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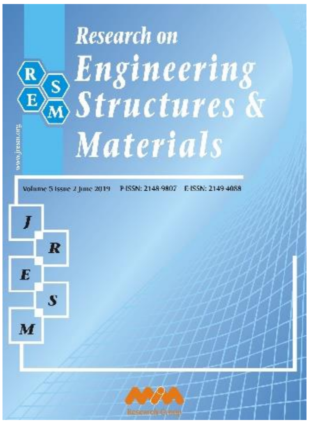

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Research Article

Wear performance investigation of $AlSi_8Cu_3Fe$ aluminum alloy related to aging parameters

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Abstract

Aluminum silicon alloys are the most preferred alloys for industrial applications due to their ease of production and lightness. It is important to improve the mechanical properties of these materials in order to increase their usage. Wear properties are one of these mechanical properties that can be improved. In this present investigation, 3 different artificial aging durations; 2hrs, 4 hrs, 8 hrs aging at 200 °C were applied after solution heat treatment for 4 hrs. at 540 °C to the AlSi8Cu3Fe alloy. Microstructural analysis, mechanical tests were applied to understand the effect of aging parameters on wear performance and also hardness values of AlSi8Cu3Fe alloy. According to the results obtained from tests and analyzes, the highest wear resistance was reached on the 4 hrs. aged sample.

1. Introduction

In recent year's aluminum, magnesium and similar materials that have the high specific strength (strength/density) have become the focus of attention by the aviation and automotive industries where weight gain is important [1–3]. The weight gain in these areas will reduce fuel consumption and therefore also reduce greenhouse gasses (GHGs) emissions. It is important to improve the mechanical properties of these materials in order to increase their use. Wear properties are one of these mechanical properties that can be improved. Factors that increase the wear rate of material adhesion, abrasion, delamination, thermomechanical effect, fatigue, sub-surface damage, and oxidation depending on the sliding conditions (contact load, relative speed, counter surface, dry or lubricated) nature of contact (pin on disc/ring/bush), metallic properties of sliding surfaces, oxidation and thermal softening behavior [4,5]. Alloying, thermo-mechanical processes, heat treatments etc. are among the methods that can be applied to develop these properties [6].

One of the most preferred elements in the alloying of aluminum metal is silicon. Due to the high fluidity provided by the silicon, it is possible to produce parts with complex and thin sections by casting. Silicon provides fluidity to the liquid metal while also reducing the tendency to tear on the spattered part [6]. Therefore, Al-Si based alloys results in as attractive combinations of low coefficient of thermal expansion, high elastic modulus, excellent wear resistance and good thermal stability [7]. Copper can be used up to 5% as an alloying element when high strength values are required but corrosion resistance is not very important [6]. Iron is generally found as an impurity in aluminum alloys especially in Al-Si alloy. It is usually considered detrimental and has the potential to seriously degrade

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castability. In the absence of Si, iron forms Al_3Fe and Al_6Fe intermetallic compounds with aluminum. These intermetallics are highly stable but have brittle nature which, negatively affects the ductility of the part and also reduces the corrosion resistance [6]. When Si is present, the dominant phases are the hexagonal α-Al_8Fe_2Si phase and the monoclinic/orthorhombic β-Al_5FeSi phase [8]. If Mg is present with Si in Al, π-$Al_8FeMg_3Si_6$ phase can form [9]. To minimize the harmful effects of iron, some manganese or cobalt is added to the alloy. Zinc is the another alloying element that has a relatively high solubility in aluminum both at high temperature and at room temperature; also, it is stated that there is no significant effect of zinc addition below 3% on the Al-Si alloys [10].

Aluminum-silicon alloys have been commonly used as components which have sliding movement with a contacting counter body. The performance of these components greatly depends on material-related parameters, e.g., shape, size, content, and type of distribution of given micro constituents etc. [11]. Also, it can be argued that service conditions have a considerable effect on the wear performance of Al-Si alloys.

In this study, attempts have been made to determine wear behavior of T6 heat treatment (artificial aging after solution heat treatment) applied to hypoeutectic Al-Si alloy which is commercially produced as AlSi8Cu3Fe aluminum alloy.

2. Materials and Method

The chemical composition of the alloy in this study was given in Table 1. In accordance with T6 heat treatment, artificial aging heat treatment was applied at a temperature of 200 °C for 2, 4 and 8 hrs. after application of the solution heat treatment for 4 hrs. at 540 °C. After aging heat treatment, all specimens were cooled by water at room temperature.

Table 1 A chemical composition of AlSi8Cu3Fe aluminum alloy (in wt.%)

ISO Norm	Fe	Si	Cu	Mn	Mg	Zn	Ni	Ti
AlSi8Cu3Fe	1.00	7.50-9.00	3.00-4.00	0.50	0.30	1.00	0.20	0.20

X-Ray Diffraction (XRD) analysis for phase identification was carried out using Rigaku ULTRA IV Diffractometer with Cu-Kα X-ray radiation under 40-kV acceleration voltage and 40 mA current. A scan speed of the measurements was 3 deg./min. and scan range was between 30° to 90°. ICDD database was used to identify the phases of the X-ray diffraction pattern of the alloys.

