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INVESTIGATION OF THE WEAR CHARACTERISTICS OF Al-Si-Mg ALLOY UNDER CONDITIONED THERMAL TREATMENT

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ABSTRACT

The study is aimed at investigating the wear characteristics of Aluminium-Silicon-Magnesium (Al-Si-Mg) alloy under conditioned thermal treatment in the presence of carbonized melon ash. The alloy was cast, machined and charged in a steel packing box containing the carbonized melon shell for heat treatment. The heat treatment comprised of solution heat treatment at 540 ^oC for 1 hour followed by ageing. The control samples were aged at 120 ^oC for 2 hours and cooled in the open air while the second aging operation was carried out at a temperature of 180 ^oC for varying times of 1, 2, 3, 4, and 5 hours respectively and cooled in air. Wear test was conducted on each sample with a constant load of 5N, speed of 250 rpm and a dwelling time of 1 minute. The result showed that increase in aging temperature and time decreases the wear rate of the alloy but at some soaking time the wear rate increases due to over aging of the alloy. The minimum wear rate, 0.1148 $mm/N/m^3$ occurred at 2 hours aging time, indicating a wear resistance of 60.67%.

1. INTRODUCTION

Wear is a persistent service condition in many engineering applications with important economic and technical consequences. In terms of economics, the cost of abrasion wear has been estimated as ranging from 1 to 4% of the gross national product of an industrialized nation (Zmitrowicz, 2006). The effect of abrasion is particularly evident in the industrial areas of agriculture, mining, mineral processing, and earth moving. Likewise, wear is a critical concern in many types of machine components; in fact, it is often a major factor in defining or limiting the suitable lifetime of a component. An important example is the wear of dies and molds. Wear generally is manifested by a change in appearance and profile of a surface. Wear is progressive in that it increases with usage or increasing amounts of motion, and it ultimately results in the loss of material from a surface or the transfer of material between surfaces. Wear failures occur because of the sensitivity of a material or system to the surface changes caused by wear. Wear results from contact between a surface and a body or substance that is moving relative to it (Bayer, 1994).

Wear occurs in different parts of materials in contact during service ranging from individual components (e.g. bearing, gears brake and clutch pads), assemblies or products (e.g. rock climbing shoes, pocket watch, engines, curling stones etc.), manufacturing process (e.g. rolling, turning, stamping, grinding etc.), construction/exploration (e.g. excavator, mine slurry pumps, oil drilling rig etc.), natural phenomena (water erosion, wind erosion etc.) Everything that man makes wears out and this wear of materials is an every-day experience and has been observed and studied for a very long time. It is difficult to predict and to control wear of rubbing elements because wear cannot be eliminated completely, but it can be reduced (Zmitrowicz, 2006).

Aluminum metal is found in the most abundant quantity in earth's crust (about 8% by weight) of the earth’s solid surface (Zadeh, 1965). Aluminum has properties like durability, light weight, extrusion ability and surface finish, which makes aluminum and its alloys to be used as an alternative for other metals (ferrous and non-ferrous), ceramics and wood. Al-Si-Mg alloy shows beneficial change in mechanical properties like hardness, yield strength and elongation after heat treatment. Silicon imparts to Al-Si-Mg alloy good fluidity, resistance to hot cracking and thermal expansion, while magnesium improves its strength-to-weight ratio and yield stress by combining with silicon to form the age-hardening phase (Mg_2Si) which precipitates from a supersaturated solid solution during heat treatment (Birol, 2009; Umaru, 2013).

In the application of Al-Si-Mg alloy for example as brake callipers, the material sometimes fails catastrophically and without any warning due to sliding wear. Thus, after a certain time, replacement of those components is required and this results in wastage of time, material and money. In recent times, several research efforts which include the use of composites and heat treatment have been done to improve on the wear performance of this alloy. But little have been done into the possibilities of conditioning the heat treatment of this alloy by burying the alloys in carbonized melon ash in the heat treatment process. Therefore, this study is aimed at investigating the wear characteristics of the alloy by conditioning the heat treatment in the presence of carbonized melon ash.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

Materials used in this research include high purity aluminum wire obtained from Northern Cable Company (NOCACO) Kaduna. High purity Silicon powder and Magnesium were obtained from Steve Moore chemical shop in Zaria. Melon shell was obtained from Samaru market in Zaria, Kaduna State, Nigeria. Some of the equipment used for this research include the charcoal furnace, muffle electrical furnace (SX-5-12), graphite crucible, machine stirrer, pyrometer, big and small tong, packing box, lathe machine (Colchester/triumph 2000), hack saw, wear test machine (tribometer), closed steel cylinder.

