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Research Article

Influence of thermal ageing on the microstructural and mechanical characteristics of banana stem particles reinforced aluminium-alloy matrix composites

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Abstract: The influence of thermal ageing on the microstructural and mechanical characteristics of banana stem particles (BSp) reinforced aluminium-alloy matrix composites was investigated. Sand casting was used to produce the composites, comprising aluminium alloy matrix reinforced with BSp of varying weight ratio of 0 wt. %, 1 wt. %, 3 wt. %, 4 wt. %, 5 wt. % and 6 wt. % were thoroughly mixed. Test samples for mechanical characterisation were prepared from the sand cast (6 mm diameter by 125 mm rods for tensile test). Thermal ageing was done for 2 hours (hrs) at 350 ^{o}C. The composites were evaluated for tensile, modulus of elasticity, hardness, and microstructural characteristics. The thermally aged samples demonstrated greater tensile strength and toughness as the concentration of BSp increased up to 5 wt. % in the composite in comparison with the as-cast samples. The greatest characteristics were demonstrated at 5 wt. % BSp concentration. Lower hardness was demonstrated by the as-cast samples in comparison with the aged-hardened samples. There was 5 wt. % BSp concentration in the alloy enhanced thermal ageing. These indicate that greater mechanical characteristics of the composites can be obtained by thermal ageing.

Keyword: Thermal Ageing, Aluminium Alloy, Banana Stem Particles, Composites, Microstructure, Mechanical Characteristics.

1. INTRODUCTION

Innovation via technology, proper energy planning, enhanced characteristics requirement and escalating costs have necessitated the development of newer materials. The aerospace industry and other industrial sectors are under constant pressure for improved materials development to achieve optimum performance. Because of this, efforts have been intensified via series of studies to enhance the characteristics of materials by suitable alloying and microstructural modification. Hence, composite materials have been developed and are used in several sectors of industry (Seshan *et al*., 1996).

Hassan *et al* (2009) studied the effect of thermal ageing on the microstructure and mechanical properties of Al–Si–Fe/Mg alloys. They reported that the alloy rose solidly during ageing with consistent and steady precipitation in the metal lattice. Age-hardened sample demonstrated accelerated ageing in contrast to the as-cast alloy. Although, the 5 wt. % Mg addition to the alloy promoted ageing, the result of the research showed that greater mechanical characteristics can be obtained by subjecting the as-cast Al–Si–Fe/Mg alloys to thermal ageing treatment.

Alaneme *et al.* (2015) studied the microstructural, mechanical and wear characteristics of aluminium matrix composites. The Al-Mg-Si alloy was reinforced with alumina, rice husk ash (RHA) and graphite. The results indicated that hardness decreased with increase in the concentration of RHA and graphite in the composites. With concentration of RHA higher than 50 %, graphite had little effect on the hardness of the composite. The tensile strength of the composites having 0.5 wt. % graphite and up to 50 % RHA was greater than that of the composites without graphite. The toughness of the composites containing 0.5 wt. % graphite was greater than that of the composites without graphite. The composites without graphite exhibited lower wear resistance

