International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161
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Research Article

Rapidly Solidified of Hyper Eutectic Aluminum - Silicon Alloys Ribbons by Using Melt-Spinning Techniques

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Accepted 01 May 2014, Available online 01 June 2014, **Vol.4, No.3 (June 2014)**

Abstract

The Al-Si alloys used in this investigation was prepared at the University of Kufa in the Metallurgy Laboratory. Heyper eutectic Al-Si alloys with compositions 15, 17, 19 wt% Si was quenched from the liquid state by using melt-spinning techniques. The as cast alloys and resulting ribbons were characterized using optical microscopy, scanning electron microscopy(SEM),X-ray diffraction (XRD) analysis, microhardness techniques and compared with their ingot alloys.Effects of chemical composition and quenching conditions on the variation in the microstructure were examined. Microstructural examinations revealed that microstructures of the melt-spun ribbons were very fine compared to their ingot alloys. The results microhardness value of the ribbons melt-spun alloy was measured as 82-200 kg/mm^2. The microhardness of as cast ingot and rapidly solidified ribbons approximately twice higher than those of original ingot alloy.

Keywords: *Melt-Spinning, Rapid Solidification AL-Si Alloys, Ribbons , Hardness*

1. Introduction

Improving the technological and operational properties of Al-Si alloys requires finishing the primary silicon and the eutectic separations. It is well known that grain size distribution and morphologies of primary silicon in hypereutectic Al-Si play an important role in determining their mechanical properties. The coarse separations of primary silicon have an unfavorable effect both on machinability and processing properties. Conventional ingot metallurgy yields a polygonal, starshaped and coarse plated primary silicon phase that limits the further improvement of the properties of hypereutectic Al-Si alloys. The reduction in size of primary silicon separations can be achieved metallurgically, by introducing new elements, as well as by intensifying the cooling rate(*B.Varga et al*,2009).

Cooling rate has a significant effect on solidifying microstructure of Al-Si alloys ,it has been shown that the morphology of eutectic silicon changes from plates to fibers when the cooling rates is increased(Jun Jia *et al*,1999).The modification of the eutectic Si in hypoeutectic Al–Si alloys is normally achieved in two different ways: by addition of certain modified elements (chemical modification) or by rapid solidification (quench modification), although ultrasonic vibration and electromagnetic field were also reported to refine the eutectic Si (Schumacher *et al*, 2012, Rafiei Jia *et al*).

Melt spinning of Al–Si-based alloys leads to fine Si particles formed directly from the liquid during solidification. The precipitation of Si from supersaturated solid solution in the α-Al matrix during subsequent cooling was also greatly enhanced in melt spun Al-Si-based alloys. The finer microstructure and the enhanced hardening effects produce better mechanical properties. The improvement in mechanical properties of the melt spun ribbon can be attributed to the supersaturated solid solution and structural refinement. However, the hardness values decreased greatly during ageing at higher temperatures. The decrease in properties after thermal ageing can be attributed to Si precipitation and the subsequent growth or ripening of the Si precipitates (J.H. Lia *et al,2012)*.

The most interesting potentialities of the rapid solidification techniques lie in their capability to produce metallic glasses or amorphous alloys (Tarek EL-Ashram ,2004) . Rapidly solidified alloys can be produced by various methods. The most applicable in industrial environment are production of metal powder by atomization and production of thin ribbons by melt spinning on a rotating wheel (M. Suler *et al*). The chill block melt spinning technique is a convenient method to study the potential of rapid solidification where little amounts of alloy are prepared and converted to metallic ribbons under a controlled atmosphere with cooling rates of about 10^6 K/s(R. A. Rodríguez *et al,2009*).Melt-spinning processes can be used to cast amorphous metallic glass ribbons or thin metal strips with fine microstructure and properties with cooling rates of 10^3-10^6 K/s , this is a rapid solidification process(Aravind Sundararajan *et al,2008*). With rapid solidification techniques higher solubility of alloyed elements in solid solutions can be

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achieved, what is especially important with a production of alloys with elements that have a small solubility in equilibrium state (R. A. Rodríguez *et al,2009*).

The rapid extraction of thermal energy during the transition from the liquid state to solid state in rapid solidification processing (RSP) yields a manufactured material of extraordinary and unique properties, i.e. reduction in grain sizes, increased solid solubility of alloying elements, reduced levels of segregation, and in some cases the formation of metastable crystalline and amorphous phases. In practice, rapid quenching of aluminum alloys by melt-spinning at cooling rates exceeding 10^6 K/s results in ribbons with superior mechanical and thermal properties compared to their conventionally processed counterparts. In the last two decades, research investigations on the rapidly solidified Al alloys have been focused mainly on their applications in aerospace industries. An important exception is the automotive industry in which melt-spun Al-Si alloys exhibiting excellent wear resistance, high strength and elevated temperature strength compared to conventional alloys are utilized (M. Lutfi Ovecoglu *et al*, 2003)**.**

