Improvement the mechanical and tribological properties of high temperature Al-Si-Ni alloys

Mohammed. Farag[1], Moatasem M. Kh[1], A. M. Omran[1*] and A. A. Atlam[2]
1. Mining and Metallurgical Engineering Department, Faculty of Engineering, Al-Azhar University, Qena- Egypt
2. Mining and Petroleum Engineering, Faculty of Engineering, Al_Azhar University, Cairo- Egypt.

Abstract

Mechanical testing plays an important role in evaluating the fundamental properties of engineering materials as well as, in developing new materials. Microstructure as light optical microscope (LOM) and scanning electron microscope (SEM) examinations were carried out on the produced alloys. Effects of Ni addition on the mechanical and microstructure properties of Al-Si cast alloys have been studied. In this study, the mechanical properties, such as the tensile strength, Brinnel hardness and wear property were investigated. The obtained results indicated that the tensile strength of Al-Si alloy without Ni increases slightly from 74 to 82 N/mm^2 as the silicon contents increase. But, the addition of Ni to Al-Si alloys at the same silicon contents increase the tensile strength of Al-Si-Ni alloys from 135 to 200 N/mm^2. Also, the hardness of Al-Si alloys without Ni increase from 49 to 61 HBN with increasing the silicon content but the hardness of Al-Si-Ni alloys rises from 60 to 102 HBN with addition of Ni to Al-Si alloys at the same silicon content. in the other hand, the wear weight loss of Al-Si alloys in the absence of Ni decreased from 2.43 g to 0.36 g with increasing the silicon content in Al-Si alloys, and the weight loss decreased in Al-Si-Ni alloys from 0.77 g to 0.17 g in the presence of Ni as alloying element. The improvement in tensile, hardness and wear testing are attributed to the presence of hard intermetallic phase Al_3Ni in the material as observed from XRD and SEM examinations.

Key words: Mechanical properties, Wear test, Nickel, Microstructure, Intermetallic phase

1- Introduction

The growing demands in the automotive and aerospace industry for reduction in energy consumption and producing more fuel-efficient vehicles continues to be a big challenge. The aluminium-silicon alloys have gained increased market shares in the aerospace and automotive industry and have replaced competing ferrous materials. Aluminium-silicon alloys are widely used in the automotive industry due to the high strength-to-weight ratio, good corrosion resistance and good castability. However, the performance of aluminium-silicon alloys at elevated temperature is limited because of degradations in the mechanical properties [1,2].

The effect of adding silicon on the mechanical properties of aluminum alloys such as tensile strength and hardness was investigated by [3,4]. The result showed that the strength properties (ultimate tensile strength) of Al–Si alloys reach the maximum value 175MPa as the silicon contents in the alloy increase up to 14 wt % of silicon. However, the hardness of the Al–Si alloy increases as the silicon content increases. When the aluminium-silicon alloys expose to elevated temperature over long times, the coarsening occurs to the eutectic silicon phases, this reduces the mechanical properties. JE Hanafee et al. [5] discussed the effect of nickel on the hardness of aluminum alloys during the high temperatures. It is shown that nickel can be utilized to improve the hardness (up to 300 °C) of aluminum-silicon (10 - 16 wt% Si) in casting and forging alloys. The maximum benefits are realized by developing a large volume and favorable distribution of nickel aluminide. The solid solubility of nickel in aluminum cannot exceed 0.04wt%. If this amount exceeds, then it would be found as an insoluble intermetallic. Nickel content of up to 2wt% increases the strength of high-purity aluminum but reduces its ductility. Binary Al-Ni alloys are no longer in use, but nickel is added to Al-Si alloys to improve both hardness and strength parameters at elevated temperatures, as well as, to reduce the coefficient of thermal expansion [6,7]. Nickel being added commonly to aluminium-silicon alloys to enhance the strength and hardness at elevated temperatures (up to 300 °C) by forming thermally resistant Ni-rich compounds such as: Al_3Ni, etc.[8]. Addition of nickel to the aluminium-silicon system is characterized by a microstructure of joined Al3Ni and eutectic silicon that strengthening the 3D-network. The silicon phases are subjected to a coarsening and spheroidizing during solution treatment that result in loss in the interconnectivity of the eutectic silicon phases in the 3D-network. However, with the presence of Ni-rich compounds, the loss of interconnectivity reduced [1, 9,10]. Kaya et al. [11] showed that a Al-Si alloy, by adding 2 wt% of nickel, modifies the characteristics of the microstructure and morphologies. A finer silicon structure with a reduced interflake spacing is achieved, as a result of improving the hardness. Riyadh A Badr [12] studied the effect of Si Addition on Microstructure and Tribological Properties of Al0.1Mg-0.35Ni-(4, 6, 8, 10) wt %Si Alloy in the aged condition. The wear rate was found to decrease with the increasing Si content and this behaviour was attributed to the formation of an intermediate phase Al3 Ni. Funda. et al.[13] studied the wear tests of Al-Ni alloys and they concluded that the wear rate of the alloys decreases with increasing the Ni content up to 3 %, further addition of nickel causes an increasing in wear rate.