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compared to the composites containing graphite. However, the wear resistance reduced as the concentration of graphite increased from 0.5 to 1.5 wt. %. Bello *et al.* (2017) studied the tensile characteristics, fractography and morphology of aluminium (1xxx)/coconut shell micro particle composites. The samples were produced by compo casting method with filler (coconut shell particles) addition from 2 to 10 wt. %. The results indicated that addition of coconut shell particles to the aluminium matrix caused a grain refinement in the microstructure of the composites. The tensile strength of the composites increased with increasing concentration of filler. The least tensile strain was exhibited at 4 wt. % filler additions, indicating a critical reinforcement level characterised by much rigidity. Agunsoye *et al* (2015) studied recycled aluminium cans/eggshell composites. Their mechanical and wear characteristics were investigated. The aluminium based metal matrix composites were produced from recycled aluminium cans and 150 µm sized eggshell particles using the stir casting method. The results indicated a uniform dispersion of the filler (eggshell particles) in the aluminium can matrix. Addition of the filler to the aluminium matrix enhanced the modulus of elasticity of the composites, which in turn increased the rigidity, yield stress and tensile strength of the composites. The low tensile strengths that were demonstrated by the control (unreinforced) and lowly reinforced (2 wt. %) samples indicated a very high level of rigidity. This is because of their prolonged elongation before fracture. The wear rate increased with increasing applied load. However, there was no significant increase in the wear rate as the load increased from 6 to 8 N. Merlini *et al*. (2011) studied the effect of surface treatment on the chemical properties of banana fibre and reported that treated banana fibre gives higher shear interfacial stress and tensile strength when compared with the untreated fibre. Dhieb *et al*. (2013) investigated the surface and sub-surface degradation of unidirectional carbon fibre. It was reported that there was under sliding in demineralized water and the simplest degradation was detected on sliding in anti-parallel direction.

There are many reports available on the mechanical and physical properties of natural fibre particle reinforced metal matrix composites, but the effect of particle size on mechanical behaviour of banana stem particle reinforced metal composites has scarcely been studied. Thus, this study was undertaken with the objective of investigating the influence ageing treatment on mechanical and microstructural characteristics of banana stem particle based aluminium alloy composites.

2. MATERIALS AND METHODS

The following materials were used in this study include Banana Stem particles, Discarded piston (aluminium silicon alloy scrap). The chemical composition of the aluminium alloy matrix and Banana Stem used are shown on the table below (table 1 and table 2 respectively)

Table 1: The percentage composition of the Al-alloy piston scrap (Bala *et al.* 2015)

El.	Al	Si	Fe	Ni	Cu	Mn	Mg
Wt (%)	79.1	16.6	0.7	1.08	1.4	0.08	0.11

El = Element

Table 2: Chemical composition of banana (Anhwange *et al.* 2009)

Element	**Weight (%)**
Potassium	78.10
Calcium	10.47
Sodium	4.30
Iron	0.61
Manganese	6.20
Bromine	0.04
Rubidium	0.21
Strontium	0.03
Zirconium	0.02
Niobium	0.02

2.1 Sample Preparation Method

The banana stems in Figure 1 were obtained from Sawmill banana plantation in Ilorin, Kwara State. The banana stem flakes were boiled at 100 ^{0}C in water containing neem leaves (Mohini *et al.* 2003), in order to prevent subsequent bacteria activities on the stem. The treated stem flakes were dried in UNISCOPE oven at 60 ^{0}C for 48 hours (Benjamin *et al.* 2009). After oven drying, the flakes were pulverised using an electric disc grinder and classified with the aid of sieves of mesh size. The banana stem particles collected in the pan is presented in Figure 2.

Figure 1. (a) Banana stem (b) Banana flakes

Figure 2. (a) Dried banana stem flakes (b) particles obtained from flakes after grinding

Scraps of aluminium pistons obtained from a mechanic workshop in Ilorin were used as the alloy. The melting of aluminum scrap was carried out in a steel crucible in a pit furnace fired with charcoal (solid fuel). The furnace contains an opening by which air was supplied to it with a blower. The aluminium scraps were made to melt by heating to 630 ^{0}C and superheated to 680 ^{0}C for fluidity of the melt. The dross was scooped out of the melt using a foundry spoon. Thereafter, at 680 ^{0}C, the banana stem particles were added to the melt using a cup and stirred manually to ensure homogeneity. The mixture was poured into a sand mould of the required dimension for the various tests to be carried out. This process was repeated with an increase in weight percent of the banana stem particles using the same amount of aluminum alloy melt. Weight percent of banana stem particles was increased from 1 to 6 %. Some aluminium alloy samples having no banana stem particles content were produced and were taken as control samples (A1). The materials formulation and composites produced are presented in Table 3.

