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Morphology and Static Micro-indentation of melt-spun Al-Si-Fe-X (X= Nb, B) alloys by the addition of Ni

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ABSTRACT:*The effect of 6 wt.% Ni addition on the morphology and static micro-hardness of Al-20Si-9Fe-1.2Nb and Al-20Si-9Fe-1.2B (at wt. %) alloy ribbons was investigated in the present study. Alloys with mentioned nominal compositions were prepared by conventional casting and further processed melt-spinning technique. The resulting ribbons of studied alloys were characterized using scanning electron microscopy (SEM) together linked with energy dispersive spectroscopy (EDS) in order to analyse the morphology and chemical composition of samples, while the hardness was synthesized utilizing Vickers microhardness test device. Results exhibited that with Ni addition Si solubility in α-Al matrix was increased in both studied melt-spun Al-alloys. Furthermore , the mechanical properties of both investigated melt-spun alloys has been improved by 6 wt. % Ni addition.*

KEYWORDS: *Rapid solidification, Al-Si alloy, morphology, microhardness*

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I. INTRODUCTION

The advantages; good resistance of corrosion, low density and elevated specific strength at room temperature of aluminum alloys are well known. Therefore, different kinds of aluminum-based alloys were developed by utilizing various strengthening mechanisms such as (1) precipitation strengthening, (2) work hardening, (3) strengthening by refinement of grain size , (4) solid solution strengthening, (5) fiber refinement and (6) dispersion strengthening [1,2]. However, the utilizing of conventional strengthening alloys lead to a relatively low tensile strength at room temperature of about 500 to 600 MPa, thus in order to evolve alternative type of aluminum alloys with much higher tensile strength was crucial. Depending on the composition and technique, melts of metal alloys can be rapidly solidified (at rate of about 10^6 k/sec) to rigid condition avoiding crystallization in order to perform (amorphous) metallic glass with high tensile strength exceeding 1200MPa[3,4]. Rapid Solidification Process (RPS) of materials was first conducted in California Institute of Technology (1959-1960) by Duwez[5,6,7]. Generally these high solidification rates can be essentially obtained by (i) Droplet methods; in which the molten metal is atomized into tiny droplets that allowed to be solidified either impinging a cold air or an inert gas (atomization solidification), (ii) Jet methods; in which the stream of molten metal is continuously impinging a rotating chill wheel to be thrown in the shape of ribbons (melt-spinning technique), (iii) Surface melting technology; the process in which the rapid melting on the surface of bulk alloy proceeded to high solidification rate to be extracted into un melted block (laser surface treatment) [8,9,10,11]. Aluminum-based amorphous alloys in particular have been paid great attention within the last decades [12], the obtained aluminum amorphous alloy by melt-spinning process can be mainly partitioned into two groups (metal-metal and metal-metalloid systems). The most important systems among these Al-based amorphous alloys are, (i) Al-EM-LM (EM; early transition metal such as Nb, Zr, Hf, Mo,Ti, V, Cr and Ta. LM; late transition metals containing Ni, Fe, Cu or Co), (ii) Al-R (R; rare earth metals such as Pr, Ce, Sm, Nd, Y, Gd, Er, Ho, Tb and La), (iii) Al-R-M (M; transition metals include EM and LM)[8,12,13,14,15]. Rapidly solidified Al-Si alloys have recently obtained a remarkable attention due to their excellent mechanical and anti-corrosion properties, numerous efforts have been devoted to study hese (RS) Al-Si alloys in order to achieve the optimum mechanical properties to be consequently persuaded to manufacturing sectors [16,17]. Zupanic[18] investigated the microstructure of Al-3Mn-5Be and Al-6Mn-5Be ribbons, with changing of Mn amounts it is observed that the smallest size of particles and the highest particle density ribbons were obtained with higher Mn amounts which resulted in higher microhardness (290 HV). In the same way Kilicaslan [19] motivated his research in analysing the microhardness and microstructure of Al-25Si-5Fe-XCo (X=0,1,3,5 at wt.%) ribbons, it is concluded that Si particles had been refined by Co addition, the microhardness had a remarkable improvement by Co addition as well. Hong [20] investigated the mechanical and microstructure properties of rapidly solidified Al-20Si-5Fe alloys by addition of Cr and Zr, results displayed that different size of β and Si particles were homogeneously distributed through Al matrix, obtained tensile strengths were 380 MPa with Cr addition and 390 MPa with Zr, with no significant wear resistance was observed after Cr and Zr additions. Rajabi [21] had studied mechanical and microstructure properties of Al-20Si-5Fe-2X(X=Cu, Ni, Cr wt.%) ribbons, results exhibited that the microstructure shows dendritic and featureless zones with ultra-fine Fe-intermetallic. The strength was improved with the added elements while among the added alloying elements the maximum stress was achieved with nickel addition.

