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Synthesis and Characterization of Al-Si Alloy Composites Reinforced with Al_2O_3 Particles by Stir Casting

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Abstract - *Al-Si alloys were obtained by reduction of Sodium-Fluosilicate (SF) with Al powder and molten aluminum. Then Al-8%Si-xAl_2O_3 composites were fabricated by reinforcement the base alloy with alumina by using stir casting at 750 °C. The addition of alumina was according to the following percentages(2%, 4%, 6%, 8% and 10%). Aluminum alloys reinforcement with alumina is of commercial importance for the enhanced mechanical properties of the resulting composites. The microstructure of the fabricated metal matrix composites (MMCs) were analyzed to ensure the alumina distribution into the Al-Si alloy. Hardness measurement and pin on disc wear test were performed on the composite specimens and reported. The results showed that, with the increase in addition of alumina the hardness value of the processed composites increases while the wear rate value decreases.*

Key Words: Al Alloy, Metal Matrix Composite , **stir casting, Microstructure, Mechanical properties.**

1.INTRODUCTION

The need for new materials, adapting active engineering requirements has led to the development of metal matrix composites. MMCs have many advantages such as high hardness, high wear resistance, corrosion resistance and high strength to weight ratio with its good performance at elevated temperature. Al-Si alloys are the mostly important of aluminum alloys. The prevalent use of these alloys compared to the other types of aluminum cast alloy refer to their good physical and mechanical properties [1, 2]. The main uses of aluminum silicon alloys are; the welding rods, for radial aircraft, internal combustion engines and on application in the automotive industry. [3]. Conventionally, Al-Si alloys were prepared by adding relatively pure silicon to molten aluminum at temperature about 900 ^oC in muffle furnaces [4, 5].

Sodium-Fluosilicate (SF) is produced from super-phosphate fertilizers plants as a by-product. SF has many uses in a small scale, such as; ceramic, enamels, glass [6]. One of the very important applications of SF is the production of aluminum silicon alloy (Al-Si) [7, 8]. Therefore, The produced Al-Si alloys are self-modified due to sodium presence in the reaction's bath; this modification will enhance the mechanical properties.

Reinforcement of MMCs based on aluminum alloys are well known because of their strength, specific modulus and good wear resistance as compared to conventional alloys [9-12]. Reinforcement of Al alloys with alumina has commercial importance for the enhanced mechanical properties of the resulting composites, especially at elevated temperatures. The market demand of such composites has been increased especially for automobile components such as diesel pistons, connecting rods, piston pins.

The present work aims to produce firstly Al-Si alloys from reduction of sodium fluosilicate with aluminum powder within molten aluminum. Then fabricate Al-8%Si-xAl_2O_3 composites by reinforcement the base alloy with alumina and then to observe the microstructures and measure the hardness and the wear rate of the produced composites.

2. Experimental Work

2.1 Materials

The materials used in the experiments were; commercial aluminum (solid & powder), sodium fluosilicate and commercial alumina. Commercial Al (solid) with assay 99.7% Al, was in the form of cylinders (25x30 mm). Commercial Al powder is with average size of (-125+63µm). SF powder has average size (-150+106µm). Alumina powder is with high purity and average size 80 µm. Tables 1 and 2 show the chemical analysis of the used aluminum and sodium fluosilicate. The as-received materials are investigated by XRD, and Differential Thermal Analysis (DTA).

Table -1: The chemical analysis of the aluminum

Component	Percentage,%
AL	99.7
Fe	0.03-0.09
Si	0.01
Cu	0.005
Mn	0.004
Mg	0.004
Ti	0.005
Zn	0.005
V	0.005
Na	0.0001

Table 2 The chemical analysis of the sodium fluosilicate

Component	Percentage,%
Na	23.72
Si	14.02
F	57.54
SO_4	0.05
Fe	0.02
Ca	0.30

2.2 Alloy Preparation

The powders (Al and SF) are manually mixed to obtain a homogeneous mixture. The homogeneous powder is pressed in a hardened steel die with 250 KN pressure force. The purpose of compaction process is to obtain a green compact of Al-powder and SF, which can withstand against the elevated temperatures to avoid the early decomposition of SF. Aluminum cylinders (200gr) are melted in a laboratory scale electrical furnace at temperature of 900°C. The green compacts of Al and SF is added to the molten aluminum after it is completely melted, then stirring process is accomplished, mechanically, using stirrer of 400-rpm speed, to ensure that the SF is well distributed into the molten aluminum. In the last step, the molten alloy is poured into a metal mold and is kept at room temperature until they are completely solidified. The Al-Si alloys preparation from reduction of SF by molten Al and the factors affecting on the production process was studied elsewhere by Wasly et al. [8].

