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Mechanical and Wear Behavior of Aluminium Metal Matrix Composites Reinforced Ceramics Materials for Light Structures

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Abstract

Aluminium Alloy based Metal Matrix Composites (AAMMCs) has widely used in defense, aircraft and automobile applications because of their enhanced engineering properties with light weight metals. Nano sized silicon nitride (80 µm) is used as a reinforcement in this study, whereas aluminium alloy 8011 is selected as the matrix material. Using the stir casting method, metal matrix composites made of aluminium alloy 8011 with varying weight percentages of Si_3N_4 (0, 4, 8, 12, and 16) are created. The stir casted AL 8011/Si_3N_4 composites further heated under T6 condition. The AL 8011/Si_3N_4 – T6 composites are further subjected to Energy Dispersive X ray Analysis (EDAX) and Scanning Electron Microscope (SEM) to identify by the presence of elements and study the microstructure characterization, respectively. The density, microhardness and wear test are conducted by employing Archimedes principle, Vickers hardness tested and pin on disc equipment, respectively. The wear test is done at different sliding distances like (500, 1000, 1500 and 2000 m), applied load like (10, 20, 30 and 40 N) and kept sliding at a speed of 1 m/s. The increasing weight percentage of silicon nitride expands the increasing of density and Vickers hardness up to 12 wt % of silicon nitride and decreasing by 16 wt % addition. The wear resistances of AL 8011/12 wt % Si_3N_4 –T6 composite exhibits higher wear resistance than other Al8011 based composites.

Keywords: *Aluminium Alloy 8011, Density, Microhardness, Silicon Nitride, Wear Test*

1.0 Introduction

The high demand for maximum strength to weight ratio with greater mechanical properties based materials are utilized in the aerospace and defence applications. Conventional alloys are replaced by metal matrix

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composites with their appropriate high stiffness and specific strength and MMCs are widely employed in aerospace, automobile and aircraft applications[1]. AMMCs possess stronger mechanical and physical properties than its matrix material[2]. The aluminium alloy 8011 has higher corrosion resistance, better cast ability and high strength to weight ratio[3]. Nano composites outperform their typical alloy counterparts in terms of mechanical strength, damping capacity, and wear resistance[4]. The various reinforcements such as TiC, SiC, B_4C, TiB_2 and Si_3N_4 ceramics are used for enhancing the properties of the matrix material[5]. The different kind of production methods are available for fabricating composites such as powder metallurgy, stir casting method and additive manufacturing techniques[6]. The stir casing methods are used for fabricating composites because of its flexibility, simplicity, cost effective and ease of high mass production than other fabrication methods[7]. The analysis is done for identifying influence of mixing time, melting temperature, stirring speed and particles condition[8]. The incorporation of nano sized silicon carbide into matrix material increases the mechanical attributes and wear resistances of the selected composites[9]. Boron carbide, when added to AL7075, improves the microhardness and tensile strength of the finished MMCs. The ultimate tensile strength is greatly enhanced as the volume percentage of boron carbide rises[10-12]. The silicon carbide with different particle size (63, 76 and 89) incorporated with aluminium alloy 8011. The lowest particle size based AL8011 processed MMCs revealed superior mechanical characteristics[13-15]. The Al8011 or fly ash with fabricated MMCs composed enhanced mechanical behavior when compared to its conventional base alloy[16]. The incorporation of ZrB_2 into aluminium alloy 7075 produces Al7075/ZrB_2 composites. The addition of ZrB_2 increases the wear conflicts of the prepared MMCs than the parent material[17]. The incorporation of silicon nitride into matrix material increases the attributes of mechanical properties and resistance of wear in processed composites[18-19]. There is no research done on the wear behavior of AL8011/Si_3N_4 composites. In this work, attempts have been made to analysis the micro hardness, density and wear behavior of AL8011/Si_3N_4 composites for light weight applications.

2.0 Materials and Methods

The aluminium alloy 8011 has selected as base matrix material because of its lowest wear resistance property. The round rod shape of the AL8011 is utilised. Table 1 (a-b) shows the mechanical and chemical characteristics of the base alloy (TMA). To make the AL8011 matrix material more resistant to wear, silicon nitride is chosen as a hard reinforcement. The particle size of silicon nitride is 80 µm and it is confirmed by particle size analyzer[20]. The silicon nitride has higher wear resistance and corrosion resistance. The SEM image of AL8011and Si_3N_4 is depicted in Figure 1(a-b). The zebrine coated steel is used for stirrer. The melted material is poured into the die.

3.0 Fabrication of Composites

The AL8011/xwt % Si_3N_4 (0, 4, 8, 12 and 16). The matrix material AL8011 is cut into several pieces of round rod and it is kept in the stir casting crucible furnace.

