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Effect of Particulate Reinforcements at Different Loads on Wear Behaviour of Aluminium Alloy Reinforced with Aquaculture Waste

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Abstract

The use of agricultural wastes which is cost-effective and environmental-friendly materials as reinforcers in metal matrix composites is growing fast in various engineering fields. With this, the research investigates the wear and microstructures behaviours of Aluminiun alloy reinforced with mussel shell powder (MSP) for developing a new material. Mussel shell powder (MSP) of particle size of 75micron (μm) was prepared for the studies. Different weight percentages of 3, 6, 9, 12, and 15 MSP were used to develop metal matrix composites for the investigations. The mussel shell powder was characterized by X-Ray Fluorescent (XRF). The morphology of the alloy and composites were studied using scanning electron microscope for the distribution of mussel shell powder (MSP) particles. The XRF showed the compositions of MSP to contain calcium oxide (95.70 %), silica (0.83 %) and others. The wear resistance of the composites increases with increase in the applied load and decreases with increases in the weight percentage of MSP and can be used in the production of brake pads and insulators in the automobile industry. The composite showed lower wear rate of 3.182×10^{-4} mm^3/Nm at 15 wt. % of MSP under load of 7N. The morphologies of the composite revealed that MSP was uniformly distributed within the matrix resulted to improvement in the wear behaviour. The composites can be recommended for the applications of brake pads, pistons, and insulators in any automobile industry

1. Introduction

The growth of world's population and increase of living standard due to technological development have increased the quantity of waste materials generated through industrial, mining and agricultural activities substantially [1]. This speedy advancement in industrial activities, in recent times, has resulted in an increased interest in composites containing low-density and low-cost reinforcements and as an alternative to the imported [2].

Aluminum matrix composites (AMCs) have unique combination of mechanical, physical and chemical properties which are scarcely attainable with the use of monolithic materials [3]. This has made AMCs a strong competitor to steel in terms of versatility for use in a wide range of engineering applications [4]. AMCs are promising materials for automotive, aerospace and mineral processing industries [5]. In automobile, parts made from AMCs include piston, piston rings, connecting rods, brake drum and cylinder head [6]. Other noticeable advantages of AMCs are the relatively low cost of processing [in comparison to other matrices types].

Aluminum matrix composites (AMCs) are presently produced by employing several conventional and patented methods. The properties of AMCs are governed by the processing method. A liquid route, such as casting, is relatively simple and economical, but the limited wettability of reinforcement in molten aluminum limits its usage. The economy, simplicity and ability to produce large and intricate parts are the key parameters that make stir casting the most preferred method for producing AMCs. The limitation of stir casting is the wettability between the molten aluminium matrix and the ceramic particle. AMCs produced through conventional casting offer difficulties in the even mixing of the reinforcement in main matrix [7, 8]. The difference in densities of the base matrix and reinforcement hinder the distribution of reinforcement in the main matrix and promotes the formation of agglomerates or clusters. This can be avoided by employing a stirrer in the molten mixture so that the difference in energies may be checked. The stirring of the molten mixture before pouring into the mould cavity promotes the uniform distribution of reinforcement in the aluminium matrix, induces vortex formation, and the reinforced particles are mixed at the side of the vortex [9].

The reinforced materials with either ashes, fibres or powders had produced materials that are quite friendly with environment and cost-effective [10]. Aluminium-based Metal Matrix Composites (MMCs) have received increasing attention in recent decades as engineering materials, and the introduction of ceramic material into a metal matrix produces a composite material that resulted in an attractive combination of physical, chemical, and mechanical properties that cannot be obtained with the aluminium alloys alone [11].

However, one limitation peculiar to most unreinforced aluminium alloys is poor tribological properties. To address this drawback, these alloys are reinforced with some other materials so that their hardness, young's modulus and abrasion wear resistance are ameliorated [12].

