

Characterization and Wear Behaviours of Aluminium Alloy/ Reinforced With Agricultural Wastes Particulates at Different Loads

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Research Article

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Abstract

The research investigates the morphology and wear behaviours of Al-Mg-Si alloy reinforced with palm kernel shell powder (PKSP) for developing composites. PKSP of particle size of 100 μm was prepared for the studies at different weight percentages of 3, 6, 9, 12, and 15 PKSP to developed composites for the investigations. The PKSP was characterized by X-ray fluorescent (XRF). The morphology of the alloy and composites were characterized by scanning electron microscope (SEM) attached with energy dispersive spectroscopy (EDS). The XRF revealed elements such as carbon (C), oxygen (O_2) with other elements as traces. The PKSP as reinforcer had improved the morphology and wear rate behaviours positively. Morphologies revealed that the composites produced showed no voids and discontinuities of PKSP particulates in the composites. The wear resistance of the matrix and composites increase with increase in load and decrease with increase in the weight percentage of PKSP. The minimum wear rate was obtained at the load of 10N while highest at applied load of 30N. The wear rate of the alloy lost under load of 10N was 1.31 times greater than that of alloy reinforced with 15 wt. % PKSP with minimum wear rate. The composites could be used as brake rotors, pistons and connecting rods in the automobile industries.

1. Introduction

The growing demands in the automotive and aerospace industries for reduction in energy consumption and producing more fuel-efficient vehicles continues to be a big challenge. Aluminum matrix composites (AMCs) have unique combination of chemical, mechanical, and physical properties which cannot be attained with the use of monolithic materials [1]. This is why AMCs were regarded as promising materials for automotive and aerospace industries [2]. The automobile parts made from these composites include connecting rods, brake drum, cylinder head and were relatively low in cost of processing when compared to others. However, the problem with unreinforced aluminium alloys is the poor tribological properties which can be resolved by reinforcing the alloys with other materials such as fly ash, Al_2O_3 , SiO_2 , Fe_2O_3 , TiC, B_4C , and SiC. With these reinforcements, their morphologies and tribological properties were greatly improved [3–5].

In an attempt to overcome the high cost of ceramic reinforcements being imported, there is growing interest of researches on the use of agricultural wastes as an alternative reinforcement in composites fabrication as being reported by the previous works [5–12]. It was also reported that reinforcement materials determine significantly the overall desired property of developed composites and led to the decrease in wear rate of the investigated composites [13].

The reinforced Aluminum matrix alloys have made significant strides from laboratory toward commercialization. But the factors understanding that influence the morphology and wear properties of these materials is really a challenge because they are sensitive to the type and nature of reinforcement, the mode of manufacture and the details of fabrication processing of the composite after initial manufacture [13,14]. It is generally agreed that the resistance to wear of AMCs was created by

reinforcement and the higher the volume fraction of particles the better the resistance will be however, there is an optimum value of the reinforcement which gives maximum wear resistance to the material [14].

The various discontinuous dispersed utilizing palm kernel shell powder (PKSP) is one of the solid wastes by product reinforcement available in large quantities in Nigeria. Hence, composites with palm kernel shell powder as reinforcement may likely succeed the cost, time and hazards associated with the imported ceramic materials for better applications.

The PKSP is a great environmental threat causing damage to the land and the surrounding area where these wastes are being dumped. The effective way of utilizing the palm kernel shell powder was to subject to treatment and convert to powder under controlled conditions. Many studies have investigated the use of mussel shell powder as agro-wastes as reinforcement for automobile parts with improvement [14]. The weight fractions of palm kernel shell powder at particle size of $100\mu m$ were varied from 0–15 wt. %. The PKSP was characterized by X-Ray fluorescence to ascertain the compositions and the morphologies of the alloy, composites and the wear mechanisms were investigated by scanning electron microscope (SEM) were studied.

Therefore, this research work is part of effort aimed at considering the potentials wide range of agro-waste powders for the development of low-cost aluminium based composites with the potentials use in wear applications among others.