Table1 (a). Weight percentage of elements of AL8011

Material	Al	Fe	Si	Mn	Cu	Zn	Ti	Cr	Mg
Wt.%	97.5	1	0.9	0.2	0.1	0.1	0.08	0.05	0.05

Table 1 (b). Mechanical properties of aluminium alloy 8011

Thermal Expansion	Density	Elastic Modulus	Strength to Weight Ratio	Ultimate Tensile Strength
21.8 µm/m-k	2.72 g/cm^2	71GPa	40 KN-m / kg	110 MPa

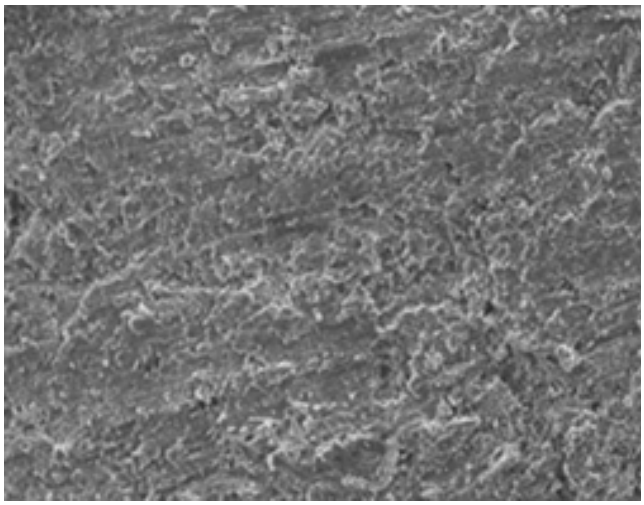


Figure 1(a). SEM picture of AL8011.

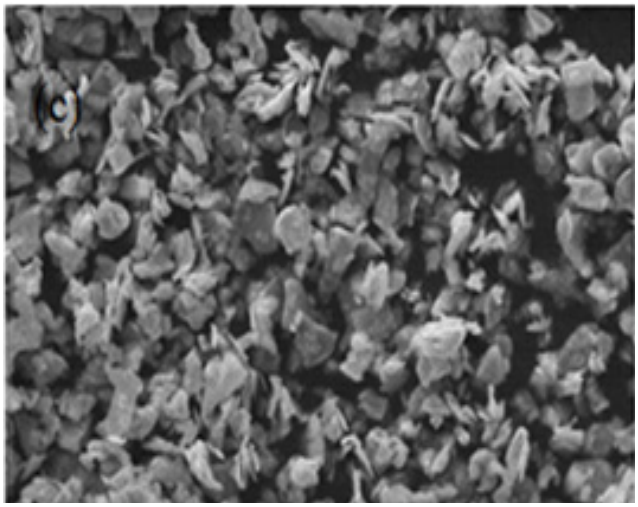


Figure 1(b). SEM picture of Si_3N_4.

The degassing tablets are used to send out entrapped gasses. The silicon nitride reinforcement is preheated at 400°C for 20 minutes. The pre heated silicon nitride is mixed with the molten aluminium alloy 8011. The 1wt % of magnesium is added with the molten metal while mixing silicon nitride to increase the wettability between aluminium alloy and silicon nitride reinforcement[21]. The stirring is done at 300 rpm for 360 seconds. The Figure 2 shows the setup for stir casting. The melted metal is cooled in atmospheric air. The same procedure is used for fabricating all kind of combination of AL8011 based composites. The fabricated AL8011/xwt % Si_3N_4 (0, 4, 8, 12 and 16) composites are further heat treated under T6 condition[22]. The furnace and stir casting setup are depicted in Figure 2(a-b), correspondingly. The fabricated specimen size is 30 mm diameter with 250 mm length.

4.0 Testing of Composites

The Al8011, Al8011/wt % Si_3N_4 (4, 8, 12 and 16) composites are subjected to EDAX, SEM, density, micro hardness and wear test. The T6 condition composites that are wire cut EDM prepared for ASTM testing are subjected to a battery of tests. Wire cut EDM is utilised to prevent components from moving about while they are being machined. Polishing the specimen with 600, 800, and 1000 sheets allows for a better examination of

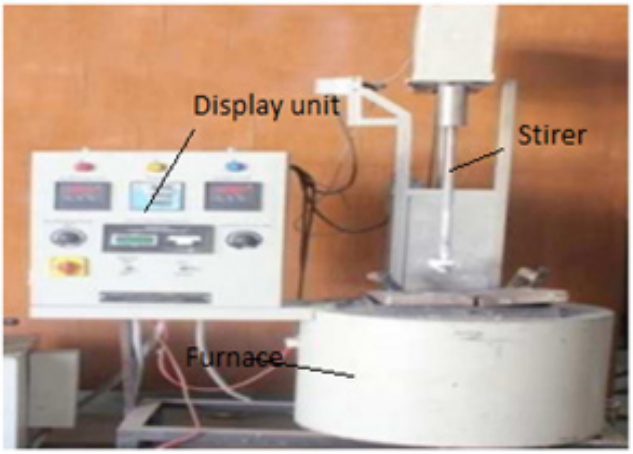


Figure 2(a). Stir casting setup.



Figure 2(b). Muffle furnace.



Figure 3. Pin on disc setup.

its microstructure. For etching the polished specimen, the keller's reagent is used in the following proportions: 1.5 ml of HCL, 2.5 ml of HNO3, 1.0 ml of HF, and 95 ml of water[23]. The Vickers hardness tester is used for conducting micro hardness test. The fabricated AL8011 based composites are subjected to wear analysis. In accordance with ASTM G99, the pin on disc setup (DUCOM) is used to analyse the wear test. Disc material, namely EN31, is being spun against a pin, which is a composite material. A wear test is carried out with varying applied loads of 10 N, 20 N, 30 N, and 40 N, while the sliding distance and speed are kept at 1000 m and 1 m/s, respectively. Additionally, a continuous applied force of 20 N and a sliding speed of 1 m/s are used to conduct the wear test at various sliding distances of 500 m, 1000 m, 1500 m, and 2000 m. By comparing the specimen's weight both before and

