2%SiC particulate composite. 90Al-10Cu/1%SiC particulate composite has the highest hardness value of 82.02BHN; the highest % reduction at failure of 1.13%, and wear rate value of 0.05982, while 90Al-10Cu/0.5%SiC particulate composite has hardness value of 80.12BHN, ultimate compression strength of 240.95N/mm², % reduction at failure of 1.06%, and wear rate of 0.0895mm³/N/m. The 1% SiC reinforced particulate composite performed better than other compositions, but it is closely followed by 0.5%SiC reinforced particulate composite for the thermal treated compositions in terms of improved mechanical properties. This correlates with their microstructures which all show the precipitation of a second phase.

Keywords Precipitation; Second phase; Particulate addition; Thermal treatment; SiC; Alloy; Microstructure

1. Introduction

Scientists and Engineers have been constantly making improvements on existing materials and sometimes developing new materials entirely with new properties and new areas of engineering application. The aluminium-copper alloys in combination with magnesium, and manganese, in small percentages have found application in the aircraft industry for some time now. This was as a result of the alloys ability to respond to heat treatment, thereby improving the mechanical properties of the alloy. In today's world of high cost of fuel engineering materials with high strength and light weight

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are preferred in the automobile and aerospace sectors. This has informed the research into the development of high strength low-weight materials like this current research [1]-[12].

According to Jain [1] aluminium alloys have the unusual property of remaining ductile and resistant to stock loading at extremely low temperatures. As the temperature decreases, their tensile and yield strengths improve, so they have got many advantages when used as a material of construction for cryogenic equipment. For example, aluminium is used in liquid fuelled missiles and rockets as storage material for liquid oxygen and forms the integral part of the missile or rocket. Composite materials have superior mechanical properties and yet are light weight [12]-[13]. The reinforcing fibres are usually glass, graphite, boron, etc. Epoxies and polyesters commonly serves as a matrix material. Reinforced plastics are being developed rapidly. New developments concern metal-matrix and ceramic matrix composites and honey comb structures. Ceramic-matrix cutting tools are being developed, made of silicon carbide-reinforced alumina, with greatly improved tool life [1]-[4].

A composite material contains more than one component. The component materials are incorporated into the composite to take advantage of their attributes, thus obtaining improved material. Components subjected to severe wear and high contact stresses can be made of duplex composite, the composite layer being located on outer or inner surface depending on the requirement. Aluminium composite alloys reinforced by ceramic have been developed and these have relative high strength to weight ratio, high modulus of elasticity and good wear characteristics [1]; [14]-[15].

Silicon carbide particles are incorporated into the surface of aluminium alloy heated to its mushy state and pressure is applied to get a good wetting between the aluminium alloy and the silica carbide particles. Stir cast method can equally be used to produce the composite. The alloy is melted and the SiC is introduced and properly stirred before casting. The composite has been found to have hardness and wear resistance about 1.75 and 10 times those of as received aluminium matrix alloy [14]-[18].

The objective of this research work is to investigate the effects of particle addition/ reinforcement and thermal treatment on 90%Al-10%Cu Alloy. The investigation would establish the improvement of fundamental mechanical and metallographic properties of the resultant particulate composite.

2. Materials and method

2.1. Materials

These listed materials were used in these research work: aluminium cable cuttings of 99% purity were obtained from aluminium cable company in Kaduna, Kaduna State, pure copper wire cuttings were obtained from Jos electrical materials market in Jos Plateau State-Nigeria; Silicon Carbide powder of 0.5μm average particle size was obtained from NMDC chemical store, Jos and other materials were clay, binding wire, water, Keller's reagent, and charcoal; these were all sourced within the foundry shop of the National Metallurgical Development Centre ,Jos. The equipment used in this work included; electric muffle furnace, charcoal furnace, electric mechanical stirrer, graphite crucible, split metal moulds, digital weighing balance, universal strength testing machine, Brinell hardness tester; tribometer, grinding belt, polishing disc machines, hot air blower, metallurgical microscope equipped with camera and computer, tongs, metal saw, sand paper, quenching bath, hot plate, and lathe machines

2.2. Method

2.2.1. Alloy Production and SiC Particles Addition Process

1kg of 90Al-10Cu alloy was produced. The charge was composed of 90% Aluminium and 10% Copper wire cuttings. The Copper wire cuttings were first charged into a graphite crucible and inserted into an electric muffle furnace; then the temperature was set to 1100^{0}C. (1100 C) When the copper melted, the 90% Aluminium wire cuttings were introduced into the crucible. The Aluminium quickly melted because copper melts at 1083 C, while Aluminium melts at 660 C. The melted alloy was thoroughly stirred; the furnace was switched off and the crucible was removed from the furnace. The molten metal was quickly poured into crucibles placed on top of charcoal furnaces and the remaining poured into two metal split moulds. The split moulds were made out of steel pipe.

The steel pipe was 20mm in diameter and cut to 250mm in length. It was divided into half to form a split metal mould. The halves were held together using a binding wire. The bottom of the split mould was sealed using moisturized clay which was mixed with water. The split edges were also sealed with clay to avoid metal leakages during metal pouring.

The molten metal was allowed to cool and solidify in the metal moulds before the binding wire was loosened to remove the solidified 90Al-10Cu Alloy bars.

The various 90Al-10Cu/SiC particulate composites were produced using Stir cast method. After pouring the molten alloy into the four crucibles on top of the charcoal furnace; the remaining molten metal was transferred into the two split metal moulds. The crucibles were already heated to avoid freezing and heat loss during pouring of the molten alloy. Based on previous calculations, 0.5%SiC, 1%SiC, 2%SiC, and 4%SiC, were added to the four crucibles, which contain the same volume of molten 90Al-10Cu alloy.

The first two crucibles had a close variation in the amount of SiC added, but the third and fourth Crucible had a larger variation of up to 2% SiC. This was intentionally done so as to find out if increased amount of SiC in Al-Cu alloy matrix will have any effect on the properties of the alloy. The crucibles were pre-marked to the same level and the molten metal was poured to that level and the crucibles were all of the same size.

After pouring the SiC in the crucible, it was stirred at the rate of 315 rpm for 5 minutes using a motorized Stirrer before each crucible was removed from the charcoal furnace and quickly poured into the prepared split metal moulds. The composites were allowed to solidify and cool to room temperature before the binding wire was removed and the split mould opened to remove the cast composite bars of 90Al-10Cu/0.5%SiC, 90Al-10Cu/1.0%SiC, 90%Al-10%Cu/2.0%SiC, and 90Al-10Cu/4.0%SiC particulate composites. The produced test sample were now ready for test specimen preparation, heat treatment by age hardening treatment, mechanical properties test, and metallographic analysis. The production of the test samples was carried out at National Metallurgical Development Center Jos, Plateau State.

2.2.2. Test Specimens Preparation

The test samples where turned on the lathe machine to produce lengths of samples with smooth surface after which the samples were cut into desired lengths for further processing. Vernier caliper was used to measure the diameter, and meter rule was used to measure the lengths of the specimen. The samples were cut using the hack saw and the face of the specimens were machined through a process called facing in order to give a smooth cross sectional area. The test specimens for wear resistance test were three in number for each sample and their standard dimension was 20mm diameter by 10mm thick. Three specimens were prepared for all the test samples and the various tests conducted. For hardness test the dimension was 20mm x 20mm; the same applied to the compression test and microstructural analysis.

