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Microstructure and Mechanical Properties of Al-20 wt% Si-9 wt% Fe-1.2 wt% Nb Alloy by the Addition of 6 wt%Ni

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Abstract: ***This study demonstrates the potential of the Al-Si-Fe-Nb system as a new precipitation hardenable aluminium alloy by addition TM alloying elements. The mentioned aluminium alloy was prepared with nominal composition Al-20Si-9Fe-1.2Nb (at wt%) as a conventional cast alloy, and again prepared with composition Al-20Si-9Fe-1.2Nb-6Ni (at wt %) to be compared with each other in order to investigate the effect of Ni addition. Experimental samples of these alloys are synthesised and analysed by optical microscopy (OM) and Micro-hardness techniques. Results show that the three-phase region of Al-Si-Fe-Nb alloy were α-Al, primary Si and β-Al(FeNb)Si phases, while the four-phase region of the alloy after Ni addition were α-Al, primary Si, δ-Al(FeNiNb)Si and β-Al(FeNiNb)Si phases. The highest hardness of 114 Hv was obtained for the Al-Si-Fe-Nb-Ni alloy which is relatively higher than that of Al-Si-Fe-Nb alloy (101 Hv).***

Keywords: Conventional cast; Al-alloy; microstructure; Intermetallic compounds

1. Introduction

Due to the increasing demand to diminish the weight of automobiles for better fuel efficiency, there has been much research interest in the use of aluminium,magnesium and Titanium alloys for various structural components [1,2]. The density of aluminium is 2.7g/cm³ which is nearly one-third as lower than steel 7.83 g/cm³, means that 170 lb for a foot cubec of aluminium. Such a weight coupled with accepted strength of some aluminium alloys, grants construction and design of light weight and strong structure that are essentially beneficial for moved objects (aircrafts, space vehicles as well as some types of land and water borne vehicles[3,4]. Aluminium in the real juncture is very soft for such utilisations and have a weak tensile strength, so it is easily to form alloys by pure aluminium with some elements such as manganese, magnesium,zinc, silicon and copper[5,6].According to outstanding mechanical properties of aluminium alloys such as machinability, durability, low density and high strength which are crucial in manufacturing industries, as well availability and lower cost as compared to the other contended materials, over the past decades aluminium alloys have received a considerable attention [5]. The main issues are meeting with the engine and block designers the failure of used materials due to the surface contacts among machine components that resulted in wear and scratching, which is attributed to a certain factors (i) the impact of hot air and gases has considerable influence on erosive wear, (ii) corrosive wear is even affected by hard phase particles, cooling and lubrication used, (iii) adhesion produced by the friction between piston rings and block cylinder wall. In addition to fatigue behaviour of used materials [7,8]. In deference to the above mentionedproblems, the many investigations are persuaded to develop aluminium alloys to avoid pointed out issues. Therefore, the development are functionally based on many ways, some selected the addition of some alloying ingredients in metal (Solid-Solution Strengthening), others utilized Cold Work Hardening (Rolling, Forging, Extrusion and Drawing), even heat treatment (Quenching, Annealing, Tempering andPrecipitation Hardening) is used by others [9]. Aluminum- silicon alloys are the mostly used materials in manufacturing the automobile components according to their outstanding wear resistance, superior cast-ability andagreedmechanical properties particularly those of hypereutectic alloys [10,11,12,13]. Generally the most modifier element for Al-Si alloy is iron which is considered to be an effective impurity with contents under accepted limitation [3]. Fe-bearing intermetallic compounds play an important role in estimating the mechanical properties of alloys, the plate-like shape Fe-bearing intermetallic such as δ-Al_4FeSi_2 and β-Al_5FeSi are very brittle and hard represent potential spots for crack initiation, these plates can also impede the flow of dendritic liquid during feeding which resulted in the formation of pores and shrinkage [3,14].Regrettably, with the conventional casting processes coarse plate Fe-containing intermetallic compounds like β-Al_5FeSi are produced which in turn resulted in poor mechanical properties [12]. In consideration to the importance of Fe-bearing intermetallic compounds on the structure and mechanical properties of Aluminum-Silicon-iron alloys, this attracted many studies in the recent decades. Mohamed [14] has experimentally investigated the conventional-cast Aluminum-Silicon nearer eutectic alloy as function of Fe, Mn, Cu and Mg elements addition, it is revealed that the volume fractions of Fe-bearing intermetallic increases as manganese or iron contents increase results in reduction of tensile properties, while Cu-containing slightly affected on tensile strength at high amounts of Cu and Mg. Gu[12] used the rheo-die-casting of semi-solid in studyingthe microstructure changes of Fe-bearing intermetallic compounds of Al-20.0Si-2.0Fe-2.0Cu-0.4Mg-1.0Ni-0.5Mn(mass fraction%) results depicted that the formation of needle-like β-$Al_5(Fe,Mn)Si$ phase was supressed by DUV treatment, and the existed Fe-bearing intermetallic compounds are the fine forms of δ-$Al_4(Fe,Mn)Si_2$ particles. Zhong[15] investigated the influence of ultrasonic vibration (USV) and the Mn addition on the microstructure of Fe-bearing intermetallic compounds in Al-20.0Si-2.0Fe-2.0Cu-0.4Mg-1.0Ni alloy, results exhibited that homogeneous temperature field and solute distribution of the melt,as well as restraining the formation of acicular β-phase with obtaining fine δ-particles in the matrix of Fe-bearing alloy. In consideration to the above mentioned discussion, this study sheds a light on the influence of Ni addition on the microstructure (morphology) and mechanical properties of the conventional cast Al-20Si-9Fe-1.2Nb (at wt%)alloy.