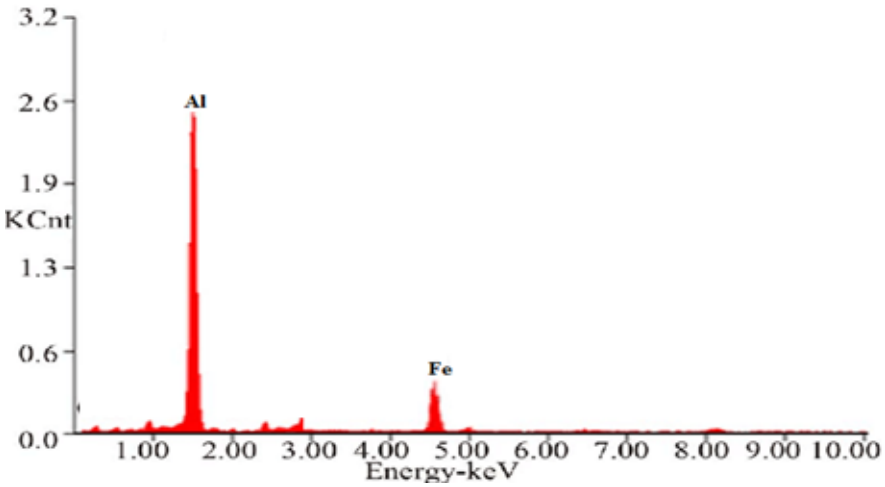


Figure 4(a). Al8011.

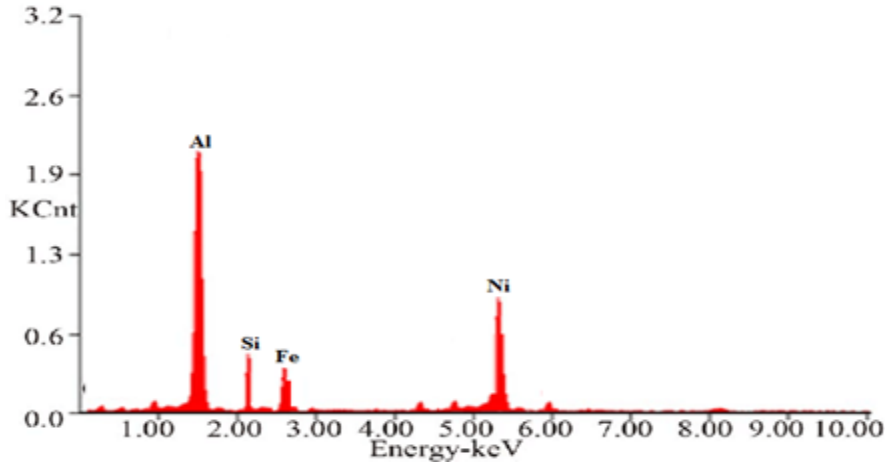


Figure 4(b). Al8011/4wt% Si_3N_4.

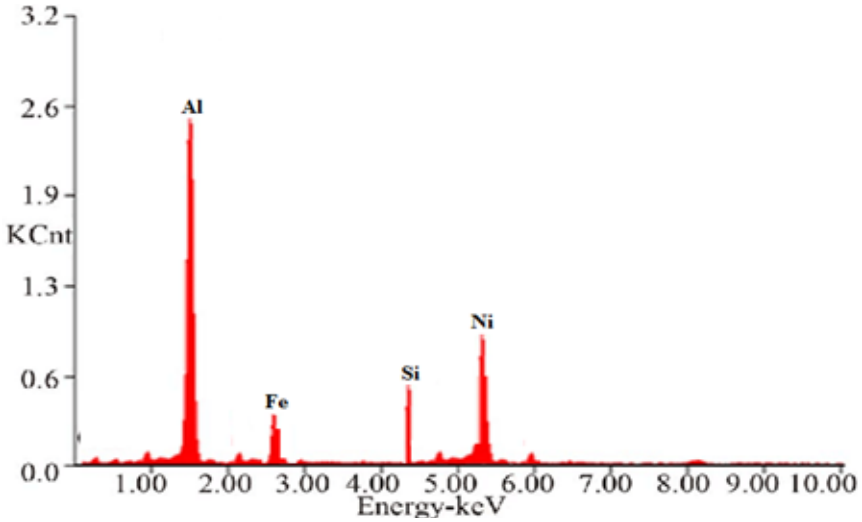


Figure 4(c). Al8011/8wt% Si_3N_4.

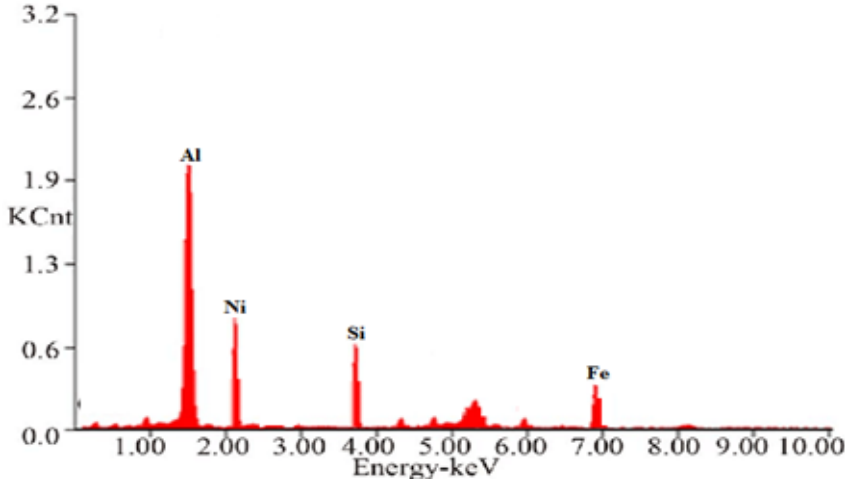


Figure 4(d). Al8011/12wt% Si_3N_4.