2.2.3. Thermal Treatment

Figure 1 Images Showing the Specimens in the Furnace

Of the prepared specimen; some were subjected to heat treatment while some were not; in order to enable the research establish the effects of heat treatment on the test specimens. For each composite of particular particulate reinforcement composition, half of the prepared samples were kept for heat treatment, while half were not to undergo any form of heat treatment, and they were all properly labeled. The samples for heat treatment were subjected to a heat treatment method called age hardening.

The samples for heat treatment were put in an electric muffle furnace and heated to a temperature of 500 C and held for 30 minutes after which it was removed and quenched in a water bath with warm water at 60 C. After quenching the samples were dried and returned to the furnace. The furnace was then set to a temperature of 170 C and held at that temperature for 3 hours after which the furnace was switched off and the specimens were removed and air cooled in the air under room temperature. The treated and untreated specimens were now ready for the various tests. The age hardening of the specimens was carried out at the Civil Engineering laboratory, University of Uyo, Uyo. Figure I shows specimens undergoing thermal treatment in the furnace.

2.2.4. Tribology Test

The specimens for the wear test were sent to Ahmadu Bello University, Zaria where the test was carried out in their Materials Testing Laboratory. Standard tribometer version 6.1.19 was used to carry out the wear test. The specimens as prepared had an average size diameter of 20mm and thickness 10mm. Two specimens were prepared for each category, that is, treated and untreated for the 90%Al-10%Cu / 0.5%SiC, 90%Al-10%Cu / 1%SiC, 90%Al-10%Cu Alloy, 90Al-10Cu/2%SiC, and 90%Al-10%Cu / 4%SiC. This categories of particulate reinforced composites were all tested using the tribometer shown in Figure 2

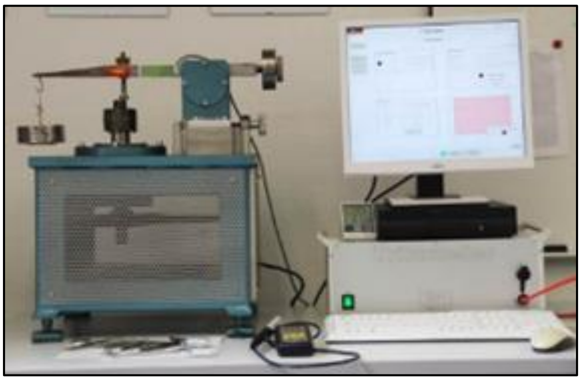

Figure 2 Tribometer used for the Work

2.2.5. Hardness test

Brinell hardness test was carried out on the test specimens at University of Uyo Mechanical Engineering Laboratory. The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter. The Specimen is placed on the machine and the load is applied from the dial. The indenter which is a ball of diameter 10mm according to ASTM specifications impresses on the sample and then stops, at this point the load is recorded and the radius of indentation is taken as well. Figure 3 shows some of the specimens tested for hardness. The value of the Brinell hardness is then calculated from [1]-[2]:

$$BHN = \frac{W}{(\pi\frac{D}{2})(D - \sqrt{D^2 - d^2})} \quad \text{.................................} \quad (1)$$

where, W is load on indenter, kg

D is diameter of steel ball, mm

D is average measured diameter of indentation, mm

Figure 3 Some Specimens Tested for Hardness

2.2.6. Compression Test

Compression test was carried out on both the treated specimens and the untreated specimens at the Mechanical Engineering Laboratory, University of Uyo, Uyo, using the universal strength testing machine. Each specimen was placed on the machine, and the load was applied, which compressed the specimen until the specimen failed and the compressive force in kilo Newton (kN) which was visible on the display was recorded. Figure 4(a) shows the test been conducted using the universal strength testing machine, and Figure 4(b) shows some of the tested specimens.

a b

Figure 4 Compression Test using the Universal Testing Machine

2.3. Microstructural Analysis

The specimens were ground and polished. A belted grinding machine with grits 240-600 was used. The specimens were then transferred to a pre-polishing disc where alumina powder paste of 1 micron was used for pre-polishing. The specimens were finally polished on the finishing disc; 0.5 micron of alumina paste was used. It was ensured that the surface were devoid of scratches and it was thoroughly washed and dried using a hand blower to avoid chemical corrosion. Keller's reagent was used to etch the specimen and rinsing was done using distilled water. It was then dried using a blower before transferring to the microscope for viewing and taking of the photomicrograph of the microstructure. The metallurgical microscope used was equipped with camera and computer for snapshots of the microstructure and processing of same.

3. Results

The results of the various tests conducted are shown in Figures 5-19, and Tables 1-5 below:

3.1. Wear Resistance Test Results

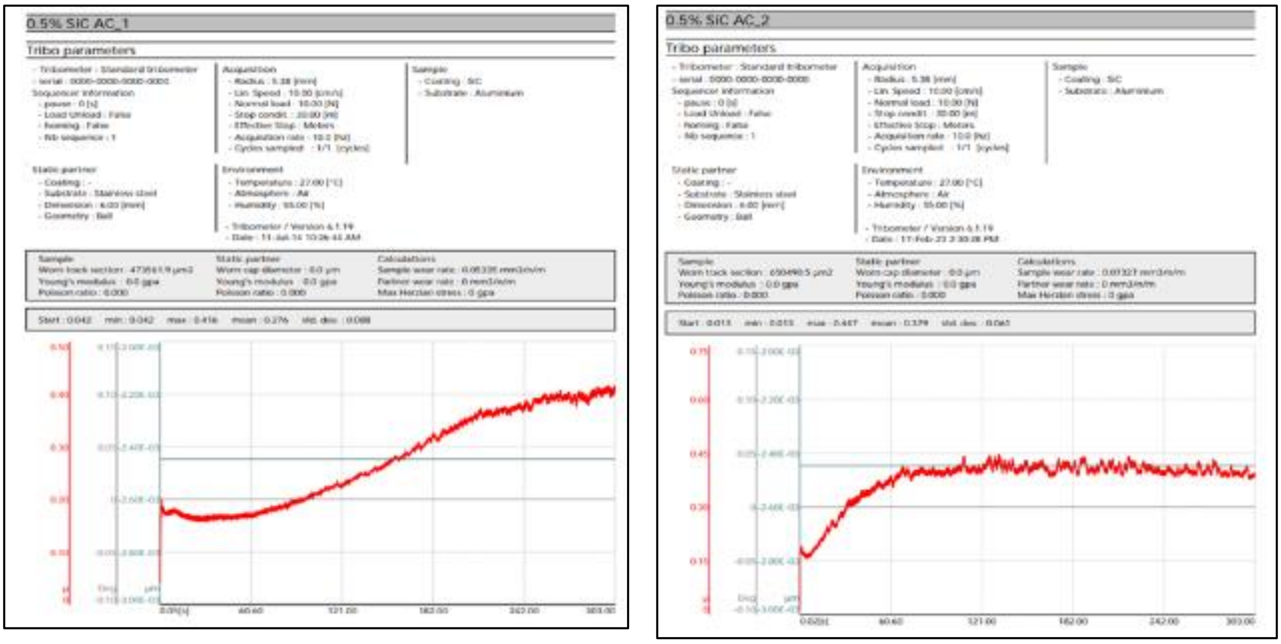

Figure 5 Wear Resistance Test Profile for Two Specimens of 90%Al-10%Cu/0.5%SiC Particulate Composites (Untreated)