2. Materials And Methods

2.1 Preparation of Palm Kernel Shell Powder (PKSP)

The palm kernel shell obtained from the palm oil producer in Nsukka, South East of Nigeria was prepared by washing with water and detergent to remove the oil and dirt. It was sun-dried for two weeks and pulverized to form palm kernel powder (PKSP). Palm kernel shell powder (PKSP) prepared was subjected to sieve analysis. The arrangement of the sieves was done using a sieve scale in which the ratio of the aperture widths of adjacent sieves. Sieve sizes from $100\mu m$ to $63\mu m$ were arranged in a stack with the coarsest sieve on the top and the finest at the bottom. The arranged sieves were placed in a sieve shaker which vibrates the materials vertically. A particle size of $100\mu m$ of palm kernel shell powder was utilized for this work. Figure 1 showed the palm kernel shell and powder respectively.

The elemental analysis of the carbonized palm kernel shell powder was analyzed by Energy Dispersive X-ray Spectrometer (Mini pal 4 ED-XRF machine, made by Panalytical of Netherlands was used). The sample was weighed and ground in mortar and pressed in hydraulic press to produce pellet. The pellets were loaded in the sample chamber of the spectrometer and a voltage of 30kv and current of 1 mA was applied to the X-rays to excite the sample for 10mins. The spectrum from the sample was then analyzed to determine the concentration of the elements in the sample. The chemical compositions of the PKSP are being presented in Table 1.

2.1.1 Charge Calculation

The compositions of aluminium alloy were presented in table 2 while table 3 presented the charge calculations for the composites.

2.3 Production of Al-Mg-Si/PKSP Particulate Composites

Based on the charge calculations shown above, the alloy ingots were melted at 750°C in a graphite crucible using an oil-fired graphite furnace [15]. After removing the dross as a result of dirt, oils, impurities, 3 wt. % of the preheated PKSP was introduced into the melt at a constant feed rate. The preheat treatment was conducted at 300°C for about 30 minutes. Mechanical stirrer made up of stainless steel was utilized to ensure thorough mixing simultaneously. The stirring lasted for almost 10 minutes. Afterwards, the mixture was poured into the already prepared sand mould of 25 × 70 mm and allowed to solidify. The same procedures were repeated for 6, 9, 12, and 15 wt. % PKSP reinforcements respectively.

2.4 Wear Test

The wear behaviours of the tested samples (alloy and composites) were determined using the pin-on-disc test under dry conditions as per ASTM G99-95 standards. The wear test specimens were 8 mm in diameter and 30 mm. The counterpart disc materials were made up of En-31 steel heat treated with 8 mm thick and surface roughness of 10 and Ra of 0.1. The initial weight of the specimen was measured using an electronic weighing machine with an accuracy of three digits (0.001g). During the experiment, the Pin (specimen) was pressed against the rotating disc with distance (500 mm). The experiment was conducted at different loads (10, 20, and 30 N) in order to investigate the wear behaviour of the investigated alloy and composites. Mass loss (ΔM), wear loss (W), and coefficient of friction (μ) between the particles were determined by using the pin-on-disc wear test unit. The sliding distance (L) was calculated in order to detect the wear rate as given in Eq. 1 [15,16].

$$L = 2\pi R^2 nt (1)$$

Where R is the radius of counterpart disc (20 mm), n is the number of revolutions (200 rpm),

t is the testing time (20 minutes), and π is a constant ($\frac{22}{7}$).

However, the volume of worn material (ΔV) was obtained from the Eq. 2 [17].

$$\Delta V = \frac{\Delta m}{\rho} (2)$$

Where Δm and ρ were mass loss and density of alloy and composites respectively.

From equations 1 and 2 above, the wear rate (W) of the alloy and composites were calculated in Eq. 3 [18].

$$W = \frac{\Delta V}{(\rho \times L)} \text{ (mm}^3\text{/N-m) (3)}$$

Where Δv , P and L are worn material, applied load and sliding distance

3. Results And Discussion

3.1 XRF Analysis

The chemical compositions of the Palm Kernel shell powder in EDS are being presented in Fig. 1 and table 1 respectively. The analysis showed that C, O, Si and Ca are the major constituents while Fe and Al are the minor elements of the powder. However, the carbon and oxygen played vital roles when used as filler in the aluminium matrix composites for industrial applications. The presence of hard elements like C, Si and Fe suggested that, the Palm kernel shell powder can be use as particulate reinforcement in various metal matrixes according the previous findings [18,19].