The main objectives of the present study are to improve the mechanical and tribological properties of high temperature Al-Si-Ni alloys synthesis by reducing the sodium-fluosilicate and nickel oxide.

2- Experimental work

2.1 Materials and experimental procedure

The materials used to carry out the experiments in the present work are commercially aluminum has a purity of 99.7% Al supplied by EGYPTALUMINUM Company. The used aluminum powder in this study has a high purity (99.4) and the particle sizes were (-125+63 μm) mesh. It was obtained as a product from powder Metals Company (Al-Gomhoria). The sodium fluosilicate Na_2SiF_6 that used in this work in its powder form has a purity of 99%, it was supplied from Al-Gomhoria for chemicals. The nickel oxide (Ni_2O_3) that used in this work is in the form of gray powder has a purity of (99.5) and the particle sizes was (10μm) mesh. The preparation and characterization of Al-Si-Ni ternary Alloys Synthesis from reduction of sodium fluosilicate and nickel oxide was published in another paper[14]. Suitable solid specimens were prepared to carry out the chemical analysis, microstructure examinations (carried out by Scanning Electron Microscopy (SEM, FEI Inspect S50, Germany attached to energy dispersive X-ray spectrometer (EDS) for performing semi-qualitative elemental analysis for the specimens and polarized reflected light microscope (Model-OLYMPUS BX51, Japan), The etchant solution used in the microstructure examination is 0.5% HF. Tensile test was performed using tensile test on (VH-F1000 KN) SHIMADZU micro-computer controlled electronic universal testing machine, made in Japan, with strain rate $5x10^{-3}$ s^{-1} and the specimens were prepared according to ASTM standard test method (the standard diameter is 10mm and the gage length is 60mm) [15]. The hardness test has been done using Brinell hardness and the specimens for hardness test were polished. The main dimensions of these cylinders were 30mm diameter and 20mm thickness. The wear test of the alloys measured using a pin-on-disk testing device. The weight loss of the specimens measured and calculated with respect to time, weight loss at constant load of 0.886 Kgf, at the same sliding speed of 250 rpm. The wear specimens were taken from the tensile specimens after fracturing and the two surfaces were cut by cutting machine to be paralleled. For accurate measurements, smooth grinding for one face was carried out.