Table 3: Materials formulation for composites production

Sample	Composition
A1	BSp (0 wt. %) + Aluminium alloy (100 wt. %)
A2	BSp (1 wt. %) + Aluminium alloy (99 wt. %)
A3	BSp (3 wt. %) + Aluminium alloy (97 wt. %)
A4	BSp (4 wt. %) + Aluminium alloy (96 wt. %)
A5	BSp (5 wt. %) + Aluminium alloy (95 wt. %)
A6	BSp (6 wt. %) + Aluminium alloy (94 wt. %)
BSp = Banana stem/stalk particles	

2.2 Ageing Treatment of the Samples

The test samples were heat-treated at temperature of 450 ^{0}C in a muffle furnace. They were soaked for 2 hours at this temperature and quickly quenched in water at room temperature. Ageing of the test samples was done at 350 ^{0}C for 2 hours after which they were cooled in the furnace. The ageing characteristics of these categories of alloy was assessed using hardness and tensile tests.

2.3 Metallographic Examination

Metallographic equipment and apparatus used include polishing machine, grinding machine, scanning electron microscope (SEM), hacksaw, conical flask, and beaker. Samples for metallographic test were cut from the samples produced. Their surfaces were smoothened using a file, ground, thoroughly polished and etched. Thereafter, microstructural examination was performed using a scanning electron microscope ASPEX 3020.

2.4 Hardness Test

The hardness of the samples was determined using a Rockwell hardness-testing machine on "B" scale (HR – 150A serial number 15729) with 1.56 mm steel ball indenter, minor load of 10 kg, and major load of 100 kg. The plunger rod and test samples were cleaned, and the samples were placed on the anvil. A load of 10 kg was applied without inducing impact or vibration with a zero-datum position. Thereafter, a major load of 100 kg was applied, and the reading was recorded when the large pointer came to a rest position.

2.5 Tensile Test

The tensile test was done using an Instron universal testing machine. Samples for the test were machined from the as-cast and the age hardened composite cylindrical rods of length 13 cm, diameter 6 mm and gauge length 80 mm. The samples were placed on the testing platform after which load was applied at a strain rate of 1 N/min until failure occurred. The tests were done at room temperature in accordance with ASTM E8M (2021) standard. Three repeated tests were done on each of the sample's formulation (Table 3) to ensure that the results are reliable.

3. RESULTS AND DISCUSSION

3.1 Microstructure of the Samples

Microstructures in Figures 3a, b, e and f contain mainly α Al, silicon eutectic and banana stem particles. Unaged hardened aluminium alloy has coarser grains compared to the age-hardened ones implying that age hardening treatment triggers refinement of the grains. Moreover, structures observed in Figure 3a-b are typical structures of high integrity as all grains are continuous without presence of any flaw that can cause high stress raisers when the alloys are subjected to loads during mechanical investigation. Similar grain refinement due to age hardening is observed when structures in Figure 3e-f of aluminium alloy containing 3 wt. % banana stem particles are compared. In addition, finer structures observed in Figure 3e-f of both unaged and age hardened composites are attributed to banana stem particle additions. Moreover, elemental composition of the control of the Al alloy without addition of banana stem fibres nor heat treatment obtained from energy dispersive X-ray spectroscopy is presented in Figure 3c. According to Figure 3c, the control Al alloy has aluminium as its matrix/host while Ti, Mg, C, Ca, Cu, Fe and Si are solutes or foreign elements. Presence of C in the control Al alloy could be linked with Fe because of its affinity for Fe. That is Fe always exists with C. According to Figure 3d, the same elements as those in the control Al alloy are found in the banana stem reinforced Al alloy composites. However, proportion each of similar elements vary. Much greater difference between C proportions of both the alloy and the composite could be linked to the fibres additions, implying that the carbonaceous material in the banana stem soot up the C contents of the composite with a decrease in the proportion of Al.