3.2 Microstructural Analysis

As established earlier that microstructures of materials played an important role in the overall performance of an engineering materials such as composite [20,21]. The physical properties of the composites however depend on the microstructure, reinforcement particle size, shape and distribution within the matrix. Figures 2–7 presented the morphologies of the matrix, 3–12 wt. % at 3 wt. % interval respectively. It was also found that there was good bonding between matrix and palm kernel shell particulates at different weight percentage. The microstructures of the composites revealed no discontinuities and reasonable uniform distribution of palm kernel shell powder within the matrix. There was good retention and good interfacial bonding of palm kernel shell powder particles in the composites. The results were also in agreement with the previous works [22, 23].

3.3 Wear Analysis

From Figs. 8–9, it is obvious that the wear rate of the Al-Si-Mg/palm kernel shell powder (PKSP) particle composite increases when the load changed from 10 to 30N. Wear resistance also increases with the increase in palm kernel shell powder content. The beneficial effect of the reinforcement on the wear resistance of the composites was observed to be the best at low load [24]. This could be attributed to the fact that palm kernel shell powder particles acted as hard solid particles and improve the wear rate [25]. However, Fig. 8 shows that least wear rate occurred in the composite containing 15 wt. % of PKSP reinforcement and the highest wear rate was observed for the unreinforced Al-1Mg-0.8Si alloy. An applied load increases, the friction at the contact surface of the material and rotating disc obviously increases and increase the wear rate. This is also similar to the results obtained by [26,27]. An increase in palm kernel shell powder in the composite restricts deformation of the matrix material with respect to load, hence the wear rate for the higher content of palm kernel shell powder composites is lower from Figs. 8–9 and similar to work [28]. The composites exhibited higher wear resistance at higher applied loads,

which can be attributed to the presence of PKSP on the counter surface, which act as a transfer layer and effective barriers to prevent large – scale fragmentation of the Al-Mg-Si matrix [29,30].

The worn surface of the alloy in Fig. 9a without applied load showed the material removal line on the specimen only. Figure 9b showed the morphology of the composite at 15 wt. % PKSP particulates at minimum wear rate at applied load of 10 N. It was observed that larger plastic deformation was noticed on the composites under load of 30 and 20 N compared with 10 N. From the result, specimen under load of 30 and 20 N experienced greater weight loss when compared with that composite under 10 N. This is also similar to the findings of previous works [24,25].

4. Conclusion

The use of pal kernel shell powder (PKSP) of particle size $100\mu m$ by dispersing it into AlMgSi via liquid metallurgy was carried out and the following conclusion were drawn from the results:

1. The palm kernel shell powder is a potential reinforcer that that had improved the morphology and wear rate behaviours studied.
2. Microstructures clearly revealed that the composites materials produced by stir casting method showed no voids and discontinuities of PKSP particulates in the matrix which resulted in sound castings.
3. It was noted that the wear rate of the base alloy lost under load of 10 N was 1.31 times greater than that for the alloy reinforced with 15 wt. % of PKSP with better wear resistance. The wear resistance of the composites increases with increase in the applied load and decrease with increase in weight percent of PKSP.
4. The composites could be recommended to be used in tribological areas such as brake rotors, pistons and connecting rods in the automobile industries.

Abbreviations

PKSP palm kernel shell powder
Al Aluminium
Mg Magnesium
Si Silicon
XRF X-ray fluorescent
SEM Scanning Electron Microscopy
EDS Energy Dispersive spectroscopy
Ca calcium
Fe Iron
ASTM American Society for Testing & Materials
CTE coefficient of thermal expansion
wt weight
O₂ Oxygen
Al Aluminium
µm Micrometre
% Percentage
Mn Magnesium

Declarations

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Competing Interests

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Author Contributions

“All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Abdullahi Tank Mohammed], [Ogheneborhie Clifford Ogheneme], [Shaibu Lasisi], [Isah Aliyu], [Abdullahi Guruza], [Suraj Jare Olagunju], [Habeeb Muhammed Sani] and [Idawu Yakubu Suleiman]. The first draft of the manuscript was written by [Abdullahi Tank Mohammed] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.”