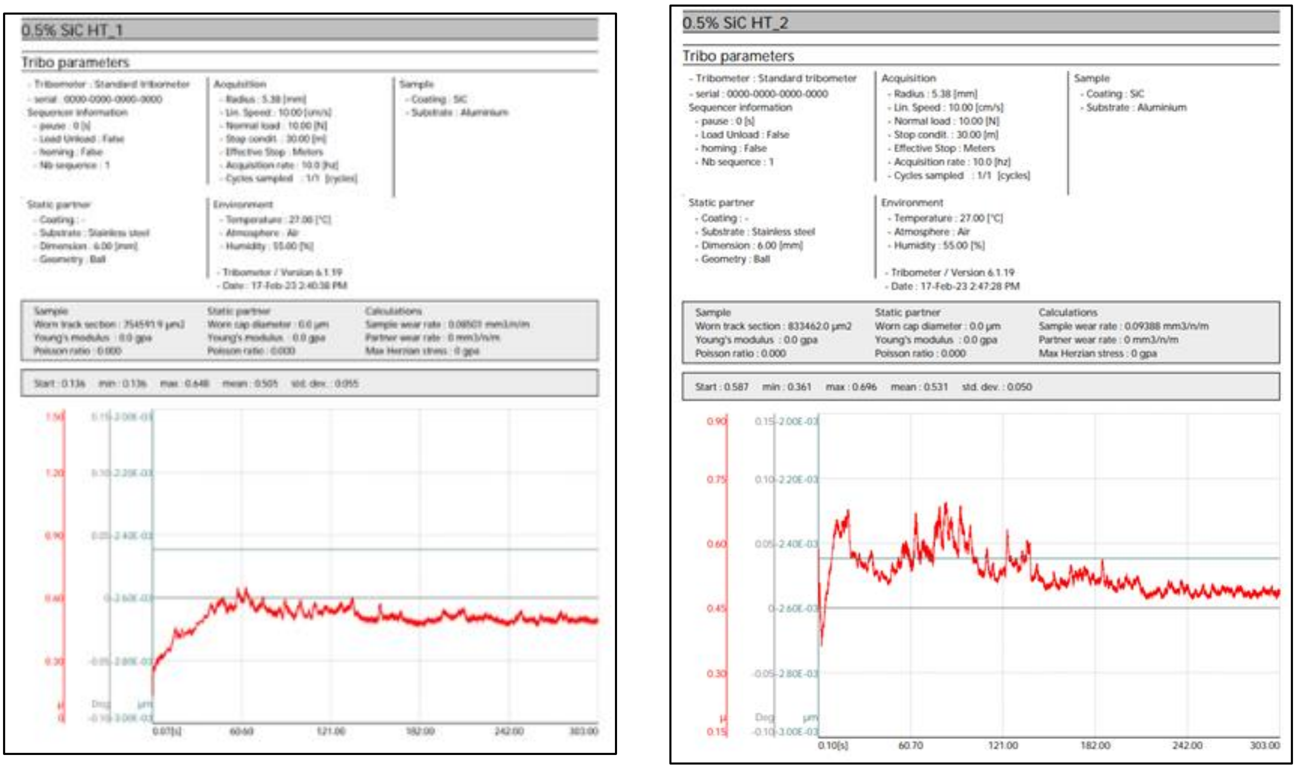

Figure 6 Wear Resistance Test Profile for Two Specimens of 90%Al-10%Cu/0.5%SiC Particulate Composites (Thermal Treated)

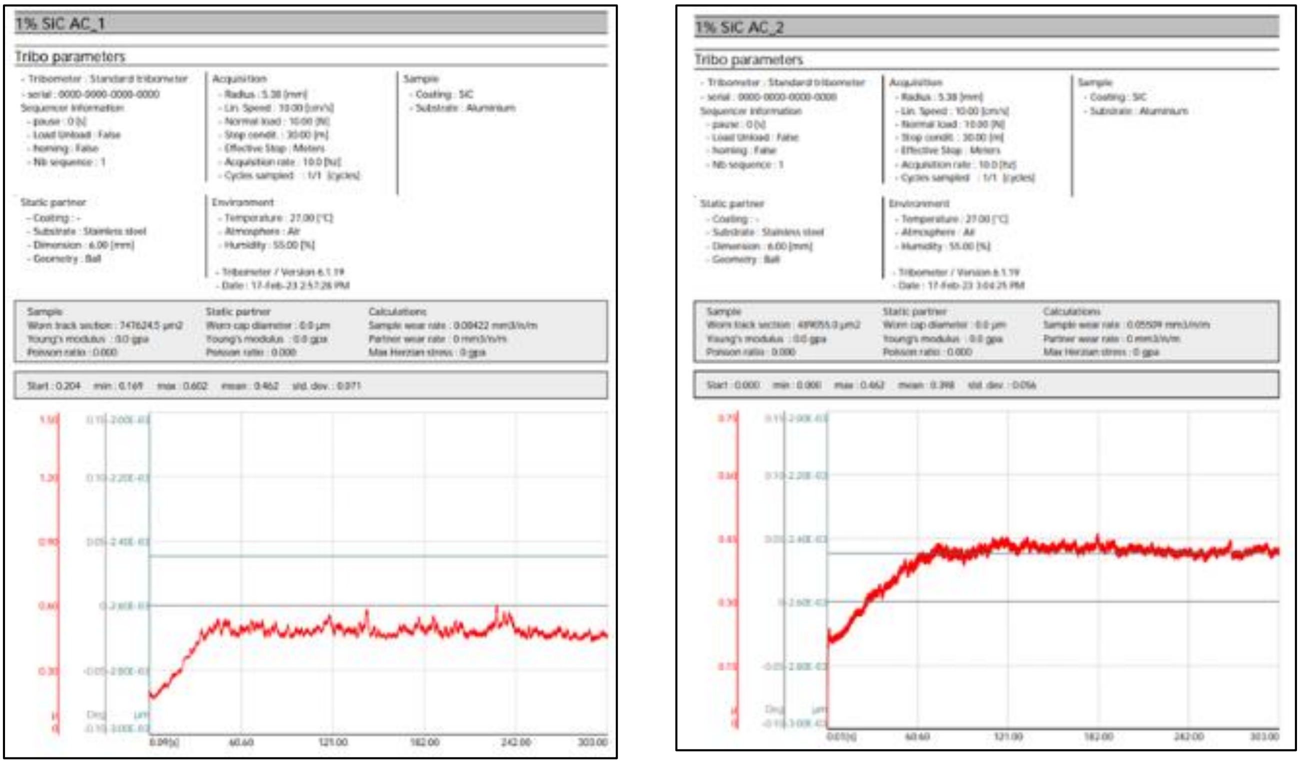

Figure 7 Wear Resistance Test Profile for Two Specimens of 90%Al-10%Cu/1.0%SiC Particulate Composites (Untreated)