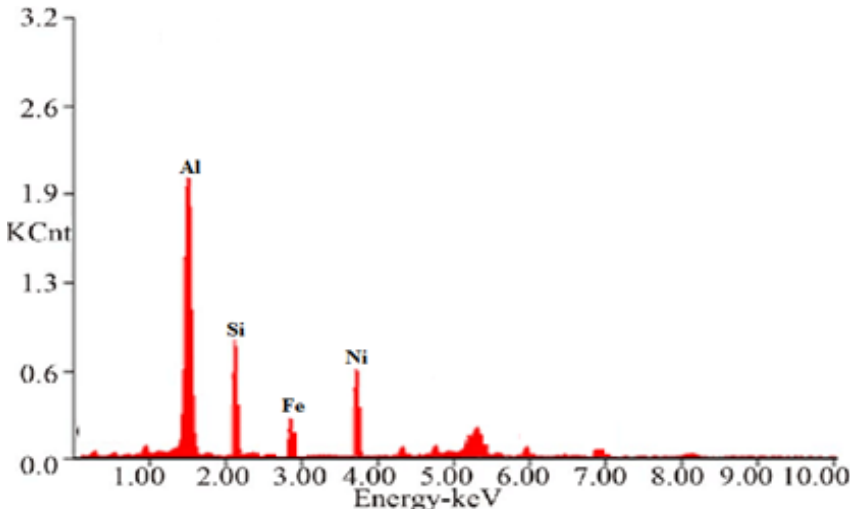


Figure 4(e). Al8011/16wt% Si_3N_4.

after the wear study, we can determine the wear failure rate. The wear test is conducted on AL8011/wt. %Si_3N_4 (4, 8, 12 and 16), Al8011/wt % Si_3N_4 (4, 8, 12 and 16)-T6 composites. Figure 3 displays the pin on disc setup.

5.0 Results and Discussion

5.1 EDAX and Microstructural Study

The below Figure shows the EDAX result of Al8011, Al8011/4wt% Si_3N_4, Al8011/8wt% Si_3N_4, Al8011/12wt% Si_3N_4 and Al8011/16wt% Si_3N_4-T6 composites. All of the components are shown in Figure 4 (a-e) according to the EDAX findings, which show a mixed blend of matrix and reinforcements. The Figure shows the SEM

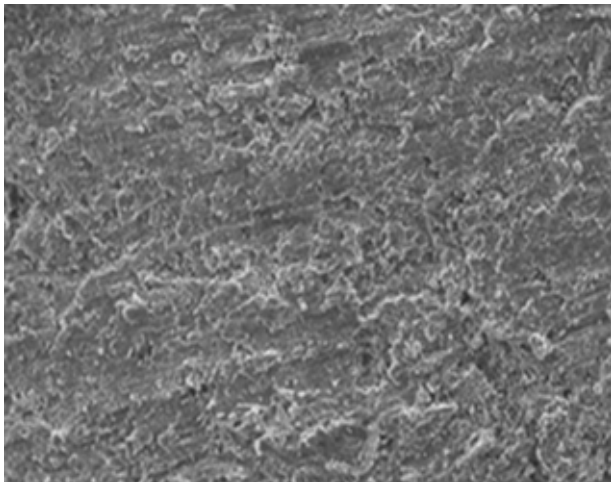


Figure 5(a). Al8011 at 50 µm.

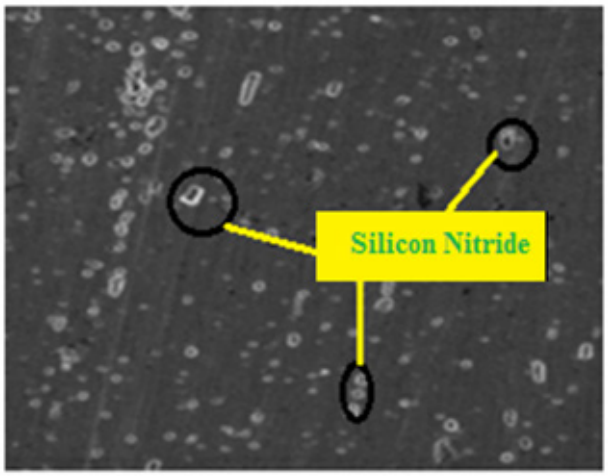


Figure 5(b). Al8011/4wt% Si_3N_4 at 50 µm.

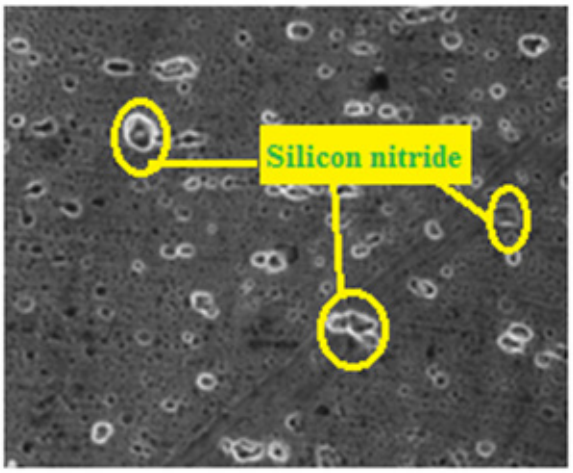


Figure 5(c). Al8011/8wt% Si_3N_4 at 50 µm.