2. Experimental

Alloys Al-Si-Fe-Nb and Al-Si-Fe-2Nb-Ni with nominal compositions as given in Table (1) (at wt%), are prepared as follow, bulk ingots of suitable compositions are produced by Induction Furnace, the mixture of high purity elements (Al, 99.99%; Nb, 99.99%; Fe, 99.99%; Si, 99.99%; Ni,99.99%) are prepared and melted in graphite crucible many times to ensure chemical homogeneity. Some additive materials melted prior to alloy melting to react with residual oxygen and nitrogen in the chamber. In this study conventional casts Al-Si-Fe-Nb and Al-Si-Fe-Nb-Ni alloys are denoted as AlCC1 and AlCC2 respectively. The microstructure of the conventional casts wasgraphically characterized by optical microscopy (OM, Leica).In order to view a metal specimen under an optical microscope samples of mentioned compositions were embedded in epoxy resin then using polishing machine samples were polished using finer and finer grits as well as polishing slurry, and finally samples were etched using Keller's reagent (2 ml HF+3 ml HCI+5 ml HNO_3+190 ml H_2O, special for aluminium alloys) in order to perfectly flat and scratch samples free when viewed with the aid of a microscope devices. The mechanical properties of the samples were measured using Vickers micro-hardness testing machine with applied load Hv 200gf and holding time 16s at different points for every sample. Where the all mentioned work and tests were prepared in the laboratories of Kastamonu University.

Table 1: Chemical composition of Al alloys investigated (wt.%).

Samples	Al	Si	Fe	Nb	Ni
AlCC1	69.8	20	9	1.2	-
AlCC2	63.8	20	9	1.2	6

3. Results and Discussion

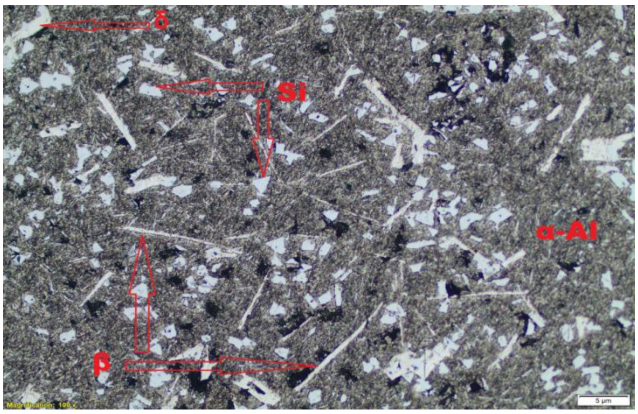

Figure 1: Optical microscopy micrographs of AlCC1 (Al-Si-Fe-Nb)