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Tables

Table 1. XRF Analysis of Palm Kernel shell powder

Elements	C	O	Si	Al	Fe	Ca
%	61.70	37.40	0.40	0.10	0.20	0.30

Table 2. Composition of Al-1.0Mg-0.8%Si alloy

Elements	Al	Si	Mg	Fe	Mn	Cu	others
wt.%	balance	0.8	1.00	0.03	0.10	0.15	0.10

Table 3. Summary of charge calculations in grams (gm)

PKSP and Elements	0 wt.% PKSP	3 wt.% PKSP	6 wt.% PKSP	9 wt.% PKSP	12 wt.% PKSP	15wt. % PKSP
Mussel Shell powder (MSP)	0	25.45	50.90	76.34	101.79	127.24
Silicon (Si)	5.09	5.09	5.09	5.09	5.09	5.09
Magnesium	8.48	8.48	8.48	8.48	8.48	8.48
Aluminium	834.7	809.2	783.8	758.3	732.8	707.5
Total	848.3	848.3	848.3	848.3	848.3	848.3

Table 4. Wear analyses for matrix and composites at different applied loads (10, 20 and 30N)

Load (N)	Wt. % PKSP reinforcement	Wear Rate = mm ³ /N-m
10	0 wt. % PKSP	2.77E-08
	3 wt. % PKSP	2.22E-08
	6 wt. % PKSP	1.80E-08
	9 wt. % PKSP	1.40E-08
	12 wt. % PKSP	1.01E-08
	15wt. % PKSP	7.01E-09
20	0 wt. % PKSP	2.99E-08
	3 wt. % PKSP	2.54E-08
	6 wt. % PKSP	2.09E-08
	9 wt. % PKSP	1.65E-08
	12 wt. % PKSP	1.27E-08
	15 wt. % PKSP	8.12E-09
30	0 wt. % PKSP	3.23E-08
	3 wt. % PKSP	2.75E-08
	6 wt. % PKSP	2.35E-08
	9 wt. % PKSP	1.98E-08
	12 wt. % PKSP	1.57E-08
	15 wt. % PKSP	9.89E-09

Figures

Figure 1

Palm kernel shell powder at 100 μ m (PKSP)