Detailed microstructural investigations of alloys are carried out by Carl Zeiss ULTRA PLUS FESEM Field Emission Scanning Electron Microscopy (FESEM). Also, Energy Dispersive Spectroscopy (EDS) was performed to assess the chemical compositions of the phases.

Brinell hardness test was performed via Q250 M QNESS macro hardness test machine using 62.5 kg loads with a holding time of 20 seconds and 2.5 mm diameter indenter. Brinell hardness values of the specimens were the averages of measurements taken at 5 different points at one indent per point.

Wear tests were conducted on UTS Tribometer T10/20 at forward and reverse movement module. AISI 52100 steel brand ball was used during the test. Wear tests were carried out at 130 mm/s. test speed with a stroke distance of 10 mm. 5 N loads were applied to the samples and 500 meters distance were taken. Lubricant was not used.

3. Results and Discussions

XRD analyses result of sample aged at 200 °C for 8 hrs. sample were given in Figure 1. In XRD analysis, only peaks of Al and Si phases were observed, any other phases were not detected. This may be due to the low amount of other phases in the structure and overlapping peaks of intermetallic phases with Al and Si peaks. Possible phases are investigated in the literature. Sallah and Omar [12] have determined the phases of Al, Si, Al2Cu, β-Al5FeSi, Al5Cu2Mg8Si6 by XRD analysis in similar alloys to the studied AlSi8Cu3Fe alloy. Some of these phases which could not be determined with XRD analysis were determined in EDX analysis.

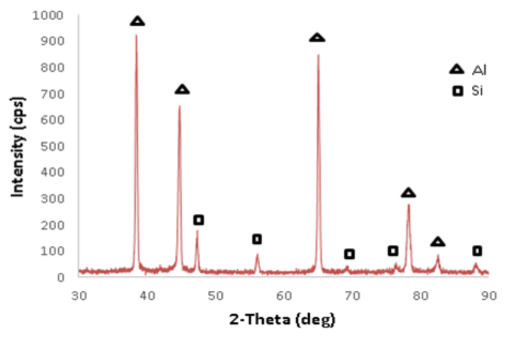

Fig. 1 XRD analyses result of sample aged at 200 °C for 8 hrs

Figure 2 shows SEM micrographs of aged alloys. Figure 3 shows EDS analyzed the region of aged at 200 °C 8 hrs. alloy and EDS results of the phases in at.%.

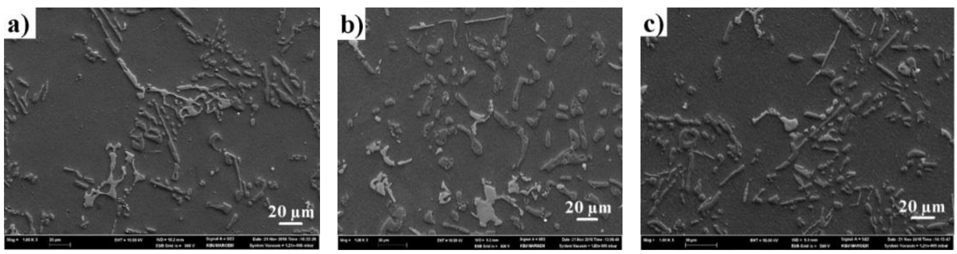

Fig. 2 SEM micrographs of aged alloys at 200 °C for; a) 2 hrs. b) 4 hrs. c) 8 hr

In both aging durations, the microstructure is relatively coarse and mostly dendritic. Three different phases were observed from SEM-EDS analyses, namely; α-Al matrix, Si and β-Al_5FeSi. α-Al matrix contains low amount of Si, Cu, and Fe elements. Si phase contains low amount of Al and intermetallic phase composed of mainly Al and other elements; Si, Cu, Fe, Mg and Mn elements. Figure 3 and Table 2 show microstructural features and their composition.

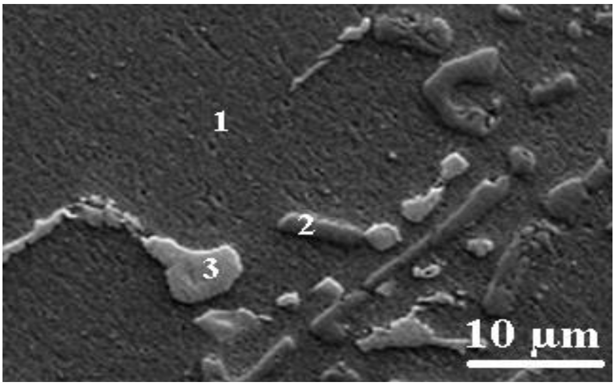

Fig. 3 EDS analysis region of the alloy aged at 200 °C for 8 hrs

Table 2 EDS results of the phases.