In the context of the above mentioned researches, the melt-spun Al-20Si-9Fe-1.2Nb, Al-20Si-9Fe-1.2Nb-Ni, Al-20Si-9Fe-1.2B and Al-20Si9Fe-1.2B-Ni alloys were prepared using melt-spinning technique, resulted ribbons were synthesized and analyzed in order to study the effect of Ni addition on the morphology and microhardness of mentioned alloys

II. MATERIAL AND METHODS

Mixture of high purity elements (Al, 99.99%; Nb, 99.99%;B, 99.99 %; Fe, 99.99%; Si, 99.99%; Ni,99.99%) was used in production of Alloys Al-Si-Fe-Nb, Al-Si-Fe-Nb-Ni, Al-Si-Fe-B and Al-Si-Fe-B-Ni with nominal composition as given in Table1. Ingots of mentioned alloys were firstly produced by traditional conventional casting using induction furnace. Consequently, resulted ingots were sliced in small pieces to be used in the melt-spinning machine, thus ingots of mentioned alloys were melted and through 2mm nozzle pressurized onto the moving brass wheel (with a diameter 250mm, and a circumferential speed of about 20 m/s). The thrown molten material onto the cylindrical surface of the wheel separated in the shape of ribbons (ribbons with dimensions of about 1-10 mm in width, and 10-30 μm thickness) as the wheel rotating. In order to analyse the studied alloys, ribbon samples were embedded separately in epoxy resins to be handled during polishing and etching processes. Keller’s reagent (2 ml HF+3 ml HCI+5 ml HNO_3 +190 ml H_2O, special for aluminium alloys) was used in etching which is crucial for the sample to be viewed with the aid of microscope devices. The morphology of resulted ribbons had been characterized by scanning electron microscopy (SEM) together linked with EDS energy dispersive spectroscopy (SEM, FEI, Model: Quanta FEG 250), while the static micro-indentation analyses obtained by Vickers microhardness device (with applied load Hv 200gf and holding time 16s at different points at the surface of every sample). Melt-spun Al-Si-Fe-Nb, Al-Si-Fe-Nb-Ni, Al-Si-Fe-B and Al-Si-Fe-B-Ni alloys are denoted as AlMS1, AlMS2, AlMS3 and AlMS4 respectively, in the present study. All the above mentioned experimental works and tests were prepared in the laboratories of Kastamonu University.

Table 1: Chemical composition of studied melt-spun Al- alloys (at wt. %).

Alloy	Al	Si	Fe	Nb	B	Ni
AlMS1	bal	20	9	1.2	-	-
AlMS2	bal	20	9	1.2	-	6
AlMS3	bal	20	9	-	1.2	-
AlMS4	bal	20	9	-	1.2	6