Different reinforcements such as aluminium oxide (Al_2O_3), silicon carbide (SiC), titanium carbide (TiC), tungsten (W), calcium oxide (CaO), silica (SiO_2) etc have been used to enhance aluminium composite properties. Studies had also shown that hardness, toughness, tensile and wear rate behaviours were enhanced [13] These unnatural reinforcers frequently used were difficult to obtain in Nigeria and the importation of such materials are at high cost and time constraint, which had impeded the production of the composites. An alternative to these reinforcements in developing countries like ours is to explore agricultural and aquaculture wastes, either in the form of ashes or powder. The wastes of coconut shell ash, melon shell ash, periwinkle shell powder, and bagasse, rice husk ashes, among others, for the development of AMCs had been investigated [14-17]. The results had also shown that waste ashes and powders generated contain high percentages of refractory materials, such as alumina (Al_2O_3), silica (SiO_2), hematite (Fe_2O_3), carbonate ($CaCO_3$) and calcium (Ca), among others, which can be explored for the production of composites for any applications.

Mussel shell is an aquaculture waste generated across Nigeria and poses a serious threat to both the environment and human lives. In order to relieve this region of this threat, the mussel shells were collected, subjected to treatments, and convert to powder under strict conditions. From the above aforementioned, the present research work investigates the effect of particulate reinforcements at different loads on wear behaviour of aluminium alloy reinforced with aquaculture waste powder via liquid metallurgy to obtain composite. Mussel shell powder (MSP) was varied from 0 wt. % to 18 wt. % at 3 wt. % interval.

2. Experimental Design

2.1. Mussel Shell powder preparation

Mussel shell powder was prepared by cleaning, washing, drying, grinding and sieving it to obtain a uniform size. Sieve of 75 microns were used for this research work. Figures 1 showed the mussel shell powder and collection at size of 75 microns respectively.

Figure 1. Mussel shells and powder (75 µm)

2.2. Equipment

Equipment used in this research are electrical resistance furnace, (scanning electron microscope (SEM), X-ray fluorescent (XRF), Set of sieve machine and Pin on Disc machine.

2.3 Production of Al-Mg-Si/Mussel shell powder particulate composites

The present study utilized aluminium alloy and mussel shell powder with a particle size of 75 µm as base matrix and reinforcement, respectively. The chemical composition of the alloy is being presented in Table 1. The amounts of mussel shell powder (MSP) used as reinforcers were determined using charge calculations presented in Table 2. The aluminium alloy was superheated to 800 °C after being charged into a crucible furnace. The stainless-steel stirrer was used to stir the molten alloy/composites manually. The reinforcement particles, MSP, were preheated to 200 °C for 30 minutes. After preheating, MSP particles were consolidated into the melt to exclude moisture. To reduce the porosity, the addition of the degassing tablet was added after the alloy/composites were completely melted. The wettability was enriched by the composition of magnesium in the melt. This magnesium improves the wettability between the matrix alloy, reinforcement thus, 3 wt. % to 15 wt. % at 3 wt. % interval by equal MSP proportions used. Preheated moulds were set before casting the alloy and the composite of 30 mm in diameter by 100 mm long respectively. Chemical analyses were performed on both the alloy and composites to ascertained the properties. Figure 2 shows the preparation, equipment and cast products (alloy/composite) for this work.

Table 1. Al-Mg-Si alloy analysis

Compositions	Mg	Si	Fe	Mn	Cr	Cu	Al
Weight Percent (wt. %)	1.0	.60	.01	.02	.01	.03	Bal.

Table 2. Summary of charge calculations in weight percent (wt. %)

S/No.	0 wt.% MSP	3 wt.% MSP	6 wt.% MSP	9 wt.% MSP	12 wt.% MSP	15 wt.% MSP
Mussel shell powder (MSP)	0	25.45	50.90	76.34	101.79	127.24
Silicon (Si)	5.090	5.090	5.090	5.090	5.090	5.090
Magnesium	8.48	8.48	8.48	8.48	8.48	8.48
Aluminium	834.68	809.24	783.79	758.34	732.89	707.45
Total	848.30	848.30	848.30	848.30	848.30	848.30

Figure 2. Showing the casting to the finished products

2.4 Wear Test

The wear behaviours of the test samples (alloy and composites) was determined using the pin-on-disc test under dry conditions as stated for wear testing in [18]. It was carried out with the use of a Taber abrasion wear-testing machine. The wear test samples were produced in the form of a disc and machined to specifications (200 mm diameter and 5 mm thickness). 5 N and 7 N loads were used, and the wear loss was evaluated according to [19].