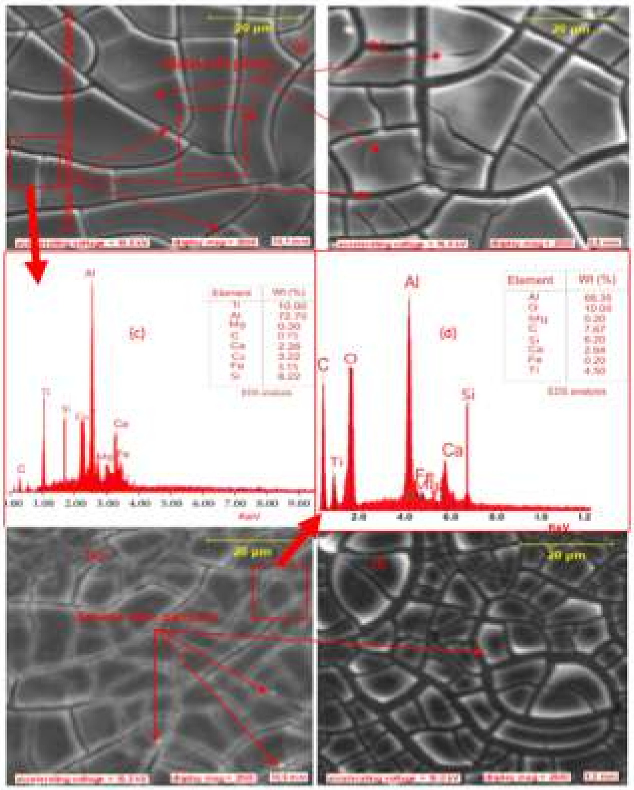

Figure 3. SEM micrographs of (a) unaged hardened aluminium alloy (b) age hardened aluminium alloy revealing island Al phases separated by grain boundary/eutectic phases with evidence of grain refinement due to age hardened treatment (c) elemental composition of unaged hardened aluminium alloy (d) elemental composition of unaged hardened banana stem particle reinforced aluminium alloy (e) unaged hardened banana stem particle reinforced aluminium alloy (f) aged hardened banana stem particle reinforced aluminium alloy composites.

3.2 Hardness of the Samples

The hardness of the composites reduced with increasing concentration of banana stalk particles in the composites as presented in Figure 4. The reduction in hardness could be due to clustering/agglomeration of the BSp in the molten aluminium matrix. This might have occurred during casting which could bring about pores in the samples. However, the age-hardened composite demonstrated higher hardness than the as cast sample indicating the positive effect of thermal aging in enhancing the hardness of the composite.

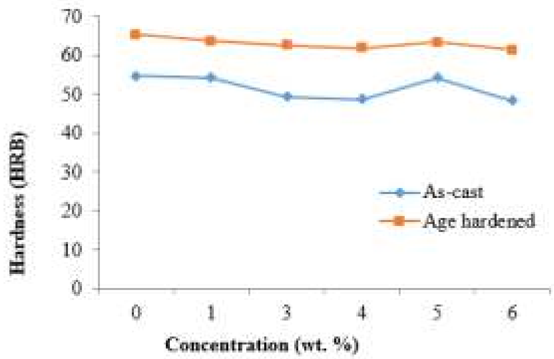

Figure 4. Plot of hardness against concentration of banana stem particles

3.3 Tensile Strength, Elongation and Modulus of Elasticity of the Samples

The tensile strength of the samples decreased as the concentration of the banana stem particles increased from 0 to 4 wt. % as shown in Figure 5. This could be attributed to morphological features of agglomeration of BSp in the matrix. However, beyond 4 wt. % of BSp concentration to 5 wt. %, there is an increase in tensile strength of the composites. The increase in tensile strength is due to increased movement of dislocation, which agrees with the report by Oyekeye *et al*., (2019) and Reza *et al*., (2009). The age hardened and as-cast composites demonstrated highest tensile strength of 194.4 MPa and 158.1 MPa respectively at 5 wt. % BSp addition.