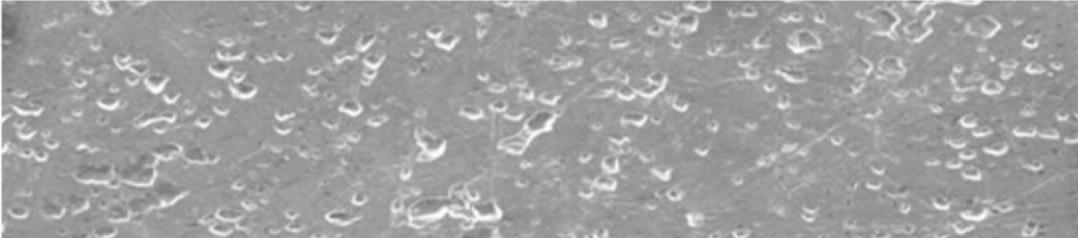


Figure 2

Morphology of Aluminium alloy matrix

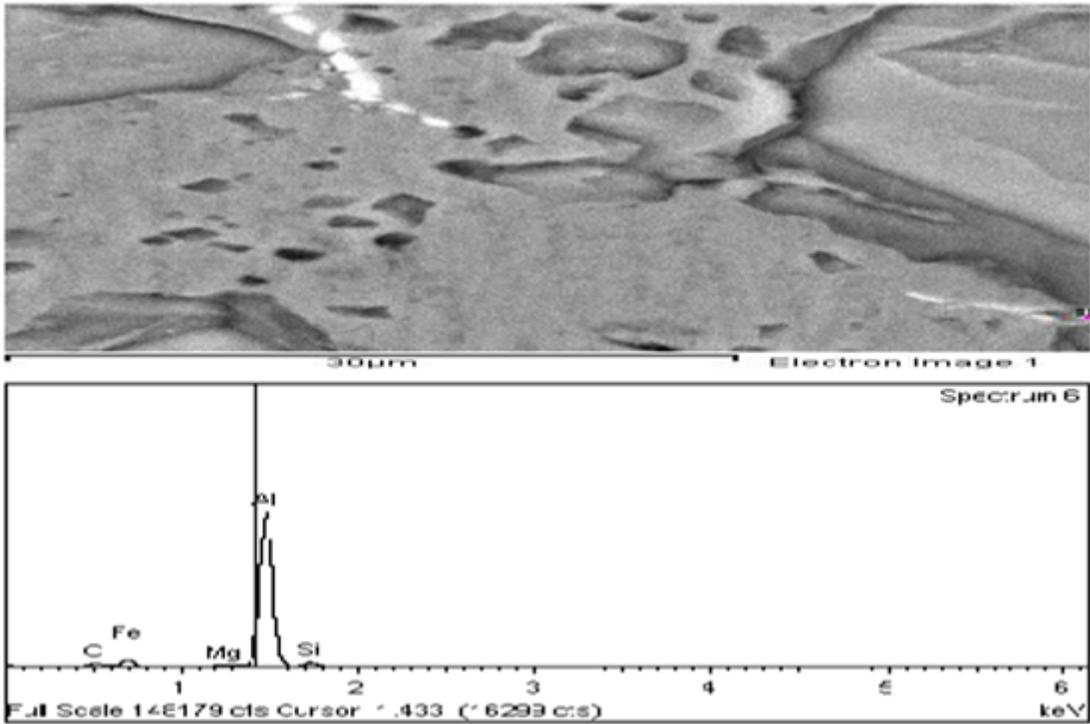


Figure 3

Morphologies of Aluminium alloy/ 3 wt. % PKSP

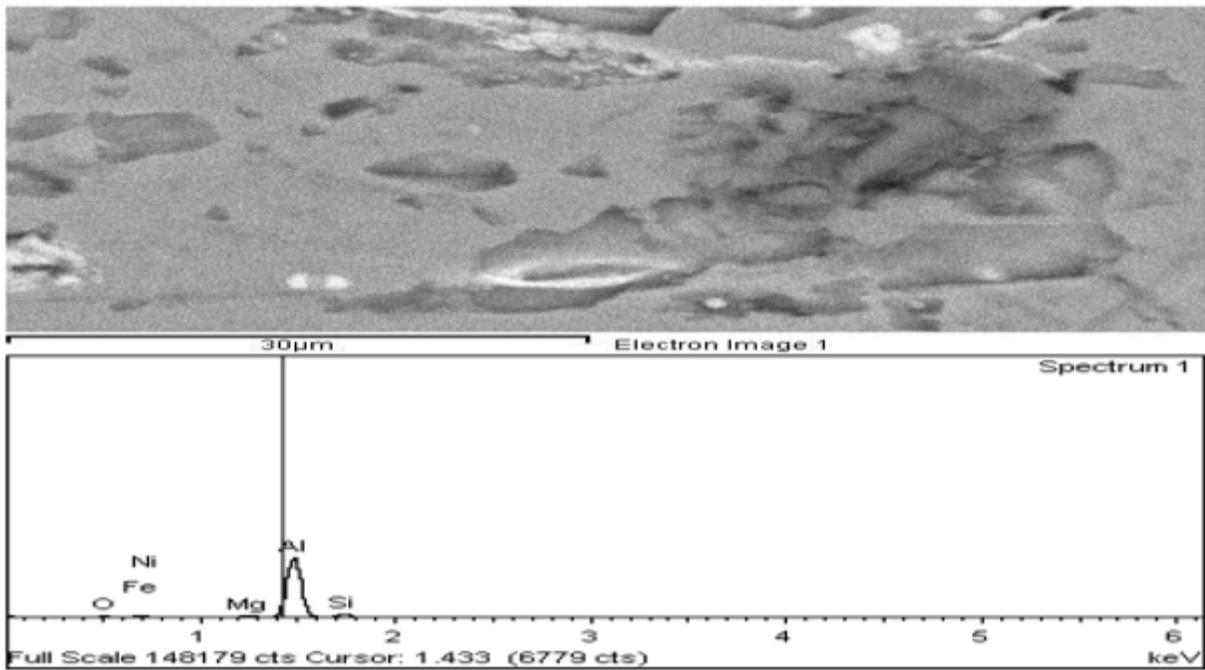


Figure 4

Morphologies of Aluminium alloy/ 6 wt. % PKSP