The effect of rapid solidification vary widely from system to system, the major effects are: **(a)** decreased in grain size, **(b)** increased in chemical homogeneity, **(c)** extension of solid solubility limits, **(d)** creation of metastable crystalline phases, and **(v)** formation of metallic glasses (Uzun *et al*, 2001)**.**

Rapid solidification is a very good method to produce nanocrystalline alloys. Nanocrystalline Al-based alloys containing silicon (Si), rare earth metal (RE) and late transition metal (Ni) combine high tensile strength and good wear resistance. Usually, those alloys have nanocrystals embedded in amorphous matrix with average size about 10-30 nm (Grzegorz Cieslak *et al*, 2008)**.** Nanocrystalline materials are characterized by grain sizes in the range of a few nanometers and a high density of grain boundaries (about 10^{-8} m^{-1}). The finite crystal size, as well as the structure and the properties of the grain boundaries, strongly affect the properties of such materials (A. A. Ebnalwaled *et al*, 2011)**.**

The aim of this study is to characterize the microstructure in the melt-spun hypereutectic AL-15-17-19%Si alloys. Optical microscopy was used to study as cast alloys and the ribbons were examined by scanning electron microscopy (SEM) technique, X-ray diffraction using Cu Ka radiation, were carried out on three alloys. The microhardness values of the as cast alloys and ribbons were also measured. The ribbons microstructure of the alloys was compared with those of the microstructure of the ingot.

2. Experimental Procedure

The experimental Al-Si alloys used in this investigation was prepared at the University of Kufa in the Metallurgy Laboratory/Department of materials engineering. To prepare the alloys the chemically pure metals of aluminum and silicon were used. Three alloys with the chemical compositions (Al -15, 17 and 19 wt. %) Si was prepared by electric arc furnace in alumina crucible and the required amount of Silicon was added to the molten aluminum at 750 C° and then mixing the molten metal for few minute. The melt-spinning device is shown in figure1. It consists of two parts the melting system and the rotating disc made from copper. Molten aluminum-Si alloy is poured through the 3mm nozzle onto the rotating wheel. As the wheel moves, the metal solidifies and separation in the form of a solidified strip. Rapidly solidified ribbons were produced by free jet melt spinning in air by means of impinging a jet of molten alloys onto the cylindrical surface of a polished brass wheel with a diameter of 250mm rotating at 2800 rpm. To clean the rotating disc grinding paper was after each pass. The measuring of temperature for molten metal is performed using infrared radiation pyrometer before ejection was 550 C°. The temperature of the as-produced ribbons was 100 C°. The dimensions of ribbons were 3-5 mm in width, and 0.12- 0.3 mm thickness. Specimens can be mounted more quickly by using some thermosetting substance (Bakelite), a transparent thermoplastics material. These substances mould at about 100 C°, which is usually too low temperature to cause any structural change in the specimen.

In order to examine the microstructures of the alloy ingots and ribbons with optical and a scanning electron microscope (SEM), preparation of samples was necessary. In preparing of ingots a specimen for microscopical examination it is first necessary to produce in it a surface which appears perfectly flat and scratch free when viewed with the aid of a microscope. This involves first grinding the surface flat, and then polishing it to remove the marks left by grinding. The polishing process causes a very thin layer of amorphous metal to be burnished over the surface of the specimen, thus hiding the crystal structure. Also preparing of ribbons cross-sections were cut in the growth direction of the grains, i. e. parallel to the grain growth direction. In order to reveal its crystal structure as cast a specimen etching in a 0.5% HF solution for about15 s. This etching reagent dissolves the 'flowed' or amorphous layer of metal. The microstructures of experimental material were studied using an optical microscope and Scanning electron microscope. X-ray diffraction (XRD) analysis with Diffractometer system=XPERT-PRO with Cu–Kα radiation (λ = 1.54060Å) was carried out at room temperature (25C°).

Seven measurements of microhardness test were taken per sample from the longitudinal section of the melt-spun ribbon and the average microhardness was determined.

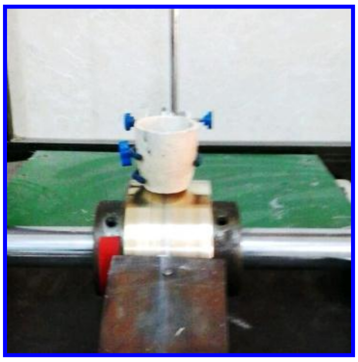

Figure 1: Melt Spinning Device.