3-Results and discussion

3-1 Microscopic examination

Microstructure

Figure 1 shows light optical microscope (LOM) and scanning electron microscope (SEM) maping images of hypoeutectic Al-Si-Ni ternary alloy. From Figure 1a the , it can be observed that a white area like kidney is α Al surrounded by small fiber (dark gray) and flake (light grey). The Figure 1b illustrated that the dark gray is eutectic Si(light blue) and the light gray phase is a Ni compound (red color) around α Al (dark Blue color). The presence Ni compound is Al_3Ni intermetallic compound evaluated in previous work [14]. When adding Ni to the Al–Si system, the eutectic transformations are characterized by the simultaneous formation of primary Al solid solution (α), eutectic (E), and Al_3Ni. Consequently, eutectic Si and Al_3Ni form a geometrically entangled system, as can be clearly seen in Figure 1. The whole microstructure as a coarsening two-phase system containing the phases of primary Al solid solution (α) and eutectic (E). According to Al-Si and Al-Ni phase diagrams, the Si dissolved in α Al up to 1.65 at 578^{o}C and form eutectic at about 11.7 Si% at the same temperature. However, Al with Ni form Al_3Ni intermetallic compound at about 25% Ni which in turns forms eutectic with the excess of Al at about 2% Ni at 640 ^{o}C. But, because of the presence of Ni with Al-Si alloys in molten state and slowly cooling, , the α Al firstly solidified below 660 according to the silicon contents followed by the direct formation of eutectic Al_3Ni on the grain boundary of α Al at temperature below 640 ^{o}C , and also according to Si%. Lastly the eutectic Si is formed in the interconnect between the solidified phase making strong geometrical entangled matrix, that confirmed with what obtained in Figure 1 and the published elsewhere [16]. When comparing the hardness or strength of these phases qualitatively, one may assume E to be stronger/ harder phase. In coarsening two-phase systems, the stronger phase will contribute significantly to the overall strength only if it is subjected to load transfer. Load transfer, however, requires a continuous network of respective phases [17]

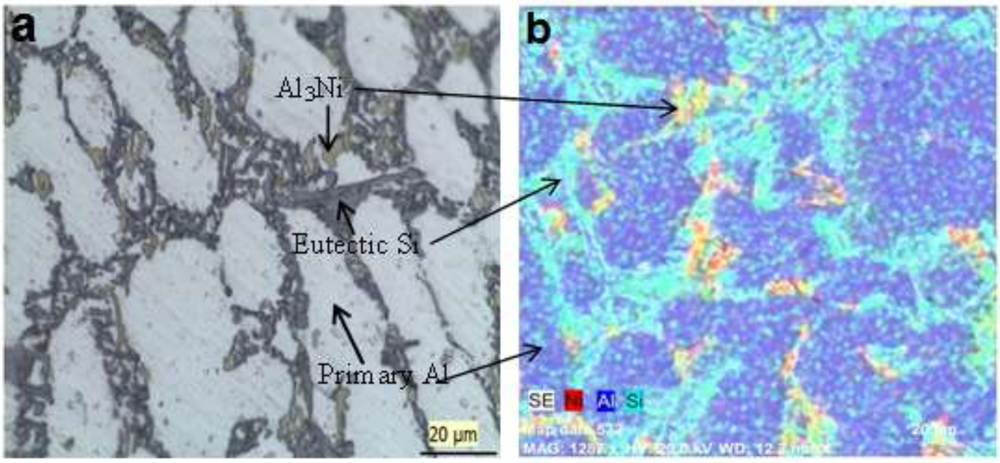

Figure (1) shows images of LOM (**a**) and SEM (**b**) of Al-Si-Ni alloy, etched by 0.5% HF acid.

The characterization results in Figure (2) that shows EDX mapping of hypoeutectic Al-Si-Ni ternary alloy indicates that microstructure of the aluminium-nickel alloys present a thin and homogeneous distribution of an intermetallic compound in the aluminium matrix, identified as Al_3Ni. Furthermore, it was indicated that the amount of intermetallic Al_3Ni increases as the nickel content in the alloy rises. From Figure 2, it is clear to observe that the eutectic Al_3Ni phase (red color) is interconnect with the α Al (blue color) but the eutectic Si (light greenish color) precipitates at the grain boundary of α Al and entangled with eutectic Al_3Ni [17]