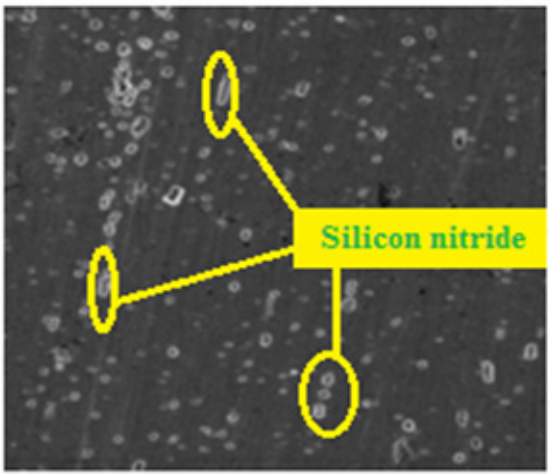


Figure 5(d). Al8011/12wt% Si_3N_4 at 50 µm.

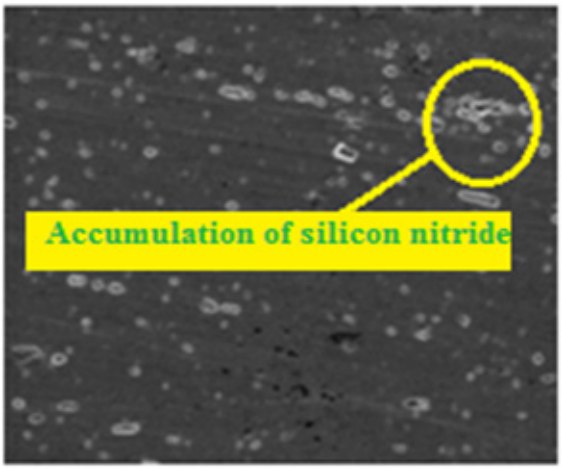


Figure 5(e). Al8011/16wt% Si_3N_4 at 50 µm.

image of Al8011, Al8011/4wt% Si_3N_4, Al8011/8wt% Si_3N_4, Al8011/12wt% Si_3N_4 and Al8011/16wt% Si_3N_4-T6 composites. The SEM image of the composites reveals that reinforcements are uniformly dispersed in the material AL8011[24]. The SEM picture of all fabricated AL8011 based composites is shown in Figure 5(a-e).

5.2 Density and Microhardness Testing

The AL8011/xwt% Si_3N_4 (0, 4, 8, 12 and 16) and AL8011/xwt% Si_3N_4 (0, 4, 8, 12 and 16)-T6 composites are subjected to density test by employing Archimedes principle. The AL8011/xwt% Si_3N_4 (0, 4, 8, 12 and 16) and AL8011/xwt% Si_3N_4 (0, 4, 8, 12 and 16)-T6 composites are subjected to micro hardness test by using Vickers hardness tester. The comparison of density and micro hardness of AL8011/xwt% Si_3N_4 (0, 4, 8, 12 and 16) and AL8011/xwt% Si_3N_4 (0, 4, 8, 12 and 16)-T6 composites is shown in Table 2. In both cases, the density of fabricated composites is compared in Figure 6(a-b). The Figure 5(a) reveals that incorporation of silicon nitride and increases the density of fabricated composites up to 12 wt% of silicon nitride and decreases by incorporation of 16 wt%. Processed MMCs density was increased which caused by superior density when silicon nitride addition into low density AL8011 matrix material[25]. The Figure 5(b) Shows that increasing wt% of silicon nitride increases the micro hardness of AL8011 based composites. The micro hardness is increased up to incorporation 12wt% of silicon nitride into AL8011 based composites-T6 condition and falls by 16 wt%

Table 2. Comparison of density and microhardness

S. No	Sample	Density g/cm^3		Micro Hardness	
		Unheat Treated	Heat Treated	Unheat Treated	Heat Treated
1	A	2.721	2.726	90	94
2	B	2.736	2.741	105.2	112
3	C	2.752	2.759	116	126
4	D	2.778	2.787	132	141
5	E	2.761	2.769	126	132

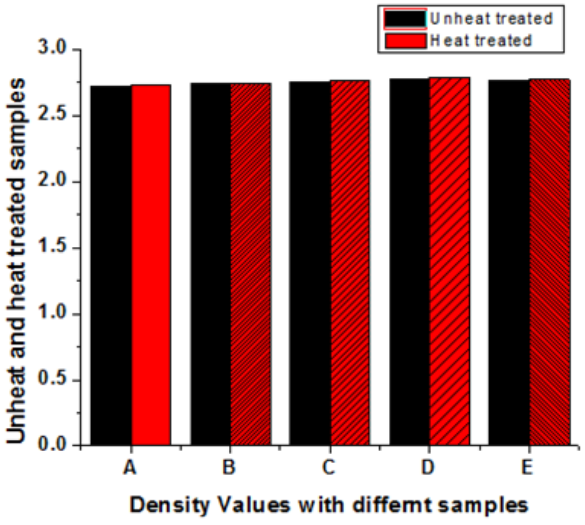


Figure 6(a). Density comparison.