3. Results and Discussion

3.1 Microstructure of as Cast Alloys and Spun Ribbons

The microstructure of the hypereutectic AlSi as cast alloys and the ribbons were investigated using light microscopy and scanning electron microscope respectively. The microstructure of as cast Al,(15-17-19) Si alloys is shown in Figure 2. It is obviously seen that the primary silicon is the pre-eutectic silicon formed in hypereutectic aluminum-silicon alloys. Primary silicon tends to assume different morphologies like massive crystals of geometric dendritic shape, blocky-type primary Si in the Al matrix.

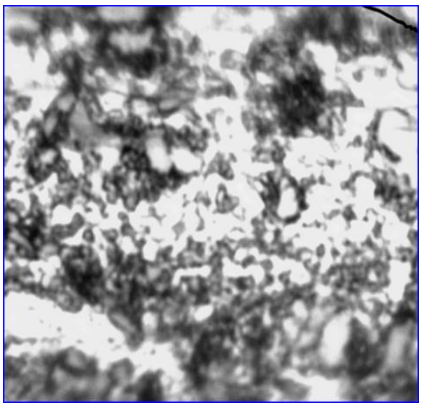

Figure 2: Optical Micrographs of Representative Eutectic Structure and Shape of Silicon in each Sample (a) Al-15Si Alloy (b) Al-17Si alloy (c) Al-19Si Alloy.

Microstructural investigations showed that the structure of melt spun ribbons was completely different from their conventionally cast alloys. The scanning electron micrograph of Al-15Si alloy is shown in figure 3.

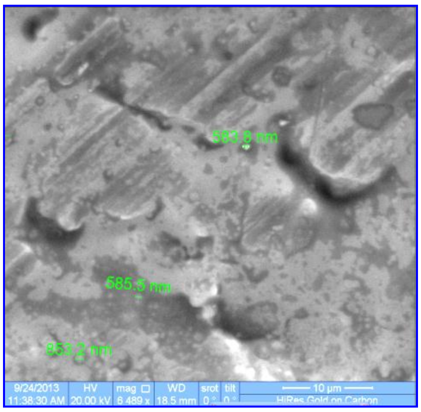

Figure 3: Electron Scanning Image of the Melt-Spun AL5Si Ribbons Revealing Nanosized Silicon Particles in the Al matrix

It is obviously seen that the microstructure melt-spun ribbon is completely composed of finely dispersed and dendrite Si phase. The morphology of primary silicon in the melt-spun ribbon were drastically changed to fine spherical-shape (maximum size of primary silicon is 853nm, minimum size of primary silicon is 583 nm and the smaller eutectic silicon can be obtained due to the rapid solidification. Figure 4 and figure 5 shows increasing silicon content up to 19% the morphology of primary silicon increase shape (maximum size of primary silicon is 728nm, minimum size of primary silicon is 653 nm.

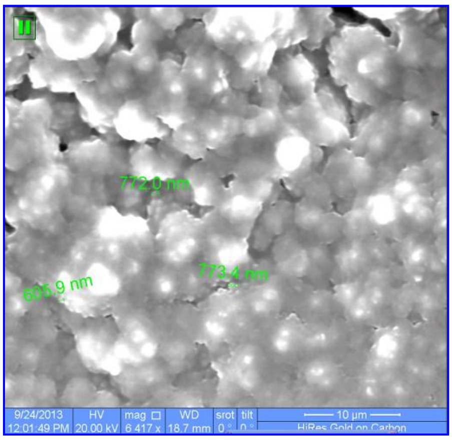

Figure 4: Electron Scanning Image of the Melt-Spun AL17Si Ribbons Revealing Nanosized Silicon Particles in the Al Matrix

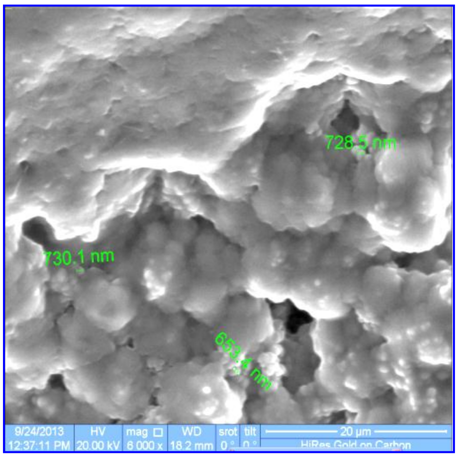

Figure 5: Electron Scanning Image of the Melt-Spun AL19Si Ribbon Revealing Nanosized Silicon Particles in the Al Matrix