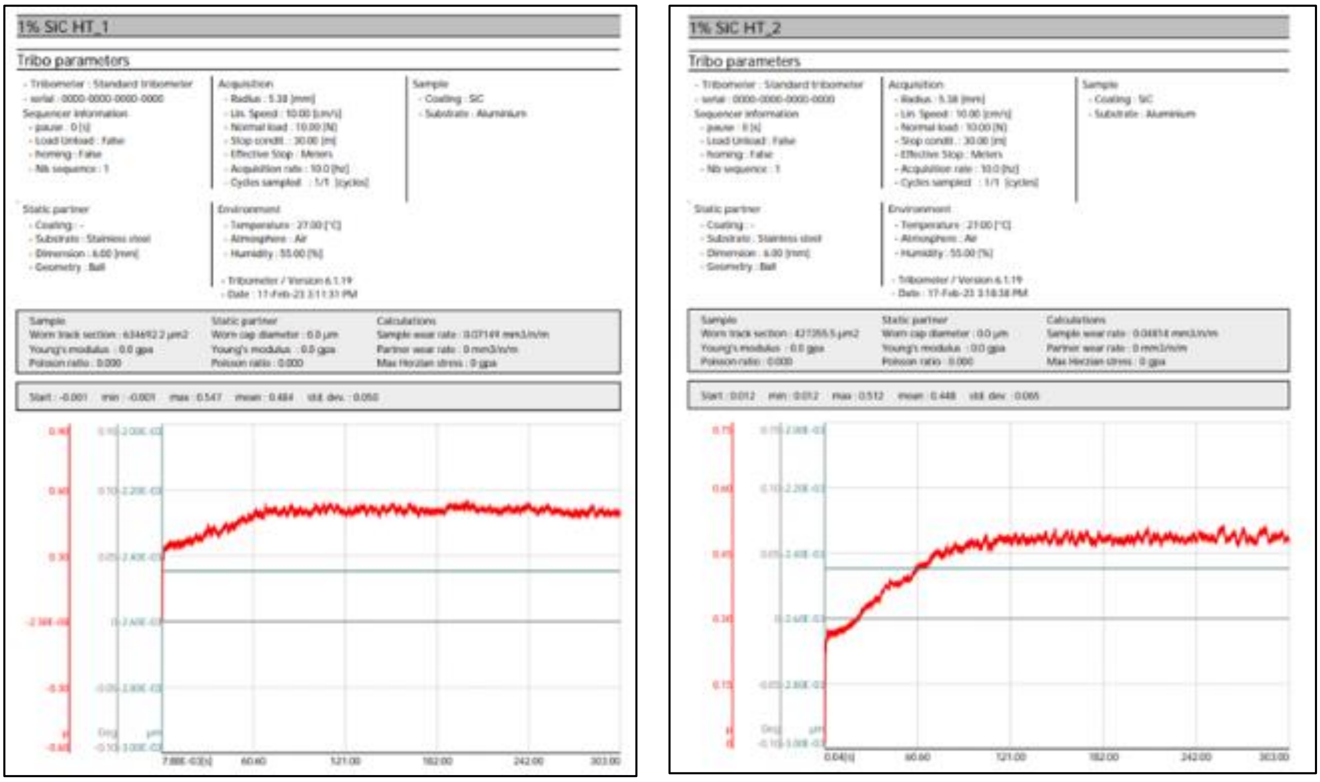

Figure 8 Wear Resistance Test Profile for Two Specimens of 90%Al-10%Cu/1.0%SiC Particulate Composites (Thermal Treated)

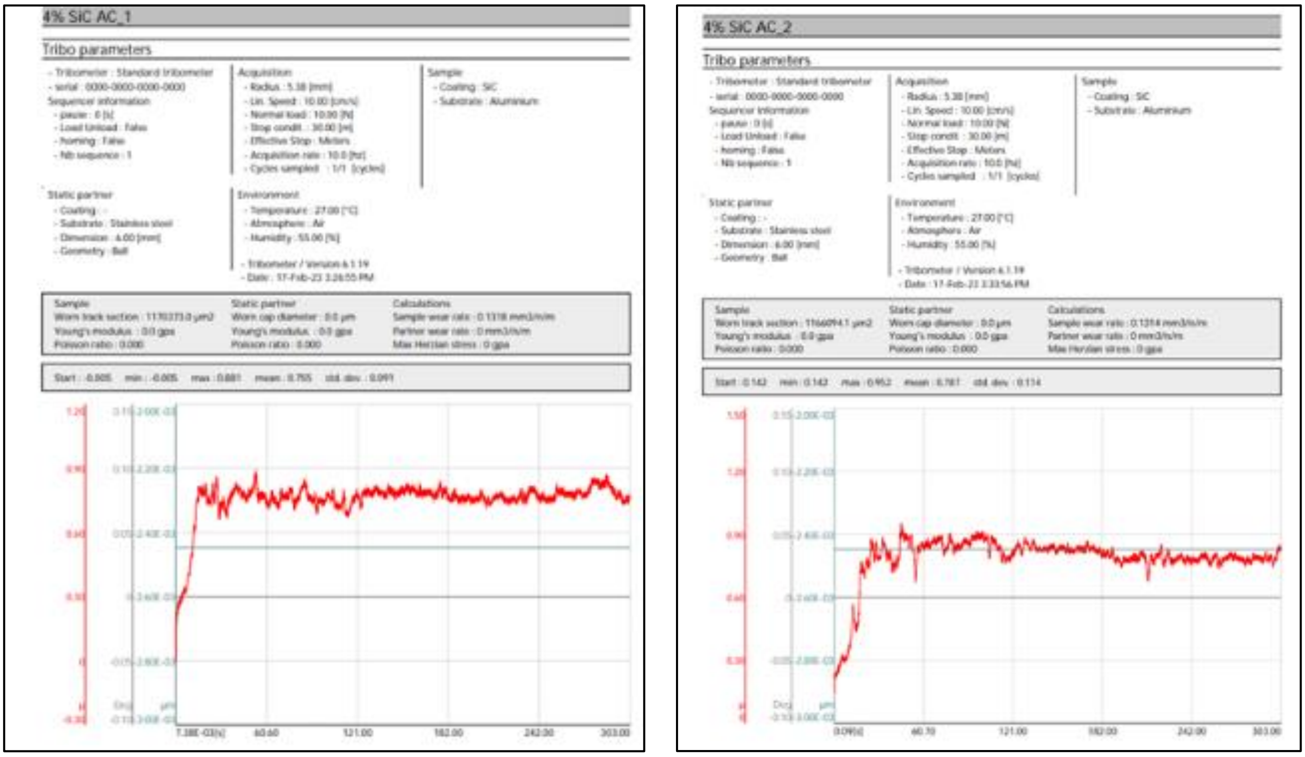

Figure 9 Wear Resistance Test Profile for Two Specimens of 90%Al-10%Cu/4.0%SiC Particulate Composites (Untreated)