Differential Thermal Analysis (DTA) was performed to estimate the enthalpy output of the transformations from the integrated area of the peaks. In a cell of Platinum, and at Nitrogen atmosphere with a flow rate of 40 ml/min, two samples of Al-SF (26, 19 mg) at 800 °C and 900 °C respectively, were analyzed with a temperature rate of 10 °C /min.

2.3 Composite Preparation

The alloy base (Al-8% Si) is placed in a graphite crucible and melted in a laboratory scale electrical furnace at temperature of 750°C. The powder of alumina, which has been saved at a temperature about 200°C to remove moisture, was added. The addition of alumina was according to the following percentages of alumina (2%, 4%, 6%, 8% and 10%). Then stirring process is accomplished mechanically at 400-rpm speed for 3 min. Because of the stirring, the powder of alumina is distributed in the Al-Si alloy, until the homogeneity of the solution, which then poured into a mold of iron. This process is repeated several times for samples containing different proportions of alumina, which were added to the alloy base.

The surface of the produced composite samples is prepared using standard metallographic techniques. After preparation, microstructures of the samples were observed under computerized optical microscope (Model: Olympus BX51). Hardness measurement was performed on the composite specimens by using a laboratory Vickers hardness tester. A pin on disc wear test was carried out to investigate the dry sliding wear characteristics. The weight of specimen was measured on a digital microbalance-weighing machine with an accurate 0.1 mg and initial weight of the specimen was noted. After running through a fixed sliding distance, the specimen were removed and weighed to determine the weight loss due to wear. The difference in the weight measured before and after test gave the sliding wear of the composite specimen and then volume loss is calculated.

3. Results and Discussion

3.1. X-ray Diffraction of the Received Materials

The as-received materials were examined by X-ray diffraction technique to identify the crystal structure and the phases present. The experimental X-ray diffraction patterns of the as-received Al, alumina and SF are shown in Figures (1a-c) respectively. Figure 1a shows that in case of commercial aluminum five main peaks are registered in the 2θ range of 0° to 90°. Sharp peaks in the diffraction pattern of pure aluminum indicate the crystalline nature of the material. Also for SF and alumina (Figures 1b, c) the crystalline nature of the material is appeared from the sharp peaks in the diffraction pattern of them.

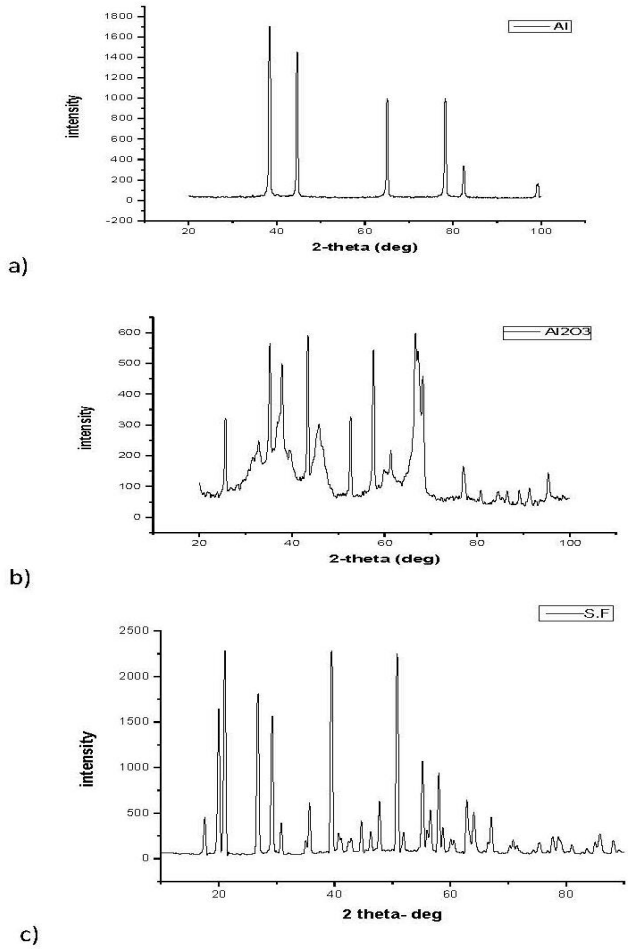

Fig -1: XRD pattern of the as-received materials a) Aluminum b) Alumina c) Sodium-Fluosilicate