Spectrum (at.%)	Al	Si	Cu	Fe	Mg	Ti	Mn	Ni
Point 1	94.99	1.16	2.00	0.59	0.00	0.17	0.00	0.21
Point 2	2.17	97.61	0.00	0.10	0.00	0.08	0.00	0.00
Point 3	63.40	11.93	4.17	15.09	5.02	0.24	5.02	0.15

Brinell hardness values from five different points of aging application samples and average values of them are given in Table 3, and graphical comparison of Brinell Hardness values as a function of aging time was given in Figure 4. Brinell hardness's of specimens are 106.8 HB, 89.2 HB, and 120.6 HB with an increasing aging duration, respectively. It is well known that the Si particles have higher hardness and lead to an increase in wear resistance [4]. With the increase in the aging time, it was found that the Si containing particles exhibited a noticeable effect on hardness and wear especially after 4 hours aging period.

Table 3 Brinell hardness measurement results related about aging duration

Aging Duration	Indentation 1	Indentation 2	Indentation 3	Indentation 4	Indentation 5	Average
2 hrs.	109	107	106	105	107	106,8
4 hrs.	92,3	84,0	89,4	90,8	89,7	89,2
8 hrs.	121	117	121	122	122	120,6

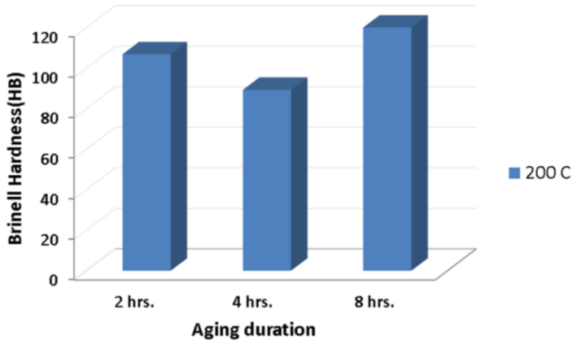

Fig. 4 Graphical comparison of Brinell hardness values of the samples

Effect of aging time on the wear loss of the alloy was given in Figure 5. Wear loss of specimens are 1.9, 1.7 and 2.6 in mg with an increasing aging duration, respectively.

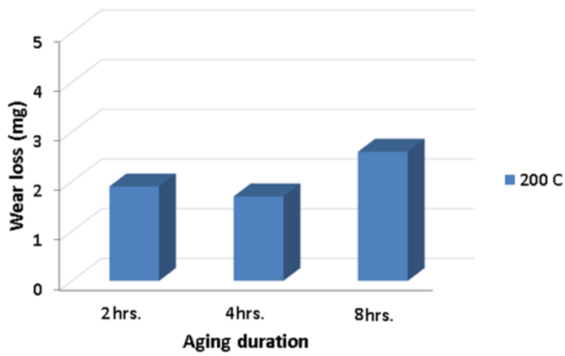

Fig. 5 Wear loss of the aged alloy

When Figure 4 and Figure 5 are compared, we see that both of them follow a similar trend. As aging duration is increased from 2 hrs. to 4 hrs., both hardness value and wear loss of the AlSi8Cu3Fe alloy decreases. Further, increasing aging duration to 8 hrs., both hardness value and wear weight loss increase to maximum values. The reason is that intermetallic particles in the structures became larger with aging duration from 2 hrs. to 4 hrs. after this duration Si-based intermetallic grows faster than the intermetallics. Therefore, these large particles on the surface resulted in less weight loss due to the breakage during wear. Lasa and Rodriguez-Ibabe express that the high wear resistance is generally attributed to the presence of hard silicon particles distributed throughout the matrix [13]. It can be said that optimum silicon particle size was approached at 4 hrs. aging for higher wear resistance.

4. Conclusion

In this study, the wear performance of the AlSi8Cu3Fe aluminum alloy was investigated depending on the artificial aging time. Solution heat treatment of the alloy was carried out at 540 °C for 4 hours. After that aging heat treatment was applied at a temperature of 200 °C for 2, 4 and 8 hrs. Minimum weight loss was detected in 4 hrs. aged sample which has also lowest hardness. On the other hand, the alloy aged for 8 hrs. has the highest hardness and weight loss.

From the results of this study, the following conclusions can be drawn:

- Microstructure of all specimens composed of α-Al matrix, Si and Al-rich intermetallic phase containing Si, Cu, Fe, Mg and Mn elements. From the ratio of the elements, it is thought to be β-Al_5FeSi.
- Although the wear rates and hardness values are parallel to each other depending on the aging time, it is inferred from the performance of the heat-treated specimens that the wear performance of the Al-Si based alloys is governed by the size and distribution of coarse Si particles, and that the impact of hardness is only secondary.

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