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EFFECT OF Cu ADDITION ON THE MICROSTRUCTURAL CONSTITUENTS AND MECHANICAL PROPERTIES OF TWIN ROLL CAST AlFeMnSi ALLOYS

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Abstract

In this study, the effect of copper addition on microstructural evolution, mechanical and corrosion properties of twin roll cast (TRC) AlFeMnSi alloy system mainly used in container foil applications was investigated. Microstructural characterization studies were conducted on as-cast, homogenization annealed and final products by employing optical and scanning electron microscopes. The mechanical properties of the samples obtained from compositional were determined at the thickness of final product by tensile and Erichsen tests. Addition of Cu improved mechanical properties and formability performance of the foil products with the contribution of final annealing parameters. Corrosion properties were also improved as compared to those of the AlFeMnSi alloys having lower Cu content.

Introduction

The twin-roll casting (TRC) process produces strips directly from the melt by combining casting and hot rolling into a single step. In TRC, molten metal is fed into the gap of two water-cooled rolls, where it solidifies. Thickness of the solidified sheet is decreased with limited amount reduction to attain required thickness to be achieved. This casting technique has numerous advantages, including relatively lower investment cost, lower energy consumption, lower operating cost, shorter lead time if managed properly compared with the conventional production route [1-2].

Strips produced by TRC have rapidly solidified surfaces due to the high cooling rate achieved through water-cooled rolls. In general metallurgical terms, TRC is expected to have refined microstructure, fine intermetallic particles and increased solid solubility which is advantageous for mechanical properties [3]. The size and distribution of intermetallic particles have fundamental role not only in the recrystallization kinetics of the alloy, but also in controlling its microstructure evolution during downstream processes [4-5]. From the corrosion perspective, intermetallic particles in aluminum alloys may be either anodic or cathodic in nature relative to the matrix by having electrochemical characteristics that differ from those of the surrounding alloy matrix [6].

Among the alloying elements, Cu is able to retain alloys strengthening characteristics to a great extent after annealing. When remaining in solid solution, copper acts as a solution strengthening element [7].

The aim of this study is to examine the influence of Cu addition on the microstructural evolution and mechanical properties of industrially twin-roll cast AlFeMnSi alloy.

Experimental Studies

8xxx series aluminium alloy was cast with three different Cu contents of 0, 0.17 and 0.25 wt. % by industrial scale twin roll caster. Table I. lists the chemical composition of the alloys used in this study. Homogenization anneal was applied at 500°C for 8h in a laboratory scale furnace. After homogenization anneal, strips were cold rolled to 0.1 mm by utilizing a laboratory scale roll. Soft annealing was performed at the final thickness at 280°C for 4h in laboratory scale furnace.

Table I. Chemical compositions of the alloys.

	Element, wt. %				
Alloy	Si	Fe	Cu	Mn	Ti
Cu free	0.16	1.43	0.03	0.63	0.01
0.17 wt. % Cu	0.15	1.44	0.17	0.63	0.01
0.25 wt. % Cu	0.15	1.42	0.25	0.62	0.01

Microstructural and mechanical characterization of the samples were conducted. Electrochemical behaviour of the samples were also determined with the help of electrolytic corrosion test. Microstructural characterization was carried out by optical and scanning electron microscope examinations. Optical and scanning electron microscope (SEM) examinations were conducted on the cross sections of the samples after preparing the samples according to standard metallographic methods. The microstructure of the samples were examined by using an SEM equipped with secondary electron (SE), back-scatter electron (BSE) and energy dispersive spectroscopy (EDS) detectors in order to determine the chemical compositions of intermetallic particles.

Mechanical properties of the samples were determined by hardness measurements, tensile and Erichsen tests. Hardness measurements were made on polished cross sections of samples utilizing a micro hardness tester with a Vickers indenter under an indentation load of 10 g.

Electrolytic corrosion tests were performed in 3.5 wt. % NaCl solution at room temperature utilizing a typical three electrode potentiodynamic polarization test unit comprising AgCl and platinium electrodes as reference and counter electrodes, respectively. Prior to corrosion tests, samples were slightly polished with 2400 grit sand paper and 24 mm circles were prepared. Samples were placed into a holder which provides a constant contact area between the samples and the solution. Electrolytic corrosion behaviour of samples was evaluated by in terms of open circuit potential (OCP). Open circuit potential measurements were conducted for 1h and recorded by a software at a frequency of 1Hz.