3.2. Thermal Analysis of Al-S.F mixture

Figure 2 shows differential thermal analysis (DTA) and thermogravimetry (TGA) for Al-SF mixture. For DTA, two endothermic peaks (blue line) appear at 560 °C and 570 °C and the other shows peak at 658oC. The first two peaks represent the decomposition of S.F according to reaction (equation 1):-

$$Na2SiF6 \longrightarrow 2NaF + SiF4\ (gas) \quad (1)$$

The second endothermic peak represents the transformation of Al from solid to liquid state (latent heat of Al fusion). TGA was applied for studying decomposition reactions; mass of the tested sample was measured with the increasing temperature. From the shown Figure it can be noticed that the weight is decreased from 26 to 19 mg at temperature ranged from 556 to 596°C. The loss of about 7 mg is come from the decomposition of SF to SiF_4 and NaF according to reaction 1[8]. The residue of the decomposed sample is Al about (13 mg) and NaF about (6mg).

For the dissolution mechanism of SF in molten aluminum, a kinetic study suggested that the dissolution of SF in molten aluminum to produce Al-Si alloys could be occurred at temperature more than 600 °C according to the reactions appeared in equations 1 and 2:

$$3SiF_4\ (gas) + 4A1 \longrightarrow 4A1F_3 + 3Si\ (alloy) \quad (2)$$

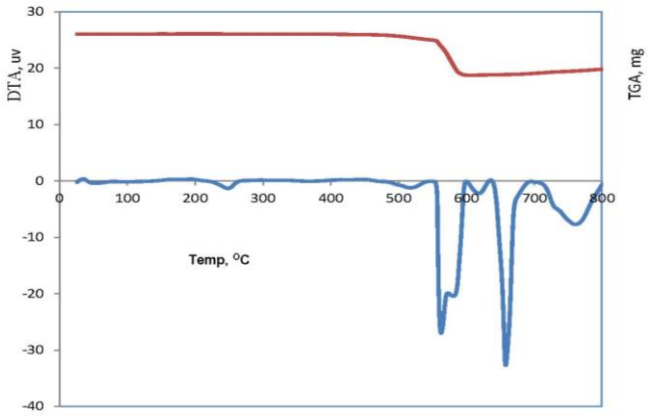

Fig -2: Differential thermal analysis (DTA) and Thermogravimetry (TGA) for Al-F.S mixture

It can be predicted that the mechanism of the reaction takes as follows; when added SF to molten aluminum, the SF firstly decomposes according to reaction (equation 1) to produce SiF_4 gas, which reduced to silicon ion in the presence of Al powder within the molten bath, which in turn combined with molten Al to form the Al-Si alloy [8].

3.3. Characterization of the Produced Al-Si Alloy & Composites

The chemical composition of the produced Al-Si Alloys for every specimen was studied. From the obtained results; the Si content is 8 % in the produced alloys. The content of sodium in the produced alloys is 0.005 % and most of it emerging from the used SF. Chemical analysis shows that total impurities in the Al-Si alloys less than 0.2% as shown in Table 3.

Table 3 The chemical analysis of the produced Al-Si alloys

Component	Percentage,%
AL	Rem
Fe	0.18
Si	8
Cu	0.006
Mn	0.003
Mg	0.001
Ti	0.004
Zn	0.003
V	0.004
Na	0.005

3.3.1 Microstructural Analysis of Composites

The results of optical microscopy for Al-Si alloys, Figure 3, show the presence of α Al dendrites

and eutectic silicon phase in the content of alloy samples. Alloys with a predominantly eutectic structure are modified to obtain adequate mechanical properties. In the present work, the produced alloys are self-modified due to sodium presence. This result is also observed by others [7, 8, 13].