2.2. Methods

2.2.1. Preparation of mold

Silica sand, bentonite and water was poured in the mixing machine until it became green sand and was ready for molding, the split pattern was used for the casting. The pattern used was a long cylindrical pipe of length 200 mm by 32 mm diameter.

2.2.2. Melting, casting and machining of the produced alloy

The high purity aluminium wire was melted in a muffle resistance furnace that was allowed to heat to 750 ^oC. The crucible was then removed from the furnace, and the alloying elements in powdered form added before returning to the furnace for further 30 minutes, during which the furnace temperature was raised to 800 ^oC for superheating to occur. Elemental sodium (0.01% Na) was then added and the mixture stirred thoroughly before pouring into the mould. The cast was then machined to a diameter of 30 mm and length of 5 mm in order to fit the standard size of the tribology wear test machine.

2.2.3. Carbonization of melon shell

The furnace temperature was raised to about 900 ^oC, melon shell was poured in a cylinder and was made air tight, then put in the furnace for about 45 minutes and then the furnace was turned off to allow the carbonized shell to cool. The carbonized shell was then ball milled into powdery form. Min pal compact energy dispersive X-ray spectrometer was used for elemental analysis of the melon shell ash.

2.2.4. Heat treatment of the aluminum alloy

The samples were charged in a steel packing box containing the carbonized melon shell. The steel box was tightly sealed with clay cover to prevent the escape of carbon and unwanted furnace gas from entering the steel pot during heating. It was then charged into the furnace for heat treatment (solution heat treatment, SHT) at 540 ^oC for 1 hour. Quenching in warm water (65 ^oC) was followed by double thermal aging treatment. The first aging operation was carried out for the samples at a temperature of 120 ^oC for 2 hours after which the control sample was removed and was cooled in the open air. The second aging operation was carried out at a temperature of 180 ^oC for varying times of 1, 2, 3, 4, and 5 hours respectively. The alloy was then allowed to cool in the air.

2.2.5. Wear rate analysis

Wear analysis was carried out on the surface of the heat treated samples using a pin-on-disc tribometer wear test machine at room temperature. Applied load of 5N at 250 rev/min wheel speed and a dwell time of 1minute at 252 laps using a radius of 5 mm were employed for all the samples prepared for the test. A typical system consists of a driven spindle and chuck for holding the revolving disc, a lever arm device to hold the pin, and attachments to allow the pin specimen to be forced against the revolving disc specimen under a controlled load condition.

2.2.6. Calculation of the percentage mitigation

The percentage mitigation was calculated from the results obtained from the wear analysis using Equation (1).

$$\text{Percentage mitigation} = \frac{\text{worst result} - \text{wear result of sample}}{\text{worst result}} \times 100 \quad (1)$$

3. RESULTS AND DISCUSSION

3.1 Result of Chemical Analysis of Melon Shell

The X-ray fluorescence (XRF) analysis indicated that silica had the highest composition of the oxides present in the carbonized melon shell followed by phosphorus (V) oxide (P_2O_5) while vanadium (V) oxide (V_2O_5) was the least present (Table 1).

Table 1: Chemical composition of the carbonized melon shell using XRF machine

Oxides	% composition
SiO_2	75.3
P_2O_5	9.87
SO_3	0.63
K_2O	4.70
CaO	2.11
TiO_2	0.16
V_2O_5	0.006
MnO	0.367
Fe_2O_3	1.30
ZnO	0.476
BaO	0.098
MgO	0.37
Na_2O	0.53
Al_2O_3	2.67
LiO	1.41

The analysis also confirmed that alumina (Al_2O_3), potassium oxide (K_2O) and calcium oxide (CaO) were also present in the ash in significant amounts. SiO_2, FeO, Al_2O_3 and TiO_2 are known to be among the hardest substances (Popoola et al., 2012; Anasyida et al., 2009; Totten, 2006). Some other oxides such as sodium oxide (Na_2O), zinc oxide (ZnO), barium oxide (BaO) was also found to be present.

3.2. Wear Results and Heat Treatment

The results presented in Figure 1 show the wear rate of the heat treated samples for applied load of 5N. The control sample showed a wear rate of 0.2919mm^3/N/m, while the double thermally aged samples showed a maximum wear rate of 0.23 at 5 hours of ageing. These results showed that the double thermally aged samples showed a decrease in wear rate with increasing temperature after one hour of ageing.