Results and Discussion

Typical cross sectional optical microscope and scanning electron microscope images of as-cast as well as homogenization annealed center plane microstructures (centreline segregation, CLS) of Cu free and 0.25 wt. % Cu added alloys were shown in Figures 1 and 2, respectively. As can be seen in the cross sectional images of etched samples, 0.25 wt. % Cu added alloy exhibits finer grain structure when compared to that of Cu free alloy in as-cast material. However, contrary to this observation, after homogenization anneal Cu free alloy possesses finer grain structure than that of 0.25 wt. % Cu added alloy. At the same time, it can be observed that 0.25 wt. % Cu added alloy retain the same grain structure as in the as-cast condition. It can be concluded that addition of Cu into 8xxx alloy suppresses the grain refinement during homogenization anneal and Cu free alloy develops much finer grains in the microstructure during homogenization anneal. On the other hand, as can be seen in the cross sectional images of the polished samples, the microstructural features at the center plane of the strip exhibit dense eutectic formations. Upon homogenization anneal, center lines segregations tend to dissolve and form needle like intermetallic particles.

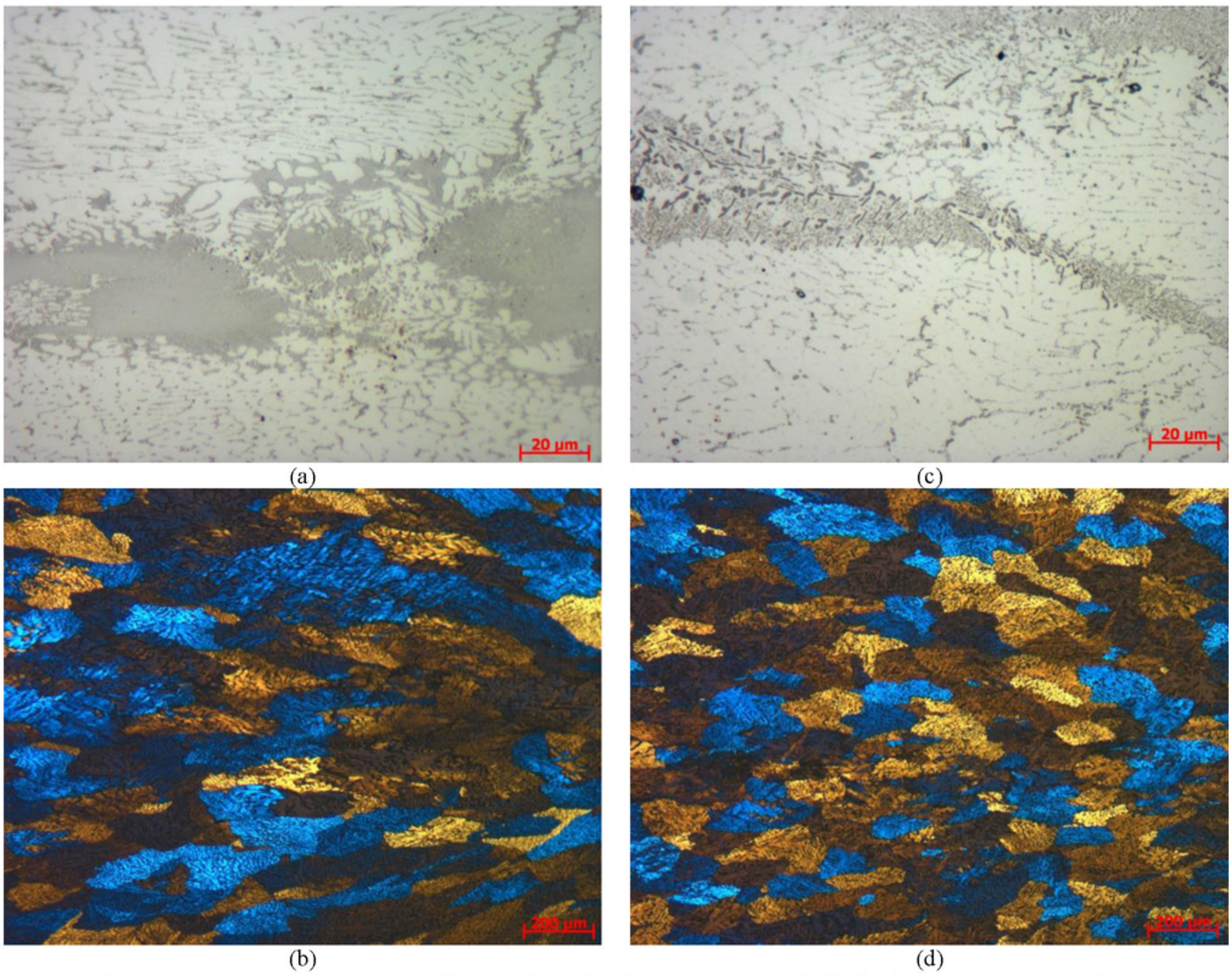


Figure 1. Optic microscope images of Cu free alloy (a) and (b) as cast, (c) and (d) after homogenization annealing.