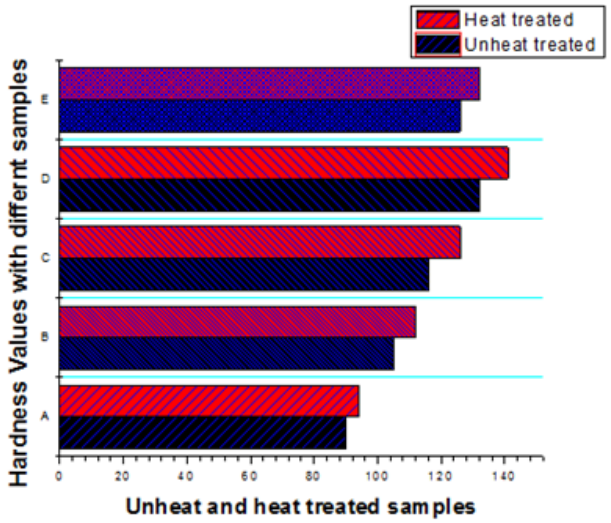


Figure 6(b). Microhardness comparison.

addition. The higher density silicon carbide increases the density and micro hardness of all kind of AL8011 based composites.

5.3 Wear Testing

Wear testing is carried out on all manufactured composites using a pin on disc setup at the specified sliding distance, which ranges from 500 to 2000 m with an increment of 500 m. Similarly, a force ranging from 10 to 40 N was applied while maintaining a sliding distance of 1 m/s. Test specimens for wear are polished to a fineness of 1 µm. With functional loads of 10, 20, 30, and 40 N, the wear is carried out at a constant sliding speed of 1 m/s and a distance of 1000 m. Table 3 shows the results of the wear tests.

The wear test results are revealed that heat treated AL8011 based composites has higher wear resistance than untreated AL8011 based composites. The heat treatment under tempering condition 6 is extended the hardness of the composites. The incorporation of silicon nitride increases the wear resistance of the AL8011/wt% Si_3N_4-T6 composites. The wear resistance of the AL8011 based silicon nitride reinforced composites is increased upto 12wt % silicon nitride and decreased by 16wt %

Table 3. Slide velocity (1 m/s) and distance (1000 m) wear loss before and after heat treatment

S. No	Applied Load (N)	Sample A		Sample B		Sample C		Sample D		Sample E	
		Before Wt. Loss (mg)	After Wt. Loss (mg)	Before Wt. Loss (mg)	After Wt. Loss (mg)	Before Wt. Loss (mg)	After Wt. Loss (mg)	Before Wt. Loss (mg)	After Wt. Loss (mg)	Before Wt. Loss (mg)	After Wt. Loss (mg)
1	10	36	31	28	23	26	21	19	15	21	19
2	20	43	39	34	29	31	26	25	19	27	26
3	30	49	44	42	36	37	31	32	27	33	29
4	40	56	51	51	46	46	42	39	35	42	37

Table 4. Wear loss of sliding velocity (1 m/s) and load (20 N) on before and after heat treatment process

S. No	Sliding Distance (mm)	Sample A		Sample B		Sample C		Sample D		Sample E	
		Before Wt. Loss (mg)	After Wt. Loss (mg)	Before Wt. Loss (mg)	After Wt. Loss (mg)	Before Wt. Loss (mg)	After Wt. Loss (mg)	Before Wt. Loss (mg)	After Wt. Loss (mg)	Before Wt. Loss (mg)	After Wt. Loss (mg)
1	500	27	23	21	18	18	13	14	10	17	12
2	1000	31	27	27	23	22	17	18	14	20	16
3	1500	37	32	32	28	27	22	23	17	26	21
4	2000	42	38	37	32	33	28	28	23	31	29

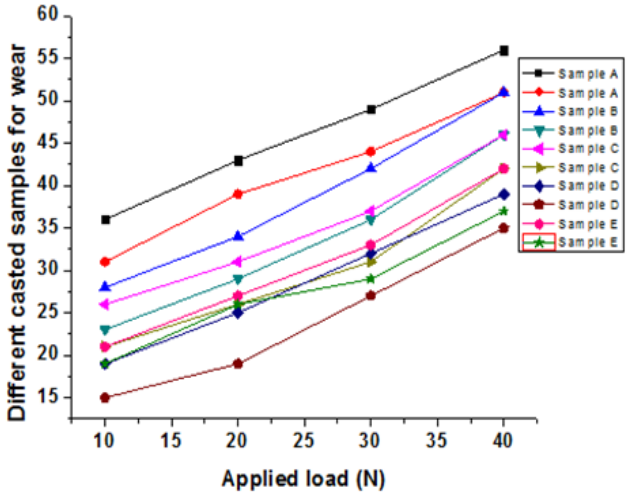


Figure 7. Wear loss at different applied load on AL8011/Si_3N_4.

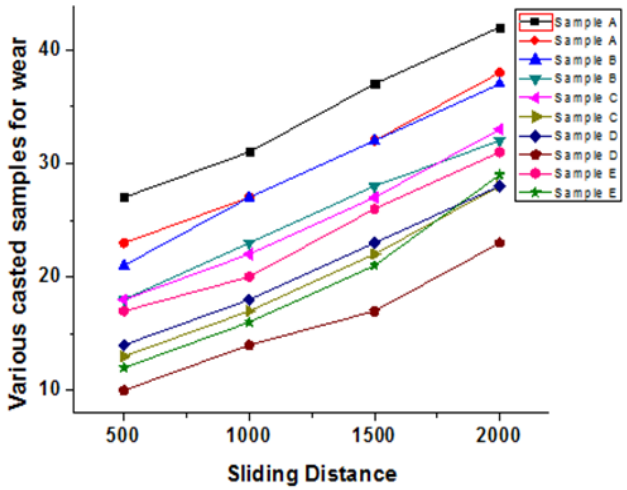


Figure 8. Wear loss at different sliding distances on AL8011/Si_3N.