3. Results and discussion

3.1. XRF Analysis of Mussel shell powder

The chemical compositions of the mussel shell powder (MSP) are being presented in table 3. It could be observed from the table, that carbon (CaO) has the highest percentage composition of 95.70 wt.% followed by SiO_2 (0.83 wt.%), Fe_2O_3Ca (0.67 wt. %), MgO (0.48 wt.%), Al_2O_3 (0.46 wt. %) and the remaining balance was lost on ignition (LOI) respectively. However, the calcium oxide and Silicon oxide played vital roles when used as filler in the aluminum matrix composites for industrial applications. The presence of hard elements like CaO and SiO_2, Al_2O_3, Fe_2O_3 suggested that, the mussel shell powder can be used as particulate reinforcement in various aluminum metal matrixes according the previous findings [18, 19].

Table 3. The mussel powder analysis

Compounds	Mussel shell powder (%)
CaO	95.70
K_2O	0.35
SiO_2	0.83
SrO	0.26
Fe_2O_3	0.67
SO_3	0.46
MgO	0.48
Al_2O_3	0.46

3.2 The morphologies of the alloy/composites

Microstructure plays an important role in the overall performance of a composite. The physical properties of the composites however depend on the microstructure, reinforcement particle size, shape and distribution in the alloy [20, 21]. The micrograph shown in Figure 3 depicts the microstructure of as-cast Al-Mg-Si alloy. From the figure, the structure was completely uniform with the solubility of silicon in the Al matrix completely.

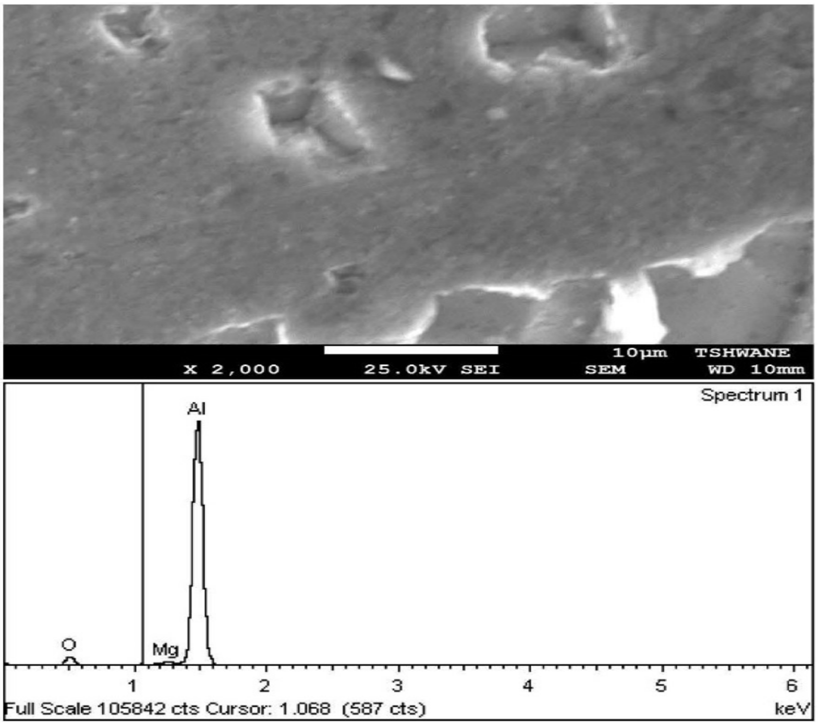

Figure 3. SEM/EDS of aluminum alloy of Al-Mg-Si

Figure 4 revealed the volume of the reinforcer of 15 wt. % of MSP. The microstructures of the composites revealed small discontinuities and reasonably uniform distribution of mussel shell powder particles in the aluminum alloy matrix. It was also found that there was good bonding between Al matrix and the filler (MSP) particles and no gap was observed between the particle and matrix [22, 23]. There was also good retention and good interfacial bonding of mussel shell powder particles in the composites with different weight percentage of reinforcers. Addition of small quantities of magnesium during stirring also improved the wettability of mussel shell powder particles. There was an increase in the particulates dispersed for the composites containing 15 wt. % of the MSP. The results were also in agreement with the previous works of [24].