III. RESULTSAND DISCUSSION

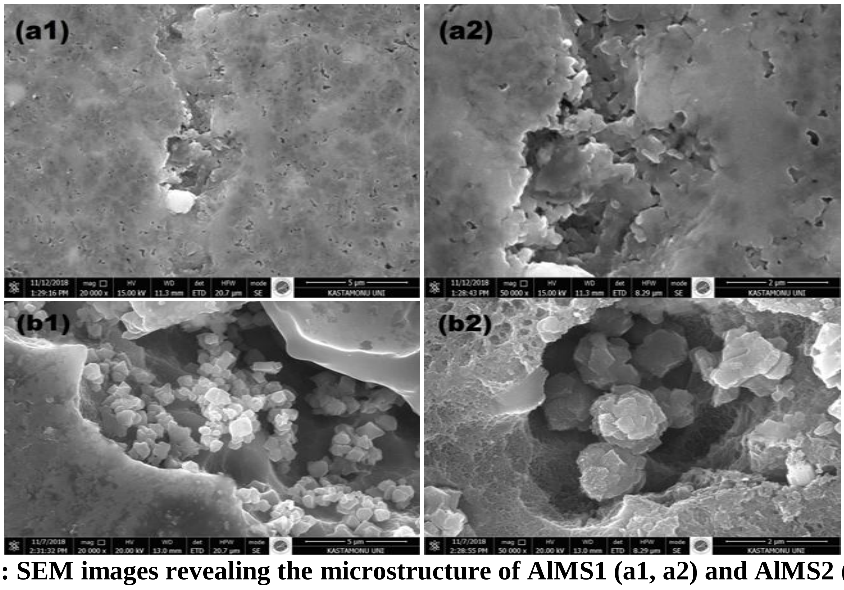

Figure 1: SEM images revealing the microstructure of AlMS1 (a1, a2) and AlMS2 (b1, b2).

Fig. 1(a, b) shows the scanning electron microscopy images of samples AlMS1 and AlMS2, the thickness of AlMS1 and AlMS2 ribbons are 15-20 and 20-28 μm, respectively. The melt-spun AlMS1 alloy was revealed as a very fine polygonal structure which is mainly composed of the α-Al phase (light gray phase) and intermetallic δ-Al_4 (FeNb)Si_2 and Si phases (dark grey phase) which can be confirmed by EDS scan results as seen in Fig.2(a) and it can even show that the structure is partially amorphous . Since the hypereutectic alloys allowing a passage to dendritic zones [22], these cellular and dendrites are in size ranged from 2μm to 5μm, while dendrite arms average diameters approximately (200 nm – 2 μm). Hence, the solid solubility of α-Al is extended because of rapid solidification process[23].

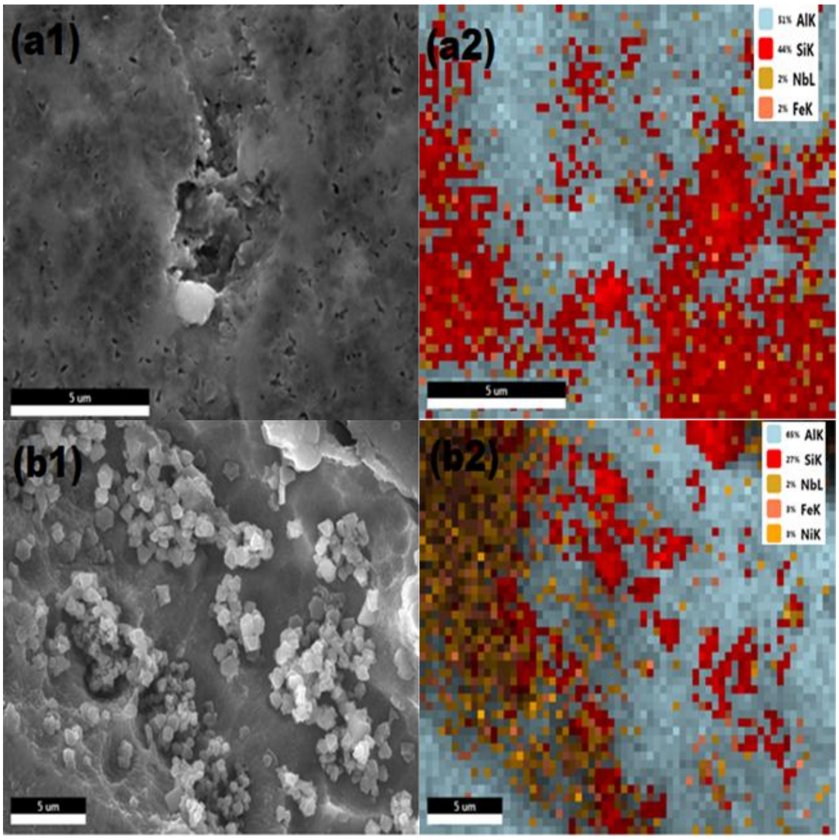

Figure 2: EDS maps of melt-spun AlMS1 (a1.a2) and AlMS2 (b1, b2) ribbons.