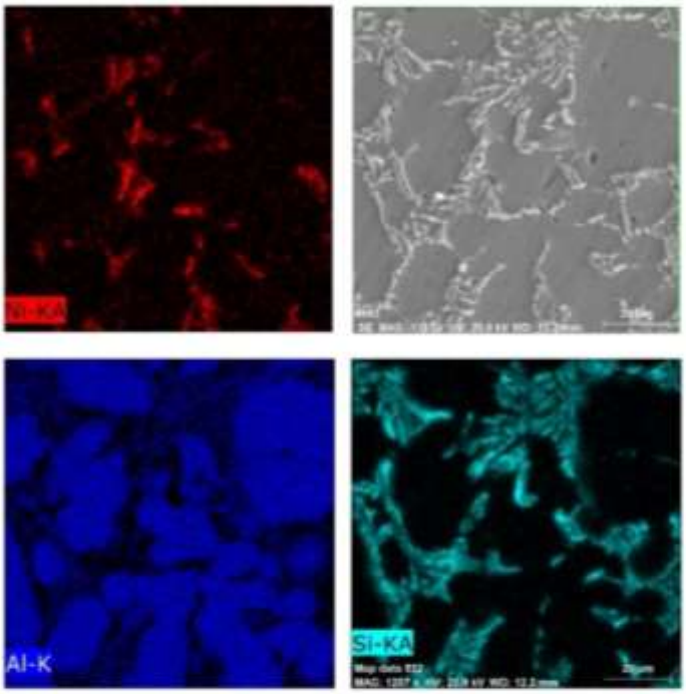

Figure (2) shows EDX mapping of hypoeutectic Al-Si-Ni ternary alloy

3-2 Mechanical properties:

3-2-1 Tensile and Hardness testing

Tensile test is the most common procedure; hence, it is an easy way to get information about the strength of materials and deformation properties in a single test. Figure (3) shows the relation between tensile strength versus silicon content % for Al-Si alloy only. The result showed that tensile strength increases slightly from 74 N/mm^2 to 82 N/mm^2 as the silicon percent increases. However, the hardness of this alloy increases from (49 to 61 HBN) with increasing the silicon contents. The increasing rate of tensile strength is close to the increasing rate of hardness, these results are confirmed by Stadler, et al[17].

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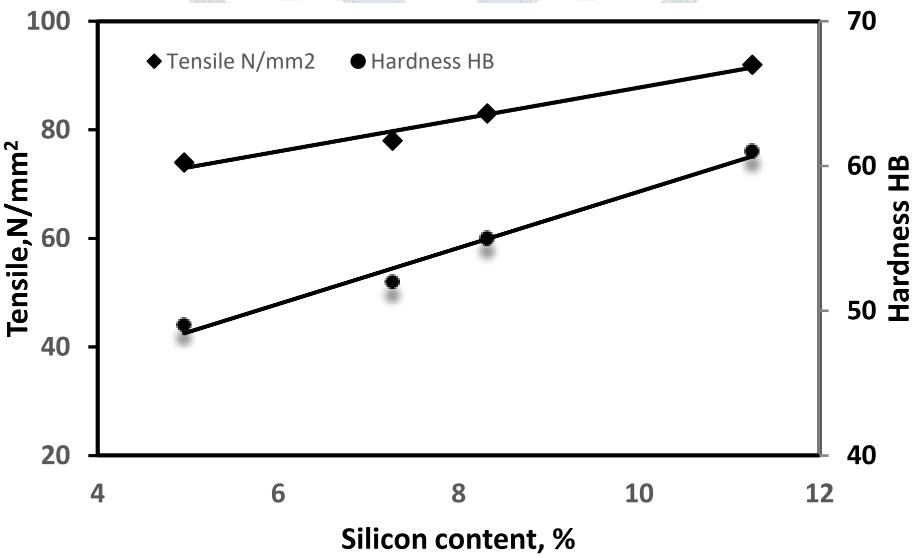

Figure (3) Relation between tensile strength and hardness versus silicon content of Al-Si alloy