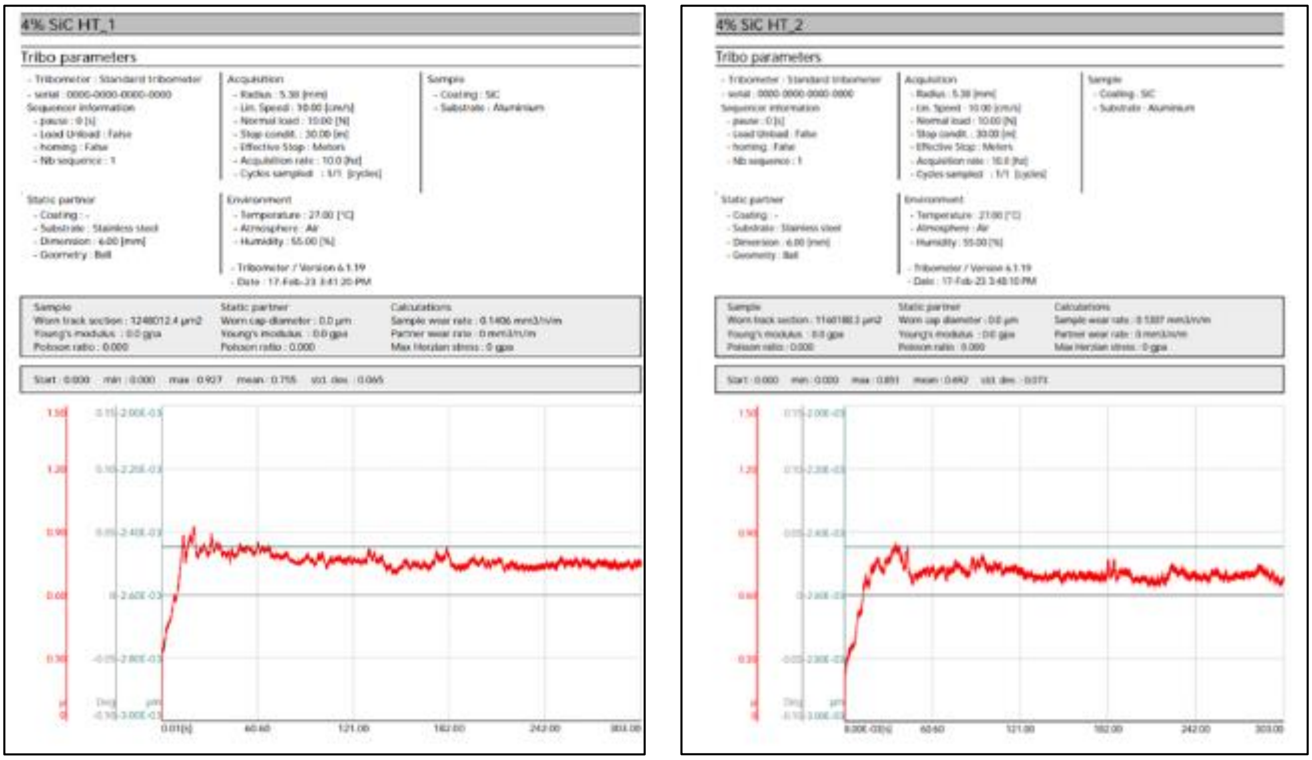

Figure 10 Wear Resistance Test Profile for Two Specimens of 90%Al-10%Cu/4.0%SiC Particulate Composites (Thermal Treated)

Table 1 Wear Resistance Test Results of the Specimens using Tribometer

S/N	Test Specimens	Wear Rate ($mm^3/N/m$)	Average Wear Rate ($mm^3/n/m$)
1	90Al-10Cu/0%SiC (Untreated)		0.02396
2	90Al-10Cu/0.5%SiC (Untreated)	0.0534	0.0633
3	90Al-10Cu/0.5%SiC (Untreated)	0.0732	
4	90Al-10Cu/0.5%SiC (Thermal treated)	0.0850	0.0895
5	90Al-10Cu/0.5%SiC (Thermal treated)	0.0939	
6	90Al-10Cu/1.0%SiC (Untreated)	0.0842	0.0697
7	90Al-10Cu/1.0%SiC (Untreated)	0.0551	
8	90Al-10Cu/1.0%SiC (Thermal Treated)	0.0715	0.05982
9	90Al-10Cu/1.0%SiC (Thermal Treated)	0.0481	
10	90Al-10Cu/2.0%SiC (Untreated)		0.02117
11	90Al-10Cu/2.0%SiC (Thermal Treated)		0.02462
12	90Al-10Cu/4.0%SiC (Untreated)	0.1318	0.1316
13	90Al-10Cu/4.0%SiC (Untreated)	0.1314	
14	90Al-10Cu/4.0%SiC (Thermal Treated)	0.1406	0.1357
15	90Al-10Cu/4.0%SiC (Thermal Treated)	0.1307	

3.2. Hardness Test Results of the Test Specimens

Table 2 Hardness Values of the Test Specimens in Brinell Hardness Number (BHN)

S/N	Test Specimens	Average Hardness (BHN)
1	90Al-10Cu/0%SiC (Untreated)	27.52
2	90Al-10Cu/0%SiC (Treated)	29.63
2	90Al-10Cu/0.5%SiC (Untreated)	64.28
3	90Al-10Cu/0.5%SiC (Untreated)	
4	90Al-10Cu/0.5%SiC (Thermal treated)	80.12
5	90Al-10Cu/0.5%SiC (Thermal treated)	
6	90Al-10Cu/1.0%SiC (Untreated)	67.38
7	90Al-10Cu/1.0%SiC (Untreated)	
8	90Al-10Cu/1.0%SiC (Thermal Treated)	82.02
9	90Al-10Cu/1.0%SiC (Thermal Treated)	
10	90Al-10Cu/2.0%SiC (Untreated)	29.10
11	90Al-10Cu/2.0%SiC (Thermal Treated)	29.45
12	90Al-10Cu/4.0%SiC (Untreated)	59.19
13	90Al-10Cu/4.0%SiC (Untreated)	
14	90Al-10Cu/4.0%SiC (Thermal Treated)	71.88
15	90Al-10Cu/4.0%SiC (Thermal Treated)	

3.3. Compression Test Results for the Test Specimens

Table 3 Compression Test Results for the Test Specimens

S/N	Test Specimens	Ultimate Compressive Strength (N/mm^2)	% Reduction at failure
1	90Al-10Cu/0%SiC (Untreated)		
2	90Al-10Cu/0.5%SiC (Untreated)	217.18	3.01
3	90Al-10Cu/0.5%SiC (Untreated)		
4	90Al-10Cu/0.5%SiC (Thermal treated)	240.95	1.06
5	90Al-10Cu/0.5%SiC (Thermal treated)		
6	90Al-10Cu/1.0%SiC (Untreated)	179.98	0.65
7	90Al-10Cu/1.0%SiC (Untreated)		
8	90Al-10Cu/1.0%SiC (Thermal Treated)	179.51	1.13
9	90Al-10Cu/1.0%SiC (Thermal Treated)		
10	90Al-10Cu/2.0%SiC (Untreated)		
11	90Al-10Cu/2.0%SiC (Thermal Treated)		
12	90Al-10Cu/4.0%SiC (Untreated)	126.24	4.75
13	90Al-10Cu/4.0%SiC (Untreated)		
14	90Al-10Cu/4.0%SiC (Thermal Treated)	145.40	2.67
15	90Al-10Cu/4.0%SiC (Thermal Treated)		

3.4. Summary of the Mechanical Test Results of the Test Specimens

Table 4 Compiled Tests Results of Untreated Composites

S/N	Compositions	Hardness (BHN)	Ultimate Compressive Strength N/mm^2	%Reduction at failure	Wear Rate(mm^3/N/m)
1	90Al-10Cu Alloy / 0%SiC	27.52	201.84		0.0212
2	90Al-10Cu Alloy / 0.5%SiC	64.28	217.18	3.01	0.0633
3	90Al-10Cu Alloy / 1%SiC	67.38	179.98	0.65	0.0697
4	90Al-10Cu/2.0%SiC	29.10			0.02117
5	90Al-10Cu Alloy / 4%SiC	59.19	126.24	4.75	0.1316

Table 5 Compiled Tests Results of Treated Composites

S/N	Compositions	Hardness (BHN)	Ultimate Compressive Strength N/mm^2	% Reduction at failure	Wear Rate (mm^3/N/m)
1	90Al-10Cu Alloy / 0%SiC	29.63	220.19		0.0246
2	90Al-10Cu Alloy / 0.5%SiC	80.12	240.95	1.06	0.0895
3	90Al-10Cu Alloy / 1%SiC	82.02	179.51	1.13	0.05982
4	90Al-10Cu/2.0%SiC	75.2			0.02462
5	90Al-10Cu Alloy / 4%SiC	71.88	145.40	2.67	0.1357

