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 synthesized 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-AlFeNiNbSi 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/cm², means that 170 lb for a foot cube 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 mentioned problems, 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 and Precipitation 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 andagreement mechanical 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-AlFeSi₃ and β-AlFeSi 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-AlFeSi 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 Aluminium-Silicon-iron alloys, this attracted many studies in the recent decades. Mohamed [14] has experimentally investigated the conventional-cast Aluminium-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 studythe 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(Fe,Mn)Si phase was suppressed by DUV treatment, and the existed Fe-bearing intermetallic compounds are the fine forms of δ-Al(Fe,Mn)Si₃ 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 (Al, 99.99%; Nb, 99.99%; Fe, 99.99%; Si, 99.99%; Ni, 99.99%) are prepared and melted in graphite crucible. In order to perfectly flat and scratch samples free when etched (HCl+5 ml HNO₃+190 ml H₂O, special for aluminium alloys) samples were etched. Where the conventional casts Al-Si-Fe-Nb and Al-Si-Fe-2Nb-Ni alloys are denoted as AlCC1 and AlCC2 respectively. The microstructure of the conventional casts was graphically 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 HCl+5 ml HNO₃+190 ml H₂O, 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.%).

<table>
<thead>
<tr>
<th>Samples</th>
<th>Al</th>
<th>Si</th>
<th>Fe</th>
<th>Nb</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlCC1</td>
<td>69.8</td>
<td>20</td>
<td>9</td>
<td>1.2</td>
<td>-</td>
</tr>
<tr>
<td>AlCC2</td>
<td>63.8</td>
<td>20</td>
<td>9</td>
<td>1.2</td>
<td>6</td>
</tr>
</tbody>
</table>

3. Results and Discussion

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 (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]. Therefore, the acicular δ-phase which was formed at higher temperature transformed into a harmful acicular β-phase.

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

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

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-Al₅(Fe,Nb)Si and small amounts of δ-Al₅(Fe,Nb)Si₂ plates. Fe-bearing intermetallic of Al-20Si-9Fe-1.2Nb-6Ni alloy are small amount of acicular β-Al₅(Fe,Ni,Nb)Si and considerable amount of coarse plate δ-Al₅(FE,Ni,Nb)Si₂.

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.

5. Acknowledgment

The authors would like to thank the University of Kastamonu / department of Engineering and Material science, for supporting this work

References