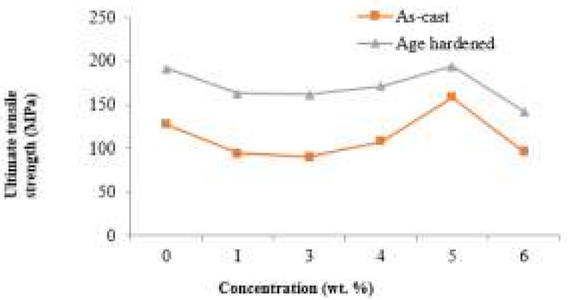

Figure 5. Plot of ultimate tensile strength against concentration of banana stem particles

All the composites demonstrated elongation within the range of 0 to 6 %. As regards increase in the content of BSp in the composites, the composites demonstrated undulating pattern of percentage elongation as presented in Figure 6. The elongation of the composites decreased with increase in BSp addition. However, the elongation increased at 5 wt. % of BSp addition but decreased when BSp addition was beyond 5 wt. %. Increase in the movement of dislocation after deformation (Kralia *et al*., 2012) could be responsible for the increased elongation. The decrease in elongation was due to restriction in the movement of dislocations thereby making dislocations not to move across the grain boundaries, which agrees with the report by Oyekeye *et al*., (2019). The modulus of elasticity of the composites initially decreased but increased as the content of BSp increased as presented in Figure 7. This is due to the increase in the movement of dislocations. The age-hardened composite demonstrated highest modulus of elasticity of 65.7 MPa at 6 wt. % BSp addition. However, the as-cast composite demonstrated highest modulus of elasticity of 127.1 MPa at 3 wt. % BSp addition.

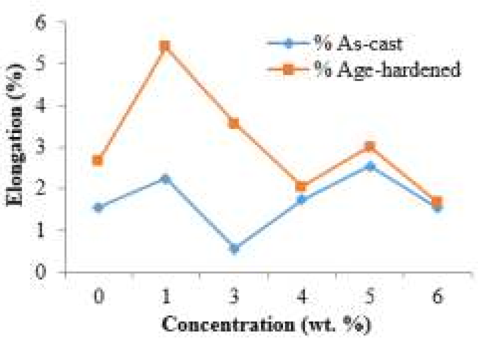

Figure 6. Plot of elongation against concentration of banana stem particles

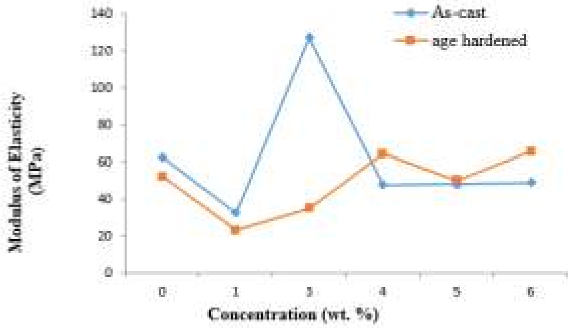

Figure 7. Plot of modulus of elasticity against concentration of banana stem particles

4. CONCLUSIONS

- In the micrographs, it was observed that the microstructure contains mainly α Al, silicon eutectic and some banana stem particles.
- Increased addition of banana stem particles to the aluminum alloy reduced the hardness. However, the age hardened composite showed acceleration in ageing compared to the as-cast composite.
- The age-hardened composite improved in toughness but the hardness decreased as the banana stem particles content increased.
- The composites demonstrated percentage elongation within the range of 0 to 6 %.
- The composites containing 1 wt. %, 4 wt. % and 5 wt. % of BSp exhibited higher percentage elongation than others. The % elongation improved through age-hardening. This research, therefore, has established that the composites responded to precipitation hardening heat treatment.

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