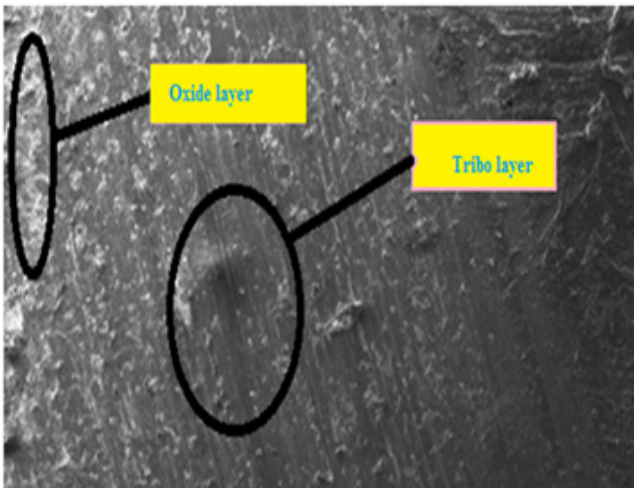


Figure 9(a). Worn surface of confirmation test specimen.

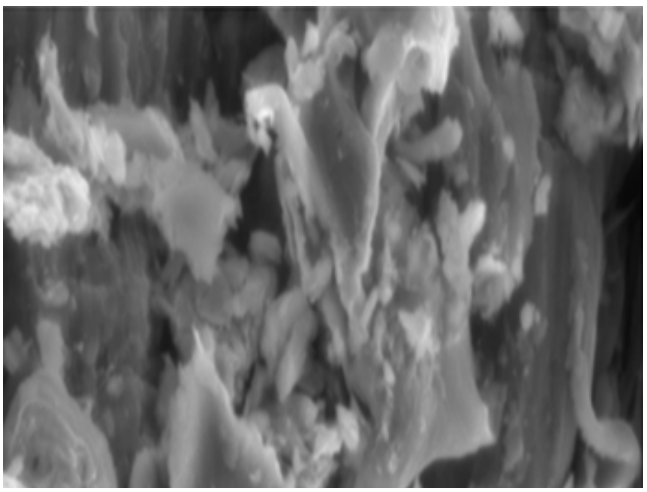


Figure 9(b). Wear debris of confirmation test specimen at 5 µm.

of silicon nitride addition[26]. The high accumulation of silicon nitride decreases the wear resistance in 16wt % addition[27]. The comparison of wear test results is exhibited in Figure7. Increased load increases composite wear loss. Al8011/12wt% Si3N4-T6 composite wears less. The wear test is also done at 1 m/s and 20 N of continuous sliding speed and applied load with 500, 1000, 1500, and 2000 m sliding distance changes. Table 4 provides wear test results. Slide distance increases wear loss for all AL8011 composites, according to wear tests. The wear loss of Al8011 based composites decreases up to 12 wt% silicon nitride addition and decreases by the 16wt% addition in all type of sliding distance. The AL8011/Si_3N_4-T6 composites has lower wear loss than untreated AL8011 based composites. The comparison of wear test results for AL8011 based composites-T6 condition is shown in Figure 8. The low wear loss is occurred in AL8011/12wt% Si3N4-T6 composites at the required conditions like 20 N, 1 m/s and 500 m of applied load, sliding speed and sliding distance, respectively. The worn surface and its corresponding wear debris were displayed in Figure 9(a-b). The observed wear mechanism is abrasion in the worn surface[28-30].

6.0 ANN Techniques on the Enhance the Tribological Performances

The artificial neural network develops the output performances by the supports of statistical and computation method which manipulated by the methods of human brain. Based on the biological based nervous systems, the ANN model was constructed and implemented into the robotics, image recognition and various related applications. Normally the ANN has some specific model to analysis the input processing parameters for testing the

Table 5. ANN outcomes for wear performances with various casted samples

S. No	Applied Load (N)	Sample A		Sample B		Sample C		Sample D		Sample E	
		Exp	ANN	Exp	ANN	Exp	ANN	Exp	ANN	Exp	ANN
1	10	31	32.1	23	23.69	21	22.02	15	15.69	19	18.01
2	20	39	39.08	29	29.36	26	25.36	19	19.34	26	27.31
3	30	44	44.98	36	36.32	31	32.15	27	27.61	29	29.36
4	40	51	51.26	46	46.39	42	43.85	35	35.63	37	37.89
5	500	23	24.56	18	18.01	13	14.21	10	11.21	12	12.82
6	1000	27	28.14	23	23.91	17	17.38	14	15.03	16	17.09
7	1500	32	32.36	28	28.31	22	23.31	17	18.62	21	22.36
8	2000	38	38.29	32	32.89	28	28.64	23	24.36	29	30.14