Figure 5

Morphologies of Aluminium alloy/ 9 wt. % PKSP

Figure 6

Morphologies of Aluminium alloy/ 12 wt. % PKSP

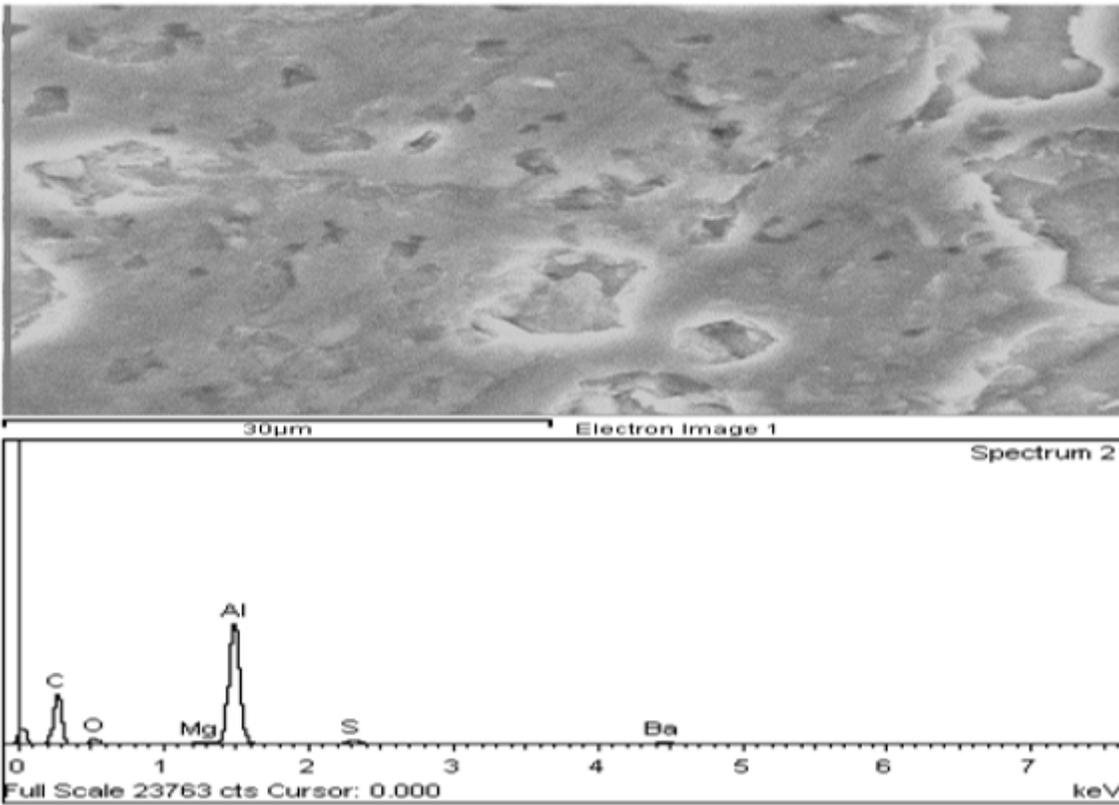


Figure 7

Morphologies of Aluminium Alloy/ 15 Wt. % PKSP

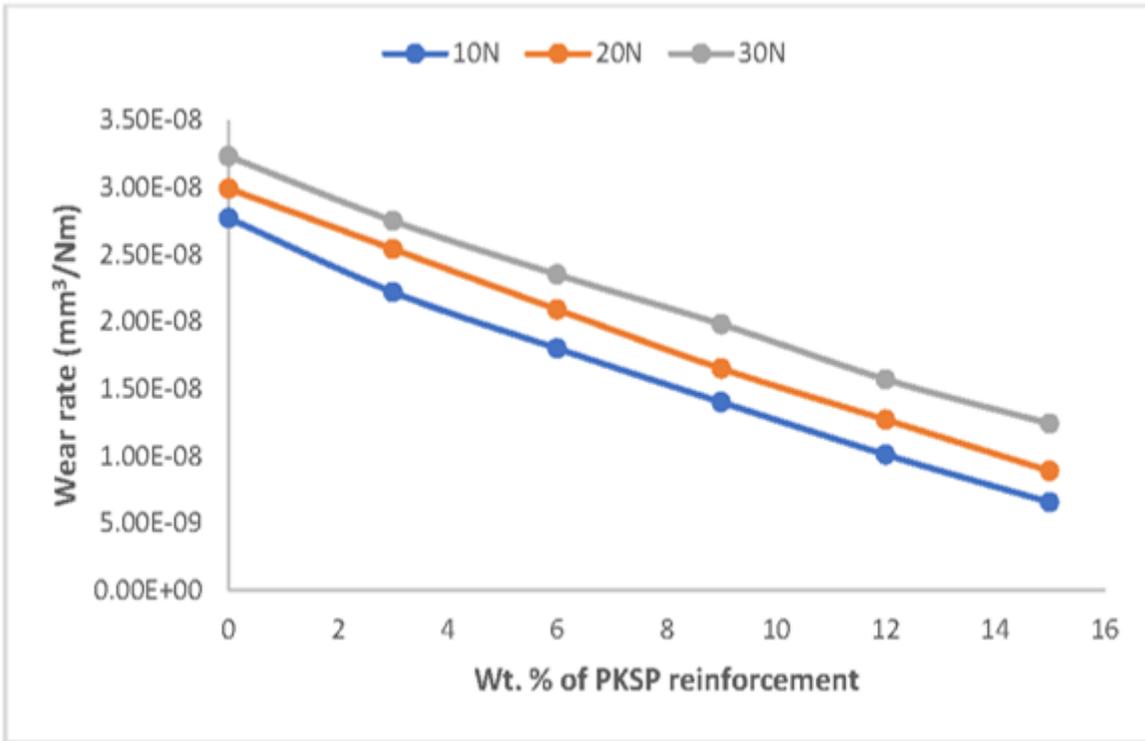