From Figure (4), we can observe the improvement in the mechanical properties (Tensile and Hardness) of Al-Si alloy by adding the alloying element here, (a Nickel element), that produced from reduction of Nickel oxide. It can observed that, the tensile strength is enhanced in Al-Si-Ni ternary alloy from (135 to 193 N/mm^2) up to the eutectic range and slightly increases at hypereutectic range from 193 to 200 N/mm^2. Also, an improvement in hardness from (60 to 102 HBN) in the produced Al-Si-Ni ternary alloy, Hence, it is concluded that the tensile strength obtained in this study is higher than those tensile strength values obtained in binary Al-Si alloy and these result agrees with work by Choi, et al [9]. The improvement in tensile and hardness testing is attributed to the presence of an amount of hard intermetallic phase Al_3Ni in the material which modifies the characteristics of the microstructure and reduces the interflake spacing in silicon structure, which results in an improvement of the tensile and hardness for Al-Si-Ni ternary alloy. However, the addition of Ni causes an increasing in UTS this improvement could be regarded as a result of a higher degree of contiguity in the 3D network of Ni-rich phases and eutectic Al–Si [11]. The little increasing in the hypereutectic range could be illustrated as there is an enough Ni to obtain strong network.

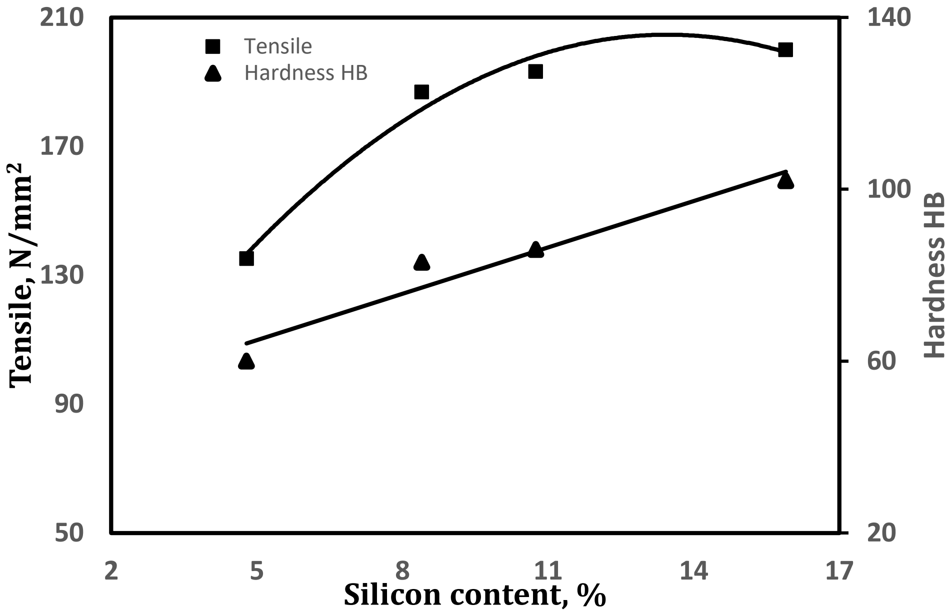

Figure (4) Relation between tensile strength and hardness versus silicon content of Al-Si-Ni alloy

3-2-2 Wear test

Generally the increasing of the silicon level in Al-Si alloys reduces the thermal expansion, increases the wear properties and reduces the machinability [2]. This study aims to know the effect of Ni in the Al-Si alloys on the wear properties. Figure 5 shows the relation between the wear weight loss g and silicon content % of Al-Si alloys without Ni. The results showed that the weight loss decreased from 2.43 g to 0.36 g as the silicon contents increases from 5-11%Si. However, the addition of Ni as alloying element as shown in Figure (6), the wear weight loss decreased from 0.77 g to 0.17 g at the same range of silicon contents mentioned before. These drops in the weight loss in Al-Si-Ni ternary alloys attributed to the presence of amount of hard intermetallic phase Al_3Ni in the material, which changes the characteristics of the microstructure and reduces the interflake spacing in silicon structure. The existence of a thin dispersion of Al_3Ni reinforcement particles in the ductile matrix (aluminum) prevents the growth of cracks when a load is being applied to the alloy and it is explained as an increasing in the mechanical and tribological properties of the produced alloy [10].