Fig.1 displays the typical microstructure of the AlCC1 sample formed by conventional casting process, based on the morphology of the phases as seen through an optical microscope, four phases can berecognized (i) composed of primary Si (grey) particles with a size of about (1.0 µm x 1.0 µm to 2.0µm x 2.0µm),(ii) fibrous eutectic Al-Si, (iii) different white needle-like or fine blocks Fe-bearing intermetallic. Due to the limited solubility of transition metals in molten aluminium, approximately all the added iron and niobium to Al-Si alloy tended to form intermetallic compounds [7]. Then referred to to the previous investigation[3,15] the white long acicular (with the dimension of about 0.5µm width x 10.0µm long) phase is β-Al_5(Fe,Nb)Si, while some fine white blocks (with a size ~2.0µm x 3.0µm) are belonging to δ-Al_4(Fe,Nb)Si_2 phase. However, the solidification process in this casefollowed this peritectic chain L+ δ-Al_4FeSi_2 → β-Al_5FeSi [12], it can be noticed that from Fig.1 the majority of metastable δ-phase which was formed at higher temperature transformed into a harmful acicular β-phase.

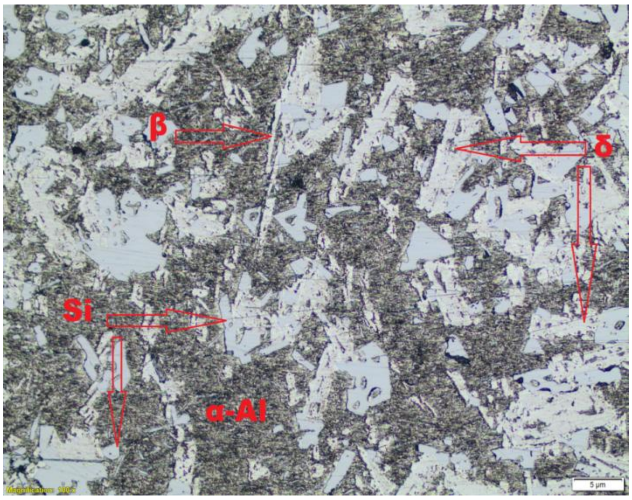

Figure 2: Optical microscopy micrographs of AlCC2 (Al-Si-Fe-Nb-Ni)

The addition of Ni appeared in a remarkable variation in the morphology of intermetallic compounds as shown in Fig.2, in comparison with Fig,1. One can notice that the phase constitution of AlCC2 alloy is same as that of AlCC1 alloy but with different quantities and dimensions of phases. As given in Fig. 2 the main four phases are (i) primary Si (grey) particles with size of about (1.0µm x 1.0µm to 4.0µm x 5.0µm) which is much bigger than those of AlCC1 alloy as seen in Fig.1, (ii) fibrous eutectic Al-Si(dark grey), (iii) both of intermetallic compounds δ-Al_4(Fe,Ni,Nb)Si_2 (in the shape of white coarse blocks and needle-like) and β-Al_5(Fe,Ni,Nb)Si (in the shape of thin long needle-like) coexisted in the microstructure[124.125]. It can be seen the rarity of β-Al_5(Fe,Ni,Nb)Si from Fig.2 after the addition of Niin compare with those of Fig.1, while δ-Al_4(Fe,Ni,Nb)Si_2 is dominant in AlCC2 alloy which reflects the effect of Ni addition in the morphology of conventional cast Al-Si-Fe-Nb-Ni alloy.

It is clear that the Fe-bearing intermetallic play an important role in improving the hardness and wear resistance of alloys. Therefore, the acicular Fe-bearing β-phase reducing the wear resistance and hardness of the alloy (inferior mechanical properties), vice versa the mechanical properties are improved with a refined δ-phase [3,12], the measured hardness of conventional cast AlCC1 alloy is 101 Hv , and after Ni addition is increased to reach 114 Hv in AlCC2 alloy.

4. Conclusion

1) The size morphology of primary Si particles is relatively coarsened after Ni addition.
2) The intermetallic compounds of Al-20Si-9Fe-1.2Nb alloy are mainly long needle-like β-Al_5(Fe,Nb)Si and small amounts of δ-Al_4(Fe,Nb)Si_2 plates. Fe-bearing intermetallic of Al-20Si-9Fe-1.2Nb-6Ni alloy are small amount of acicular β-Al_5(Fe,Ni,Nb)Si and considerable amount of coarse plate δ-Al_4(FE,Ni,Nb)Si_2.
3) The hardness of alloy is improved by Ni addition; it is relatively increased from 101Hv in Al-20Si-9Fe-1.2Nb alloyto 114Hv in Al-20Si-9Fe-1.2Nb-6Ni alloy.

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