Figure 8

Variation of weight rate with wt. % of PKSP in AlMgSi at 10,20 and 30N

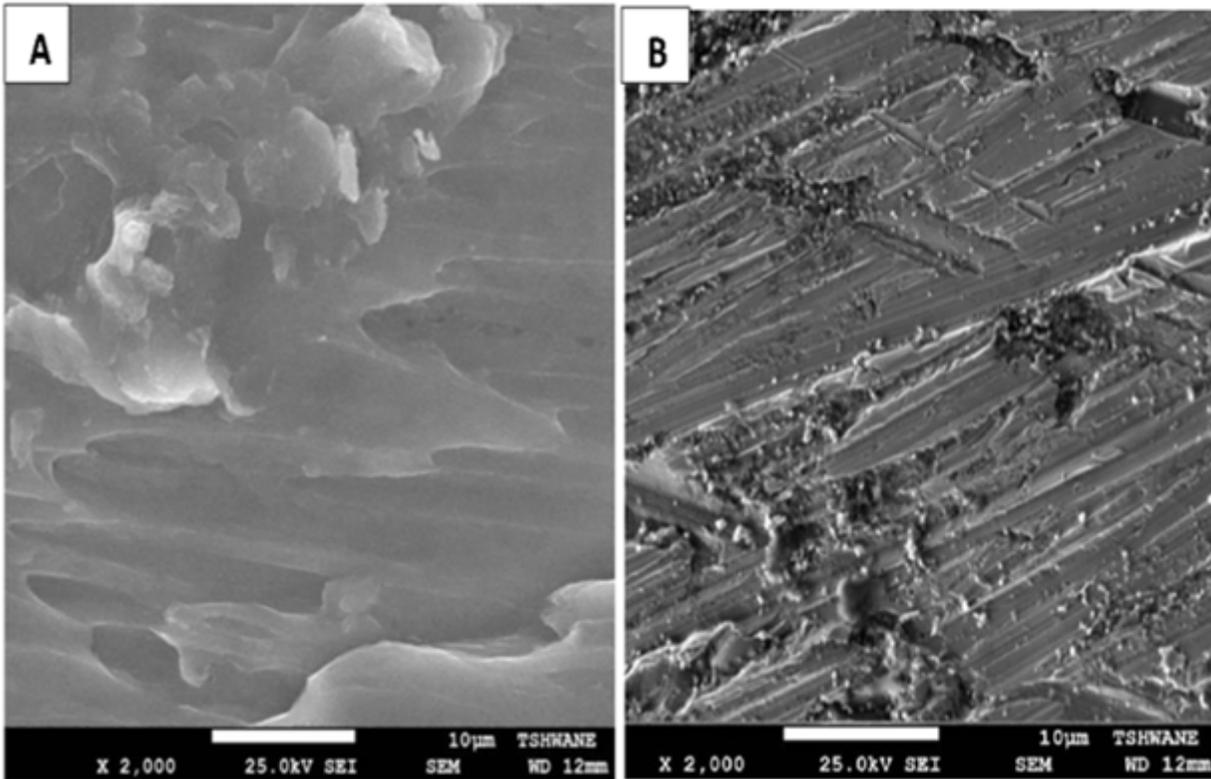


Figure 9

SEM image of AlMgSi alloy (a) at applied load of 10 N (b) reinforced with 15 wt. % PKSP particles with minimum wear rate at applied load of 10N