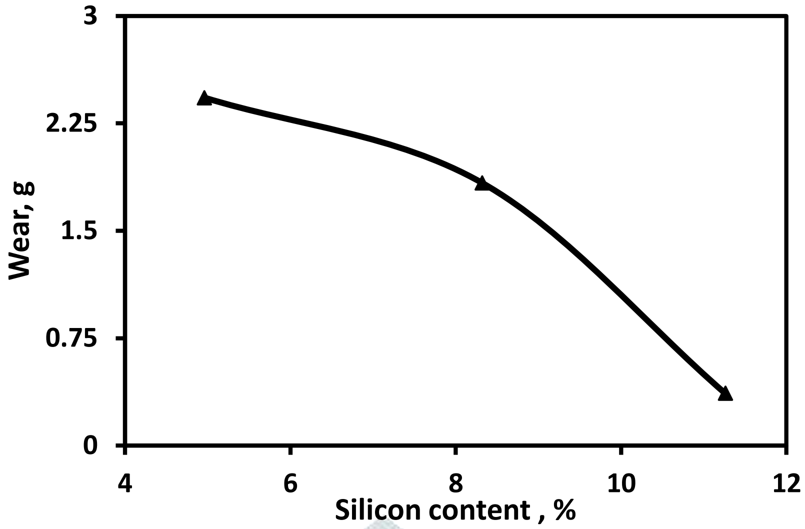

Figure (5) Effect of silicon content on wear rate of Al-Si casting alloy

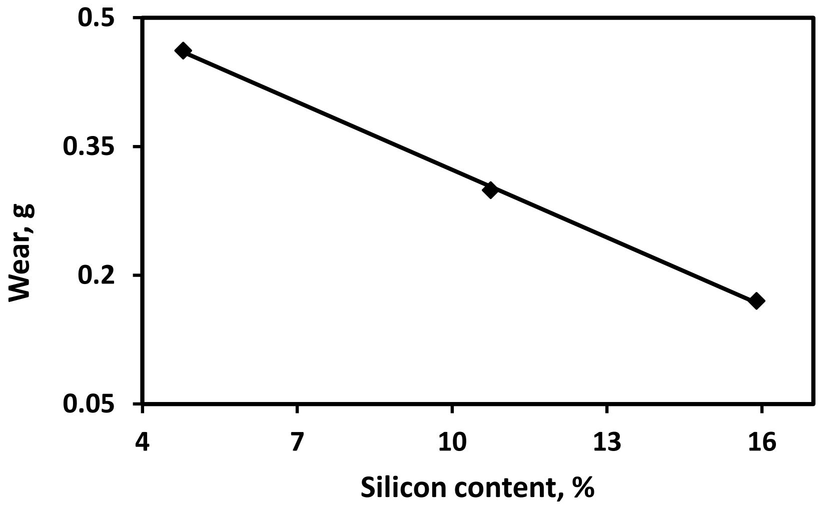

Figure (6) Effect of silicon content on wear rate of Al-Si-Ni ternary alloys

4-Conclusions

The effect of Nickel addition to the Al-Si alloys with different contents of silicon as alloying elements is improved the mechanical and tribology properties. The results could be concluded as the following:

1. The eutectic Al_3Ni phase make an strong bond with the other phases by interconnected with **α** Al, and the eutectic Si forming an entangled system with them.
2. it can be observed that an improvement in Tensile from 82 to 200 N/mm^2 and the Hardness from 61-102 BHN in the produced Al-Si alloy by adding about 2.8% Ni as an alloying element.
3. The weight loss, due to wear, decreases from 2.43 g to 0.36 g as the silicon contents increases. However, by adding of 2.8% Ni as alloying element, the weight loss decreased from 0.77 g to 0.17 g at the same silicon increasing.

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