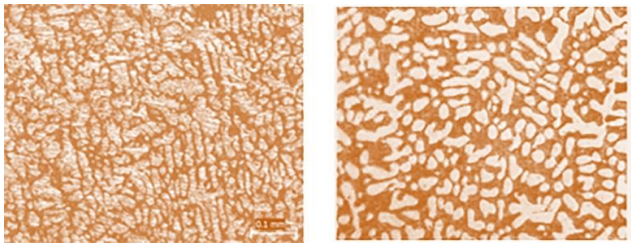

Fig -3: Microstructure of the produced Al-Si alloys with 8 Si % content, X= 100

Microstructure of Al-Si-Al_2O_3 composites with different alumina content are shown in Figures (4 a-c). Figure 4a show the microstructure of Al-Si – 4%Al_2O_3 composites in which it can be noticed alumina particles in Al matrix which may be crushed due to thermal stress or found in melted state in some areas. In Figure 4b, Al-Si–6%Al_2O_3 the particles are smaller and distributed in homogeneous form in the internal matrix of the base alloy. In addition, there are some clusters where fine particles collected in some places of the matrix that may be referred to cooling rate and chemical composition of the alloy. In Figure 4c, Al-Si – 10% Al_2O_3 it can be noticed that there are fine particles distributed in the alloy matrix which may be due to that the thermal conductivity of alumina is lower than the base alloy. So cooling rate for alumina particles is lower and the molten found around them will solidify lastly and this action increases the number of fine particles.

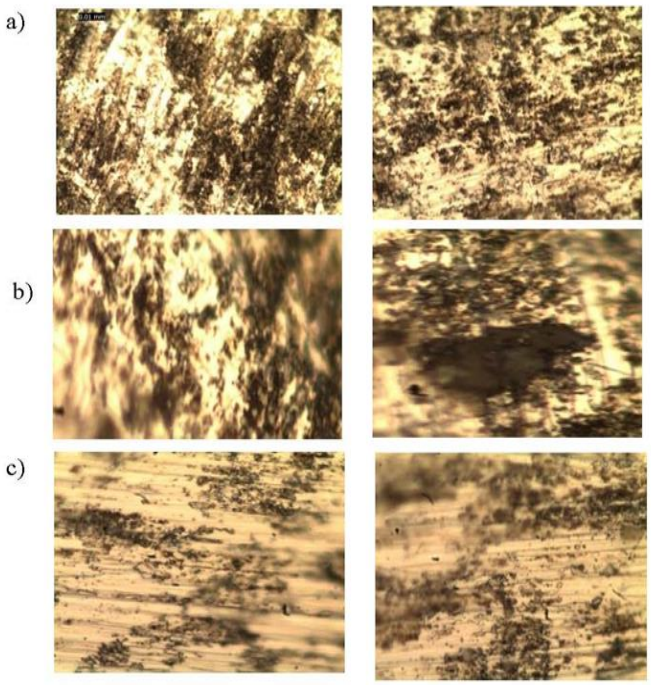

Fig -4: Microstructure of Al-Si-Al2O3 composites with different alumina content using light microscopy, X= 100; a) 4% alumina b) 6% alumina c) 10% alumina

Figure 5 shows XRD patterns of the Al-8Si alloys and Al-8Si-xAl2O3 composites. As indicated in Figure 5a, the alloy peaks of Al and Si are formed between Al and silicon. While in Al-8Si/Al_2O_3 composite, Coesite, Kyanite and Ablykite minerals was formed by a thermite reaction between Al alloy melt and SiO2, together with Al_2O_3.