From Fig.1(b1,b2) it is observed that the morphology of structure is dendritic, which has an average arm space of about. 100 ± 20 nm. Nano-crystalline particles scattered in these colonies with different quantities and dimensions, size range of spheroid particles from 50 nm to 1 μm, these particles related to δ-Al_4 (FeNiNb)Si_2 and primary Si Particles and it is difficult to distinguish them from each other. Therefore, it is known that such changes play an important role in improving mechanical properties [24,25]. As given in Fig.2(b1,b2) the microstructure is partially crystalline which can be noticed though the nano-metric precipitations of contained phases furthermore with the addition of Ni the solubility of Si in Al matrix was increased [26] .

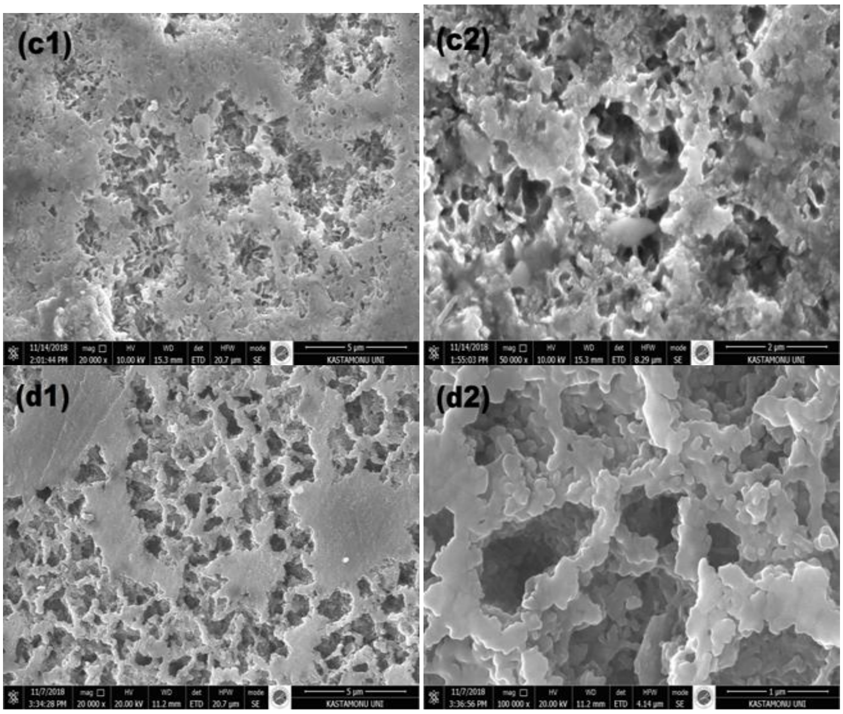

Figure 3: SEM images revealing the microstructure of AlMS3 (c1, c2) and AlMS2 (d1, d2).

It is clear from Fig.3(c1,c2) the dendritic morphology of AlMS3 ribbons revealed as spongy microstructure, dendrite arm spacing of several areas was about 0.5μm ± 0.2 including non-homogeneously distributed particles of Si and δ-Al_4 (FeB)Si_2 phases. According to EDS results given in Fig.4(c1,c2) the microstructure appeared to be partially amorphous in presence of un-soluble particles of primary Si. Whereas, It can be noticed that dendritic solidifications were the dominants and semi-cellular structure for AlMS4 ribbons as shown in Fig.3(d1,d2), means that the rich phase primary aluminium in Al-Si-Fe system of this alloy grew dendritically. The average dendrite arm spacing measured from the micrograph is about 0.2μm which is twice lower than that of melt-spun AlMS3 ribbons. It can also confirmed that from Fig.4 (d1, d2) with the Ni addition the resulted ribbons of AlMS4 are fully amorphous.