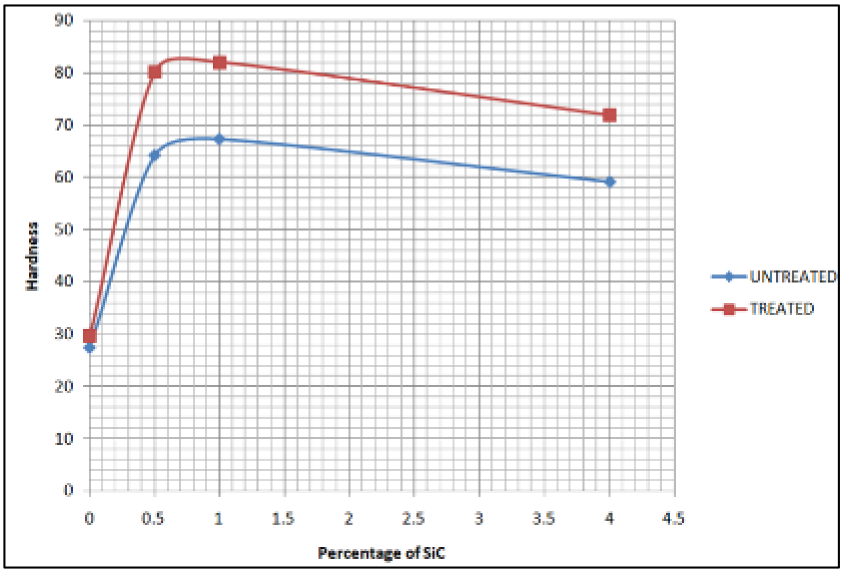

Figure 11 Graph of Hardness for both Treated and Untreated Specimens against the Various Percentages of SiC Particulate Additions

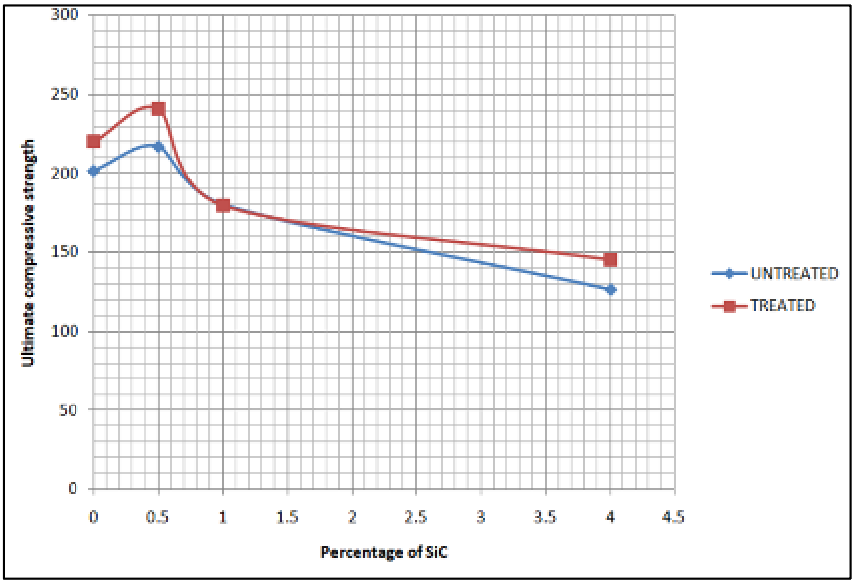

Figure 12 Graph of Ultimate Compressive Strength for both Treated and Untreated

Specimens against the Various Percentages of SiC Particulate Additions.

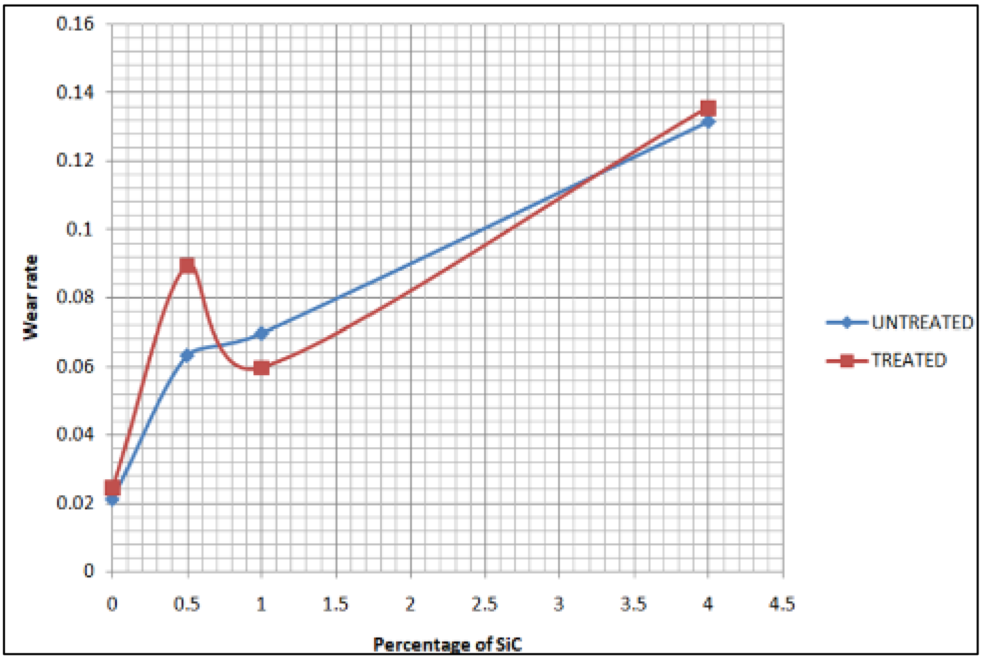

Figure 13 Graph of Wear Rate for both Treated and Untreated Specimens against the Various Percentages of SiC Particulate Additions

3.5. Microstructural Examination and Analysis

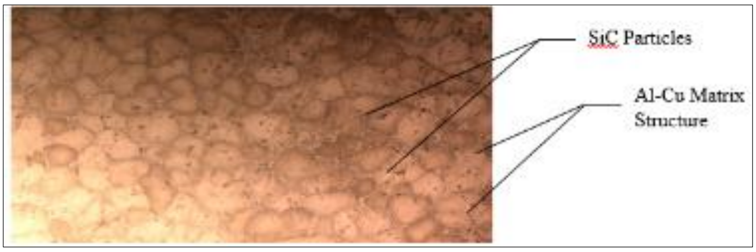

Figure 14 Microstructure of 90Al-10Cu/0.5%SiC particulate composite as cast

The micrograph shows Al-Cu Matrix and Small Black SiC particles distributed with the matrix at a magnification of 200X

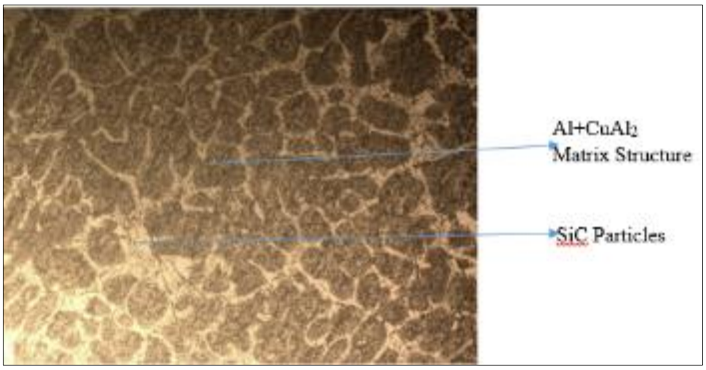

Figure 15 Microstructure of 90Al-10Cu/0.5%SiC particulate composite as age hardened

The Micrograph shows the Microstructure of the age hardened composite showing dark precipitate phase ($CuAl_2$), light Aluminium matrix and SiC particles. X200.