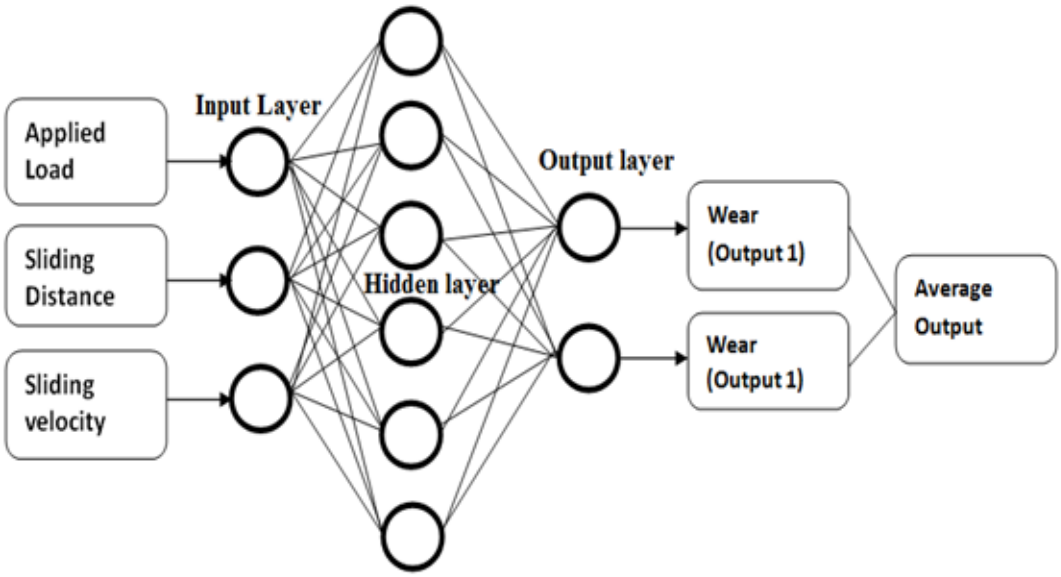


Figure 10. ANN model for wear performances with their processing layers.

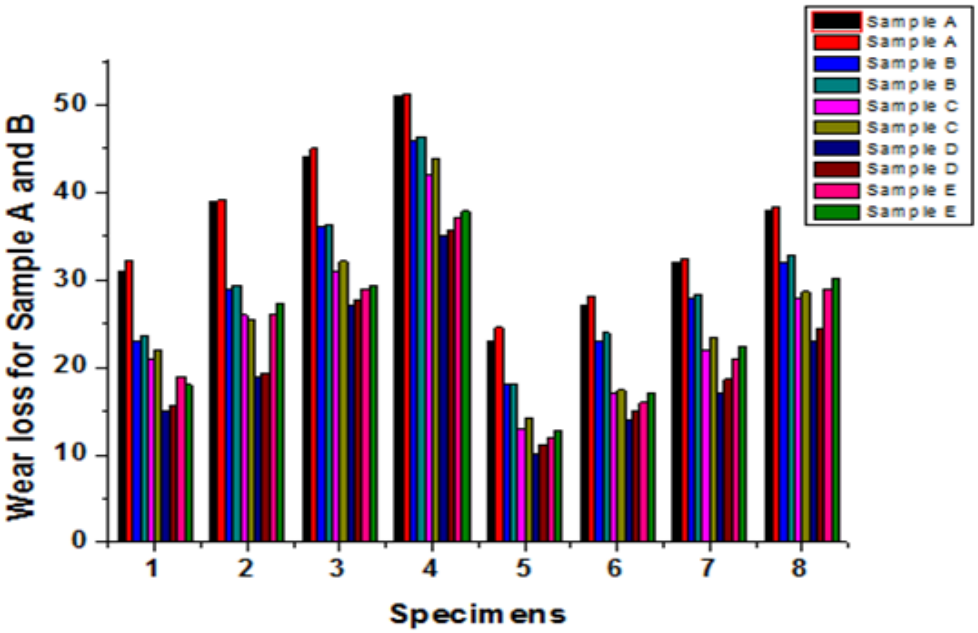


Figure 10. ANN model for wear performances with their processing layers.

trial data and then tested data was utilized to determine the outputs of wear performances which having the wear loss on the casted specimens of aluminium alloy and its reinforcement particles. Normally the ANN has some steps like collection of input data, structure the network arrangements, analysis the input processing parameters, various hidden layers are formed between the parameters, replication of the network and weight bias are measured by the instruction and learning method. The ANN was functioned the current situations of the real issues in the different fields. There are different grouping techniques like classification of outline, forecasting, manipulating the data of input processing parameters, optimization, grouping, and categorization. The feed forward and back propagation algorithm was performed to produce the forecasted outcomes. The ANN structure of the present studies was presented in Figure 10. The predicted values of wear performances with different loading conditions were displayed in Table 5. From the Table 5, the overall outcomes of wear performances were developed by the ANN method. Figure 11 shows the overall outputs of ANN and experimental wear behaviors.

6.0 Conclusion

The AL8011/wt% Si_3N_4 (0, 4, 8, 12 and 16) and AL8011/wt% Si_3N_4 (0, 4, 8, 12 and 16)-T6 composites are fabricated by using stir casting technique. The EDAX test confirms the presents of reinforcements and matrix material in the AL8011/Si_3N_4 composites. The scanning electron microscope confirms the uniform dispersion of silicon nitride in the AL8011 matrix material. The density, micro hardness and wear resistance of AL8011/wt % Si_3N_4 (0, 4, 8, 12 and 16)-T6 composite are higher than the matrix material and its composites. The increasing of wt% of silicon nitride increases the density, microhardness and wear resistance upto 12wt% Si_3N_4 incorporation and falls by 16wt% silicon nitride incorporation. The high accumulation of silicon nitride decreases the density, micro hardness and wears resistance. The constructed ANN model composes the better outcomes by the enhanced predicted wear responses. The future studies of this work is to utilize other machine learning techniques like support vector, random forest method may be utilized to generate the optimal processing parameters.

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