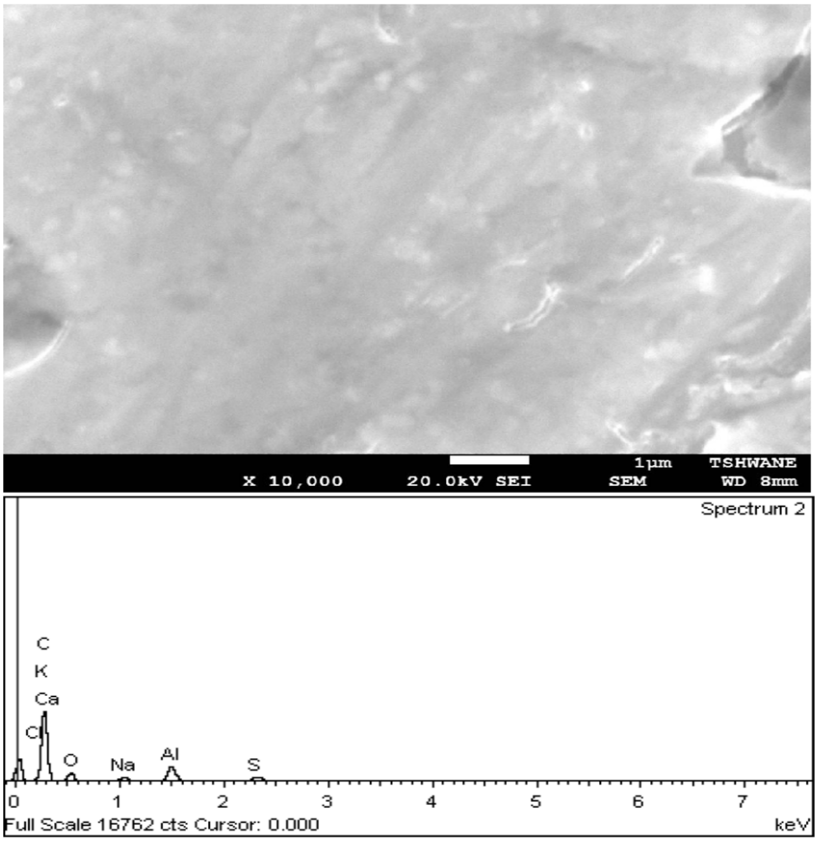

Figure 4. SEM/EDS of aluminum alloy /15 wt. % MSP of 75 µm

3.3 Wear analysis

Figure 5 presented the composite subjected to various loads at different reinforcements. It indicates that the wear rate of the Al-Si-Mg/mussel shell powder (MSP) particle composite increases when the load changed from 5 to 9 N. Wear resistance also increases with the increase in mussel 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 and also agree to the findings of [24, 25]. This could be attributed to the fact that mussel shell powder particles acted as hard solid particles and improve the wear rate. However, figure 5 indicates that the least wear rate occurred in the composite containing 15 wt.% of MSP reinforcement. As applied load increases, the friction at the contact surface of the material and rotating disc obviously increases and increases the wear rate. This is also similar to the previous work by [18, 20]. An increase in mussel shell powder in the composite restricts deformation of the matrix material with respect to load; hence, the wear rate for the higher content of mussel shell powder composites is lower and similar to the work of [9, 12]. The composites exhibited higher wear resistance at higher applied loads, which can be attributed to the presence of MSP on the counter surface, which act as a transfer layer and effective barriers to prevent large-scale fragmentation of the Al-Mg-Si matrix [16, 18]. Figure 6 presented the morphologies of Al-Mg-Si and the composite at 15 wt.% MSP particulates at minimum wear rate at applied load of 5 N. It was observed that larger plastic deformation was noticed on the composites under load of 9 and 7 N compared with 5 N. From the results, specimen under load of 7 and 9 N experienced greater weight loss when compared with that of composite under 5 N. This is also similar to the findings of previous works [24, 25].