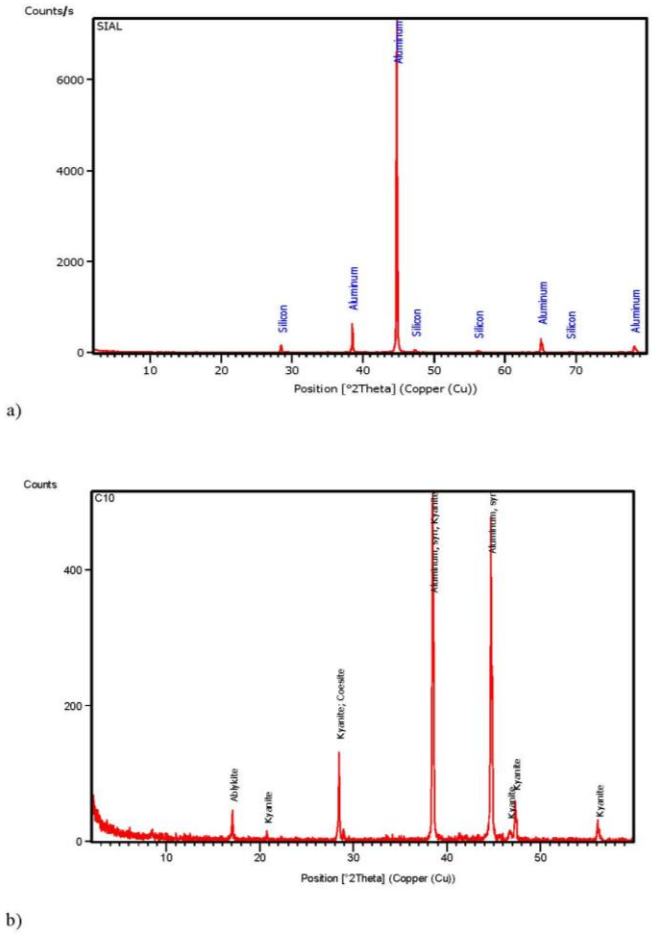

Fig -5 : XRD patterns of a) Al–Si alloy and b) Al-Si-Al2O3 composites

3.4. Mechanical Properties

a) Hardness

The hardness values (Vickers hardness) of the matrix alloy and the MMCs are shown in Table.4 It is clear that the hardness value of the composites increases with the increase in addition of alumina particles. The reinforcement of the alloy with alumina led to improve its mechanical properties. This refers to the nature of these hard particles, which distributed in the base alloy in different sizes and resulted in increasing the strength (Figure 6). This result is also observed in other literatures [14].

Table 4 The hardness values (Vickers hardness) of the matrix alloy and the MMCs

Material	Hardness(HV)
Matrix Material	82
Al-8% Si- 2%Al_2O_3 (2 % MMC)	88
Al-8% Si- 4%Al_2O_3 (4 % MMC)	90
Al-8% Si- 6%Al_2O_3 (6 % MMC)	93
Al-8% Si- 6%Al_2O_3 (8 % MMC)	94
Al-8% Si- 6%Al_2O_3 (10 % MMC)	97

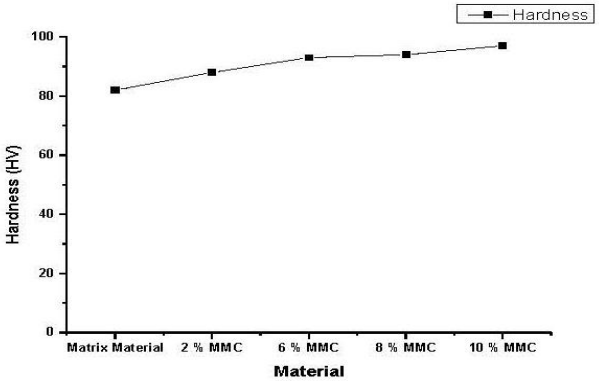

Fig -6 : Microhardness of Matrix Material and MMCs

b) Wear Test

A pin on disc wear test was carried out to investigate the dry sliding wear characteristics. The load used was 0.886 kg and the sliding speed was 250 rpm for 30 min. The wear rate values of the MMCs are shown in Table.5. It is clear that the wear rate value of the processed composites decreases with the increase in addition of alumina particles (Figure 7).

The presence of reinforcement particles, for composites, is the most important characteristic whose hardness is much greater than the matrix alloy. Al_2O_3 particles in the matrix alloy strengthen the base alloy matrix. The wear resistance of the composites may be basically related to the wear resistance and hardness of the reinforcement particles. The result is similar to that obtained by others [15, 16].

Table 5 The wear rate of the MMCs with different alumina content

Material	Hardness(HV)
Al-8% Si- 2%Al_2O_3 (2 % MMC)	9.7
Al-8% Si- 6%Al_2O_3 (6 % MMC)	8.6
Al-8% Si- 10%Al_2O_3 (10 % MMC)	7.6

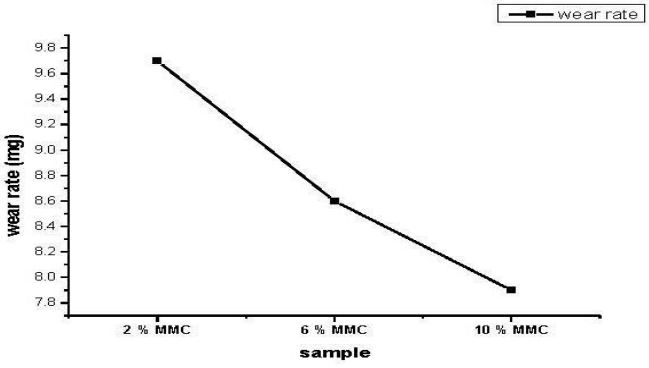

Fig -6 : Wear rate of Al-Si-Al2O3 composites

4. Conclusions

Al-Si-Al_2O_3 composites were manufactured with different proportions of alumina by the stir casting method. Microstructural observation shows the alumina particulates distribution in the Aluminum alloy matrix. The hardness value of the reinforced Al base alloy matrix composites increased with the increased addition of alumina particulates in the matrix. While the wear rate value of the processed composites decreases with the increase in addition of alumina particulates.

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