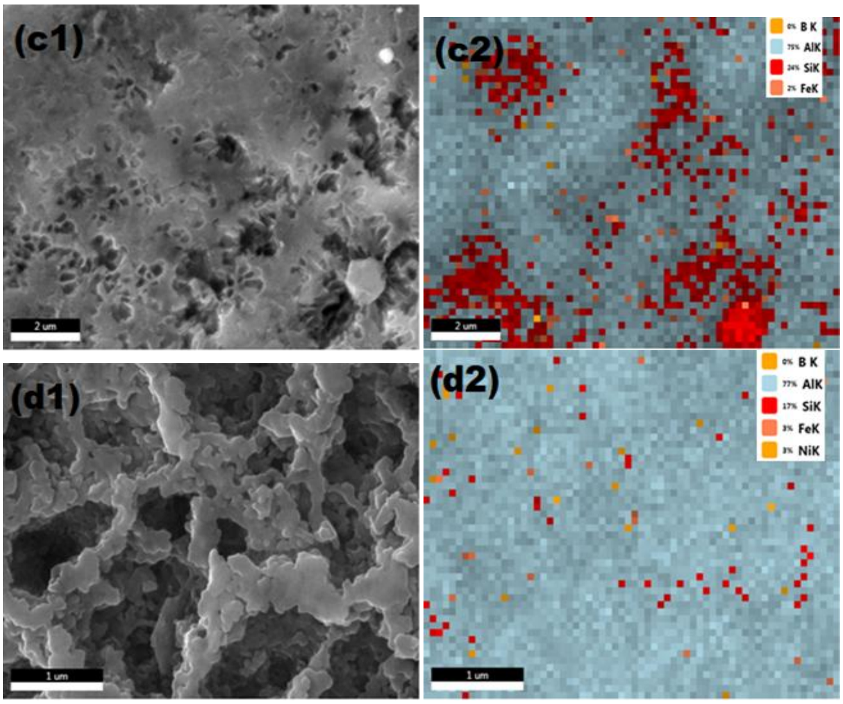

Figure 2: EDS maps of melt-spun AlMS3 (c1.c2) and AlMS4 (d1, d2) ribbons.

Fig.5 displays the changes in Vickers microhardness values of the investigated ribbons due to the effect of Ni addition. It is clear that addition of Ni resulted in a slight increment in (Al-Si-Fe-Nb) AlMS1[20], in contrast it had a drastic increment in case of (A-Si-Fe-B) AlMS3[21]. The obtained Vickers microhardness values of AlMS1, AlMS2,AlMS3 and AlMS4 are 206.6, 211.6, 215 and 272.2 respectively.

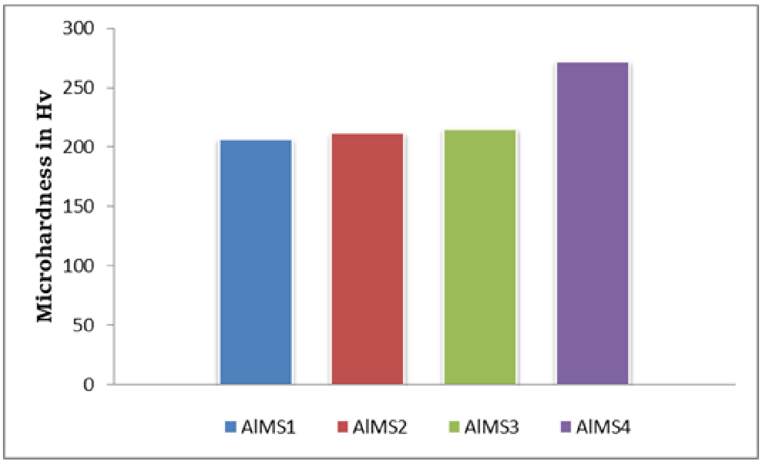

Figure 5: Changes in the static microhardness (Hv) values of melt-spun AlMS1, AlMS2, AlMS3 and AlMS4 ribbons.

IV. CONCLUSION

The Al-Si-Fe-Nb, Al-Si-Fe-Nb-Ni, Al-Si-Fe-B and Al-Si-Fe-B-Ni alloys were rapidly solidified using Melt-spinning technique, resulted ribbons analysed in order to investigate the effect of Ni addition and it is concluded that;

- Ni addition was observed to increase Si solubility in α-Al matrix in both studied melt-spun Al-alloys.
- The obtained ribbons of Al-Si-Fe-Nb alloy after and before Ni addition were partially amorphous, while the fully amorphous Al-Si-Fe-B-Ni ribbons obtained by addition of Ni to the partially amorphous Al-Si-Fe-B ribbons.
- The Vickers microhardness has a slight increment from 206.6 Hv in Al-Si-Fe-Nb ribbons to 211.6 Hvin Al-Si-Fe-Nb-Ni ribbons, while it is drastically increased from 215 Hv in Al-Si-Fe-B ribbons to 272.2 Hv in Al-Si-Fe-B-Ni ribbons.

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