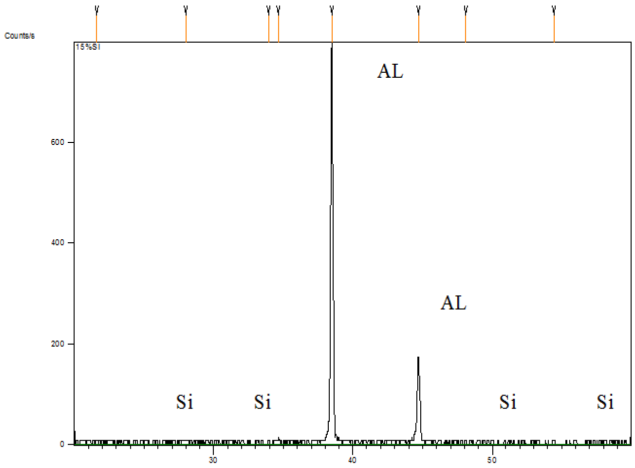

Figure 6: The XRD Patterns of as-Quenched Melt-SpunAl-15Si (in wt%) Alloy

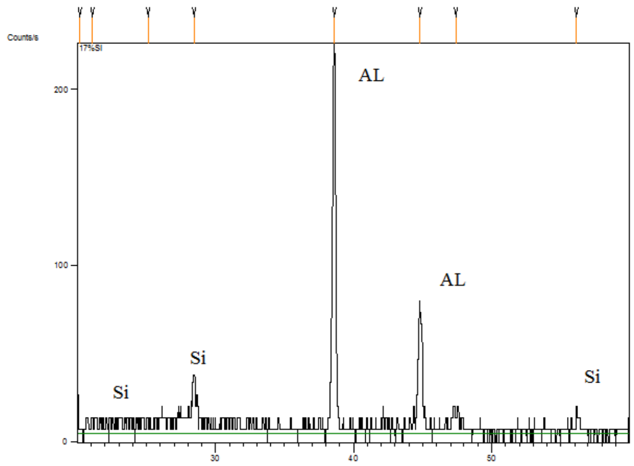

Figure 7: The XRD Patterns of as-Quenched Melt-SpunAl-17Si (in wt%) alloy

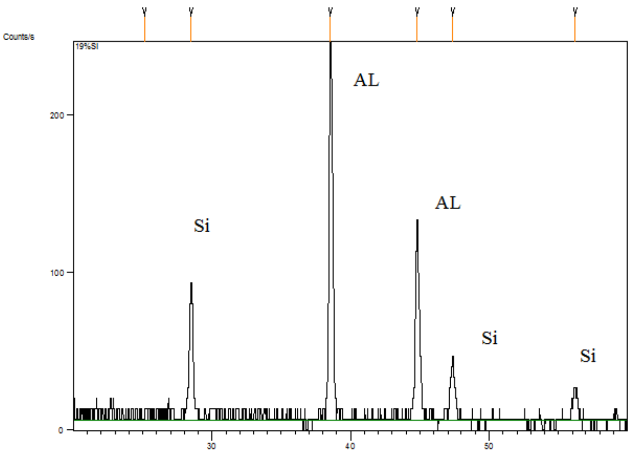

Figure 8: The XRD Patterns of as-Quenched Melt-SpunAl-19Si (in wt%) Alloy

The X-Ray diffraction patterns obtained for the as-quenched melt-spun AL-15Si, AL-17Si and AL-19Si alloys are illustrated in Figures 6,7 and 8. Figures show the pattern sharp peaks due to crystalline phases.

3.2 Microhardness

The microhardness of the solidified materials depends on the solidification parameters, such as cooling rate. In the present work, microhardness Vickers measurements were performed in digital microhardness tester TH-715. The microhardness of as cast ingot and rapidly solidified ribbons were measured. The applied load to determine the hardness was 2.942N; five measurements were performed on the longitudinal section of each ribbon.

The hardness of the alloys increased with increasing Si content; the values of hardness of 15, 17, 19% Si melt spun ribbon approximately twice higher than those of original ingot alloy. The particle size of rapidly solidified ribbons is much smaller in compared with the particle size of those as cast alloys. Therefore, increase in hardness values for melt spun alloys compared with their as cast can be attributed to supersaturated solid solution of α-Al, grain refinement and changes in microstructure occurred during the melt spinning process. The comparison of Vickers microhardness values of ribbons and ingot hardness of the three alloys in the as-cast ingot and melt spun ribbon conditions is presented in Table 1.

Table 1: Hardness Values for Melt-Spun Ribbon and as Cast Alloys

Si content %	**Microhardness(Hv)**	
	As cast	**Melt-spun ribbon**
15	**82**	**170**
17	**92**	**191**
19	**103**	**200**

Conclusions

1. The microstructures of the melt-spun ribbons were very fine compared to their ingot alloys.
2. The hardness of the as cast alloys increased with increasing Si content.
3. The microhardness of as cast ingot and rapidly solidified ribbons approximately twice higher than those of original ingot alloy.
4. The particle size of rapidly solidified ribbons is much smaller in compared with the particle size of those as cast alloys.

Acknowledgements

The author would like to express their appreciation to the University of Kufa/College of Engineering /Materials Engineering Department for its support of this work. The authors would like to thank all the technicians in the laboratories for their valuable help.

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