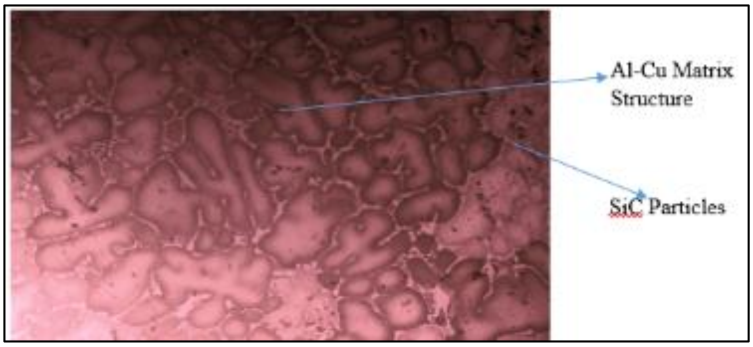

Figure 16 Microstructure of 90Al-10Cu/1%SiC particulate composite as cast

The micrograph shows Al-Cu Matrix and SiC particles distributed within the matrix at a magnification of 200X.

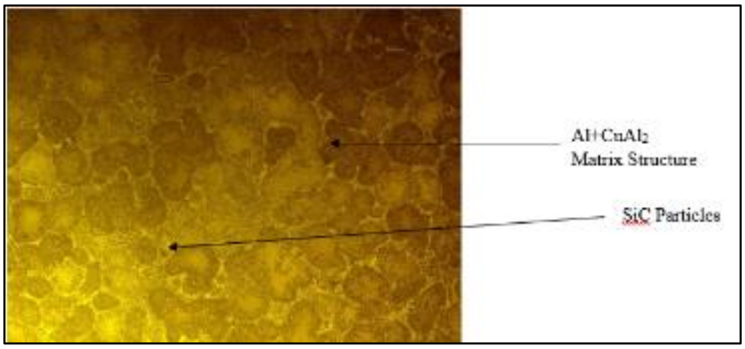

Figure 17 Microstructure of 90Al-10Cu/1%SiC particulate composite as age hardened

The Micrograph shows the Microstructure of the age hardened composite showing dark precipitate phase ($CuAl_2$), light Aluminium matrix and SiC particles X200.

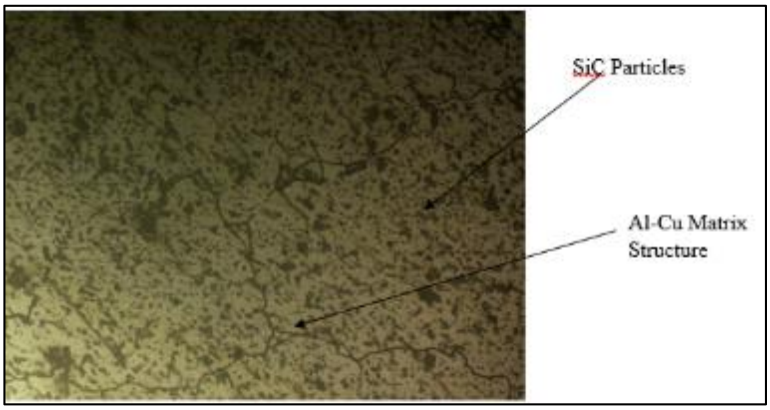

Figure 18 Microstructure of 90Al-10Cu/4%SiC particulate composite as cast

The micrograph shows Al-Cu Matrix and SiC particles distributed with the matrix at a magnification of 200X.

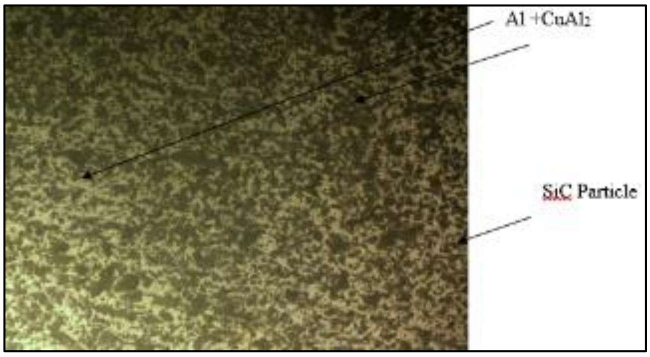

Figure 19 Microstructure of 90Al-10Cu/4%SiC particulate composite as age hardened

The Micrograph shows the Microstructure of the age hardened composite showing dark precipitate phase ($CuAl_2$), light Aluminium matrix and SiC particles. X200

4. Discussion

4.1. Tribology Test

Figures 5-10 show the wear profile of the treated and untreated composites. Two specimens were used in each case and the average wear rate was taken. In all the profiles there was a region of zero wear rate which was followed by a gradual wear rate, a peaking point, and finally a constant wear rate region. This pattern can be seen for both the untreated and untreated specimens. This wear rate pattern is also seen in practice with components and parts; for newly installed parts in service [1].

Table 1 shows the wear resistance test results of the specimens for both the untreated and treated specimens. The results show that 90Al-10Cu/2%SiC particulate composite (untreated) had the lowest wear rate of 0.0117 $mm^3/N/m$, this was followed by the untreated alloy (90Al-10Cu), which had a wear rate of 0.02396 $mm^3/N/m$ and then 90Al-10Cu/2%SiC particulate composite (treated) which has the wear rate value of 0.02462 $mm^3/N/m$. The highest wear rate occurred with the 90Al-10Cu/4.0% SiC composite for both the treated and untreated with values of 0.1357 and 0.1316 $mm^3/N/m$ respectively. The untreated composite, have better wear rate resistance. The wear rate of a material depends very much on its hardness and toughness; this has determined the wear rate of the various compositions in both the untreated and treated state. The microstructure of the compositions also support their wear rate values [15]-[18].

4.2. Hardness Test

Table 2 shows the results of the hardness of the tests specimens both the untreated and the treated. The results, show that the treated specimens have higher values than the untreated for each composition. 90Al-10Cu/1%SiC (thermal treated) had the highest hardness value of 82.02BHN, which is closely followed by 90Al-10Cu/0.5%SiC (thermal treated) with hardness value of 80.12BHN. The alloy composition of 90Al-10Cu has the lowest hardness value of 27.52 BHN. The improvement in hardness of the compositions after thermal treatment is as a result of super-saturation on solutionising and quenching, which creates a lot of vacancies in the compositions; upon aging at 170 C precipitation takes place quickly through diffusion to fill-up the vacancies leading to increase hardness of the treated compositions [1]-[15].

4.3. Compression Strength Test

Table 3 shows the compression strength test results for the alloy and the composites for both the untreated and treated test specimens. In most of the compositions (test specimens) the treated specimens had the highest ultimate compression strength. The % reduction at failure, however, is highest with the untreated specimens. This is in order because the strength of the treated specimen was altered during the ageing treatment; as strength increases ductility decreases [1]-[4]. 90Al-10Cu/0.5%SiC (thermal treated) had the highest ultimate compression strength of 240.95 N/mm^2 and followed by 90Al-10Cu/0.5% SiC (untreated) which has 217.18N/mm^2. 90Al-10Cu/4.0% SiC (untreated) has the highest % reduction at failure of 4.75; it is followed by 90Al- 10Cu/0.5% (untreated) with a value of 3.01%. The microstructure of the compositions agree with the compression strength values.