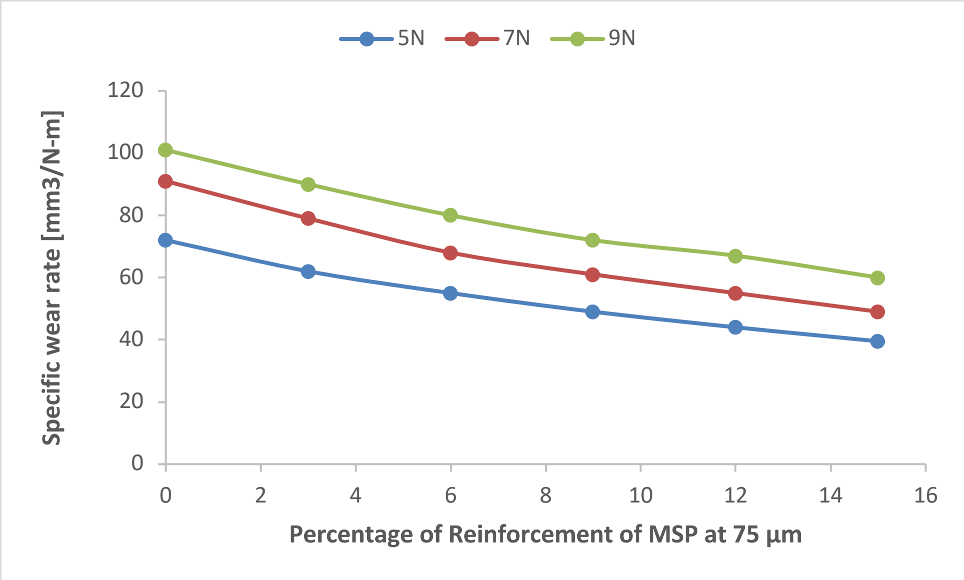

Figure 5. Effect of reinforcement on specific wear rate

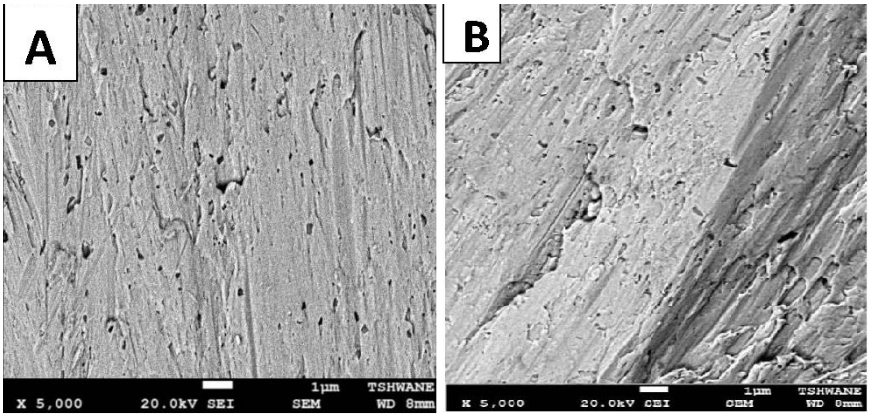

Figure 6. SEM morphology of Al-Mg-Si alloy (a) without load (b) reinforced with 15 wt.% MSP particles at minimum applied load

Conclusions

The purpose of this work was to investigates the use of aquaculture MSP of particle size 75 µm by dispersing it into aluminium metal composites via liquid metallurgy to obtain composites for wear properties analysis at different loads. Therefore, the following conclusion have been drawn from the results:

1. The mussel shell powder is a potential reinforcer that had improved the wear rate behaviours greatly.
2. Thus, composite with 15 wt. % reinforcement of MSP showed better wear resistance compared with other composites.
3. The wear resistance of the composites increases with increase in the applied load and decrease with increase in the weight percentage of MSP.
4. The morphologies of the wear rate of the composite revealed that the material removal was mainly due to micro-cutting and as such, MSP was a good substitute for the imported material.
5. This could be recommended to be used in tribological areas of application. Thus, the composite can be exploited as a material for brake, rotors, pistons and connecting rods in the automobile applications.

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