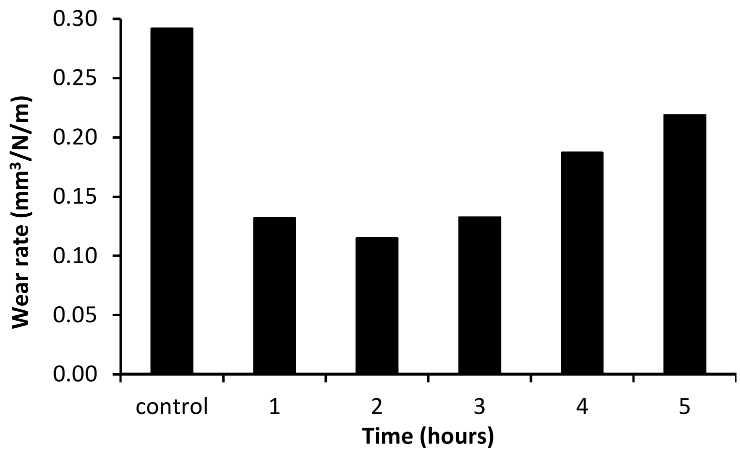

Figure 1: Variation of wear rate with aging time for applied load of 5N

This may be attributed to the fact that β-phase precipitation may not have taken place like the others and the sample may said to be under aged (Anasyida et al., 2009). At the second stage of aging (180 ^oC), the wear rate decreases from 0.1318mm^3/N/m to 0.1148mm^3/N/m with time for 1 and 2 hours and then increases from 0.1326mm^3/N/m to 0.2187mm^3/N/m with time at 3 to 5 hours. The decrease in wear rate may be attributed to the fact that at soaking time of 1 and 2 hours, the β-phase precipitation increases with increase in soaking time and temperature which leads to strengthening and hardening and hence leads to reduction in wear rate (Anasyida et al., 2009). As observed, wear rate increaseds at soaking time of 3, 4 and 5 hours. This is because strengthening and hardening reacheds its maximum and finally began to diminish. The reduction in some mechanical properties that occur after a long period of time is known as over aging and this may be attributed to the fact that as the soaking time increases, the β precipitates continues to develop with time and this causes softening and weakening of the precipitates which therefore causes a reduction in the resistance to slip that is offered by the precipitate particles. This has been reported elsewhere (Anasyida et al., 2009).

3.3. Percentage mitigation

The result (Table 2) shows that 2 hours of soaking time gave the best percentage mitigation failure for the alloy up to 60.67%. This is due to maximum strengthening that was obtained during aging.

Table 2: Percentage mitigation of wear failure of conditioned Al-Si-Mg alloy

Soaking time (hrs)	1	2	3	4	5
% mitigation	54.85	60.67	54.57	35.86	25.07

4. CONCLUSION

The use of carbonized melon shell during heat treatment has improved the surface property of the alloy within the time and applied load studied. Wear behavior of solution heat treated, quenched and artificially aged alloy (Al-Si-Mg) is dependent on temperature and time. The result showed that increasing the soaking time reduces wear failure of the alloy up to 2 hours of ageing time. Sample that undergo double thermal aging at soaking time of 2 hours showed minimum wear rate.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Anasyida, A.S., Daud, A.R. and Ghazali M.J. (2009). Dry sliding wear behaviour of Al-4Si-4Mg alloys by addition of cerium, *International Journal of Mechanical and Materials Engineering*, 4(3) pp.127-130

Bayer, R.G. (1994), Mechanical wear Prediction and Prevention, Marcel Dekker, New Delhi

Birol, Y. (2009). Response to Artificial Ageing of Dendritic and Globular Al-7Si-Mg Alloys. *Journal of Alloys and Compounds*, 484, pp.164-167.

Popoola, A.P.I., Ochonogo, O.F., Abdulwahab, M., Pityana, S. and Meacock, C. (2012). Composite for Advanced Materialsm. *Journal of Advanced Materials*, 4(2) pp. 66-68.

Totten, G.E. (2006). *Handbook of Lubrication and Tribology, Application and Maintenance*. 2nd ed, New York: CRC Taylor & Francis Group.

Umaru, O. B. (2013). Effect of pre-ageing conditions on the hardness and corrosion characteristics of double thermally aged Al-Si-Mg alloy, (Unpublished Msc. dissertation). Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria-Nigeria.

Zadeh, L.A. (1965). Fuzzy Sets. *Journal of Information and Control*, 8(3). pp. 338-353.

Zmitrowicz, A. (2006). *Wear Pattern and Laws of Wear*. 4th ed, New York: John Wiley & Sons, Inc.