4.4. Summary of the Mechanical Test Results of the Specimens

Table 4 is a compilation of test results for the untreated alloy and composites. The results show that all the composites have better results than the alloy. The wear rate is however, smaller in the case of the alloy.

Table 3 is a compilation of test results for the thermally treated alloy and composites. The treated specimen showed improvement in some parameters over the alloy when the alloy mechanical properties are compared with those of the composites. The composites showed improvement in hardness, ultimate compression strength, and even in wear rate were 90Al-10Cu/2.0%SiC has a wear rate of 0.02462 $mm^3/N/m$. This agrees with the principle of composite production to have improved properties over the alloy metal [1]-[12].

Tables 4-5 can best be explain by Figs. 11-13. Fig.11 is the graph of hardness for both untreated and treated specimens against the various percentages of SiC particulate additions. The graph shows that the hardness of the composites increases as the SiC particles in the alloy increases, it reached a peak and then starts decreasing with further increase in SiC particles. The same pattern can be seen in the untreated and treated specimen. The graph of the treated specimen is above that of the untreated specimen indicating that the treated specimens have improved hardness. Figures 14-19 also confirms improvement in hardness as a result of the formation of precipitates of $CuAl_2$. This agrees with previous works [13]-[18].

Figure 12 is the graph of ultimate compression strength for both treated and untreated specimens against the various percentages of SiC particulate additions. The two curves showed that the ultimate compression strength increase as the SiC particles in the alloy matrix (90Al-10Cu) increases. The two curves showed that as the SiC particles were increased the ultimate compression strength too was increasing. The curves both peaked and then sharply dropped and then gradually decreased with increase in further SiC particles. The graph showed that the thermal treated specimens had higher improved ultimate compression strength than the untreated, since the curve for the treated is placed above that of the untreated. This observation agrees with previous literatures [14]-[18].

Figure13 is the graph of wear rate for both untreated and treated specimens against the various percentages of SiC particulate additions. The two curves show that as the SiC particles increase the wear rate for both untreated and treated composites increase until a peak is experienced. For the curves showed a peaking point and a sharp drop in the case of the treated before rising again sharply to rise above the untreated specimens which only dropped a little after peaking. The graph has shown that the treated specimens have higher wear rate in some compositions than the untreated. It is however, seen that the reinforcement has greatly improved the wear resistance of both the untreated and treated in both specimens.

The wear resistance of the untreated and treated composites is competitive from 0-0.7%SiC untreated composite are better and from 0.7-3.2%SiC treated composites compositions are better than untreated composition. It is common for materials to wear in this pattern as can be seen in the wear rate of the materials earlier in Figures 5-10 [1]-[10].

4.5. Microstructure Analysis

Figure 14 is the microstructure of 90Al-10Cu/0.5%SiC particulate composite as cast. The microstructure shows Al-Cu matrix and small black SiC particles distributed within the matrix at a magnification of 200X. Figure 15 is the microstructure of 90Al-10Cu/0.5%SiC particulate composite as age hardened. The SiC particles are no longer conspicuous as they were in Figure 14, but can be seen in minute quantities finely distributed in the matrix of the composite. Thick dark precipitates can now be seen in the matrix which are precipitates of $CuAl_2$ and the light areas are Al matrix (α). The treated composite has a different structure from the untreated. This explains the variation in properties between the untreated and the treated composite [1]-[4].

Figure 16 is the microstructure of 90Al-10Cu/1%SiC particulate composite as cast. The microstructure show Al-Cu matrix and SiC particles distributed within the matrix at a magnification of 200X.

Figure 17 is the micrograph of 90Al-10Cu/1%SiC particulate composite as age hardened. The micrograph shows Al + $CuCl_2$ matrix structure with dark precipitates. The structure is completely different from that of Figure 16 of the untreated composite. The SiC particles after the thermal treatment have been difficult to differentiate. The changes of the microstructure after thermal treatment is responsible for the change in mechanical properties of the composite [2].

Figure 18 is the microstructure of 90Al-10Cu/4%SiC particulate composite as cast. The micrograph shows Al-Cu matrix and SiC particles distributed within the matrix at a magnification of 200X. Figure 19 is the microstructure of 90Al-10Cu/4%SiC particulate composite as age hardened. The micrograph show the microstructure of the age hardened composite showing heavy dark precipitates phase ($CuAl_2$), light Al matrix (α) and SiC particles at a magnification of 200X. The change in microstructure after thermal treatment explain the change in mechanical properties [1]-[15].

Finally it is noticed from Figures 14, 16, and 18 that as the SiC particles were increased the microstructure also kept changing. Figures 18-19 which has the highest amount of SiC particles of 4%SiC showed a marked difference from the microstructures with lower amount of SiC particles. This may also explain the marked differences in mechanical properties seen in Tables 4-5 [18].

5. Conclusion

Investigation of the effects of SiC particles addition and thermal treatment on 90Al-10Cu alloy has been carried out and the following findings established:

- The addition of SiC particles to 90Al-10Cu alloy affected both the microstructure and the mechanical properties of the composites formed.
- The thermal treatment which was age hardening; administered on the alloy, and the composites affected the microstructure; there was precipitation of a second phase. This led to changes in the mechanical properties of the thermally treated compositions.
- For the untreated compositions the alloy and 90Al-10Cu/2%SiC particulate composite had the lowest wear rate value of 0.0212mm^3/N/m. 90Al-10Cu/1% SiC had the highest hardness value of 67.38 BHN. 90Al-10Cu/0.5%SiC particulate composite outperformed other compositions with the following mechanical properties: hardness value of 64.28BHN; ultimate compression strength of 217.18N/mm^2; % reduction at failure of 3.01; and wear rate value of 0.0633.
- For the thermally treated compositions; the lowest wear rate of 0.0246mm^3/N/m is with the alloy composition and 90Al-10Cu/2%SiC particulate composite. 90Al-10Cu/1%SiC has the highest hardness value of 82.02BHN; the highest % reduction at failure of 1.13% and wear rate value of 0.05982, while 90Al-10Cu/0.5%SiC has hardness value of 80.12BHN, ultimate compression strength of 240.95N/mm^2, % reduction at failure of 1.06% and wear rate of 0.0895mm^3/N/m. The 1% SiC reinforced particulate composite performed better than other compositions, but it is closely followed by 0.5% SiC reinforced particulate composite for the thermal treated compositions in terms of improved mechanical properties. This correlates with their microstructures which all show the heavy precipitation of a second phase.

Compliance with ethical standards

Acknowledgments

The authors of this work sincerely acknowledge the assistance received from the Technologists of various organizations to which the experiments of this work was carried out. We thank the technologist in the Metallographic Laboratory of National Metallurgical Development Centre, Jos. Finally, we thank the Technologists in the Materials Testing Laboratory of the Department of Materials and Metallurgical Engineering, ABU Zaria, Technologists of Faculty of Engineering workshop, University of Uyo, Technologists of Materials Testing Laboratory of the Departments of Mechanical and Aerospace Engineering, and Civil Engineering.

Disclosure of conflict of interest

This paper has no conflict of interest; all the authors have agreed that they should publish their paper in this journal. Again it should be noted that the research is self sponsored.

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