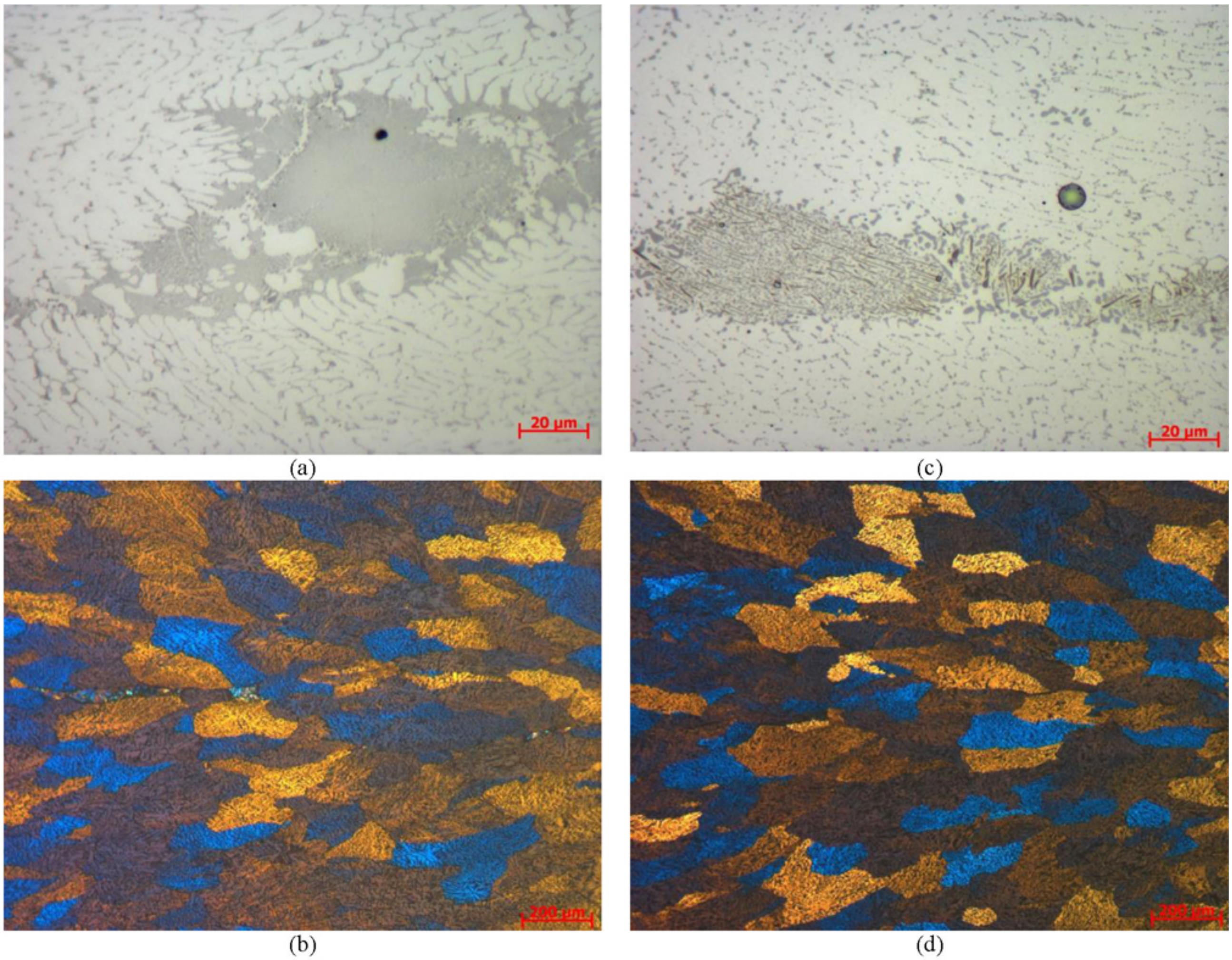


Figure 2. Optic microscope images of 0.25 wt. % Cu added alloy (a) and (b) as cast, (c) and (d) after homogenization annealing.

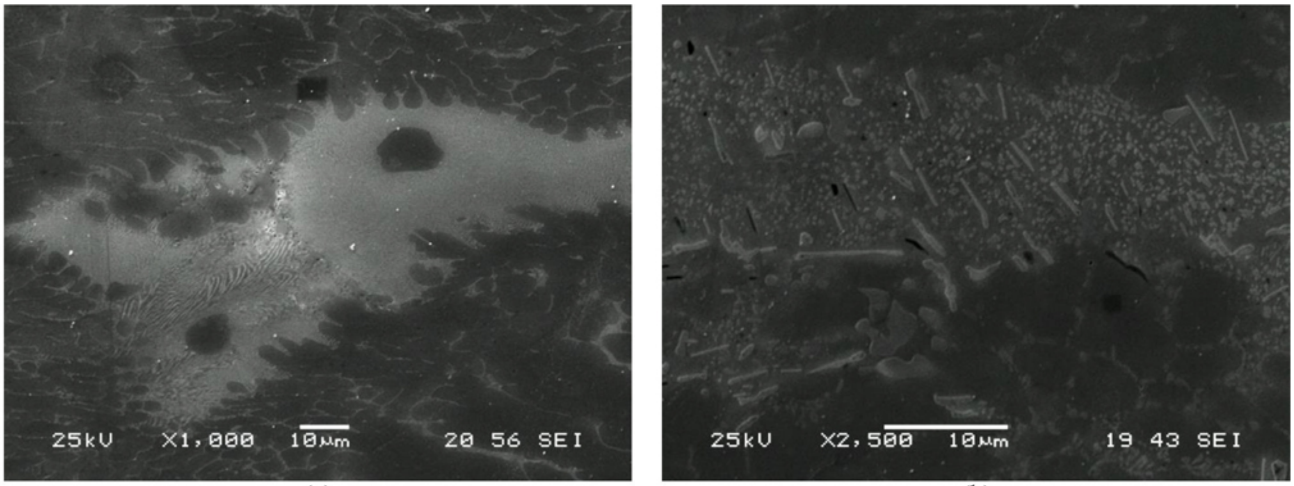
High magnification SEM images show (Figures 3 and 4) that CLS are composed of eutectic formations, however, morphological transformation occurred after homogenization annealing and intermetallic particles having different size and geometries were formed. EDS analysis revealed that spherical and needle like particles in the center plane of as-cast strip are composed of Fe (~6.0 wt. %), Mn (~ 1.0 wt. %) while balance is Al. On the other hand, no Cu signals were detected out of these particles. When all these observations are taken into consideration, it can be concluded that Cu addition does not affect the chemical composition of the microstructural constituents at the center plane of the as-cast strip. After homogenization anneal, morphologies of these constituents change from dense eutectic structure to needle like and spherical intermetallics without resulting in any compositional change as compared to those of as-cast state.

The results of hardness measurements performed on the samples at as-cast thickness are summarized in Table II. In general, centerline segregations (CLSs) exhibit much higher hardness values than those of Al matrix. The addition of Cu enhances the hardness. Upon homogenization anneal, hardness of the alloys tends to decrease. However, this observation is more pronounced in centerline segregation, compared to other regions of the cross section.

Table II. Hardness values ($HV_{0.01}$) of alloys at as-cast strip thickness.

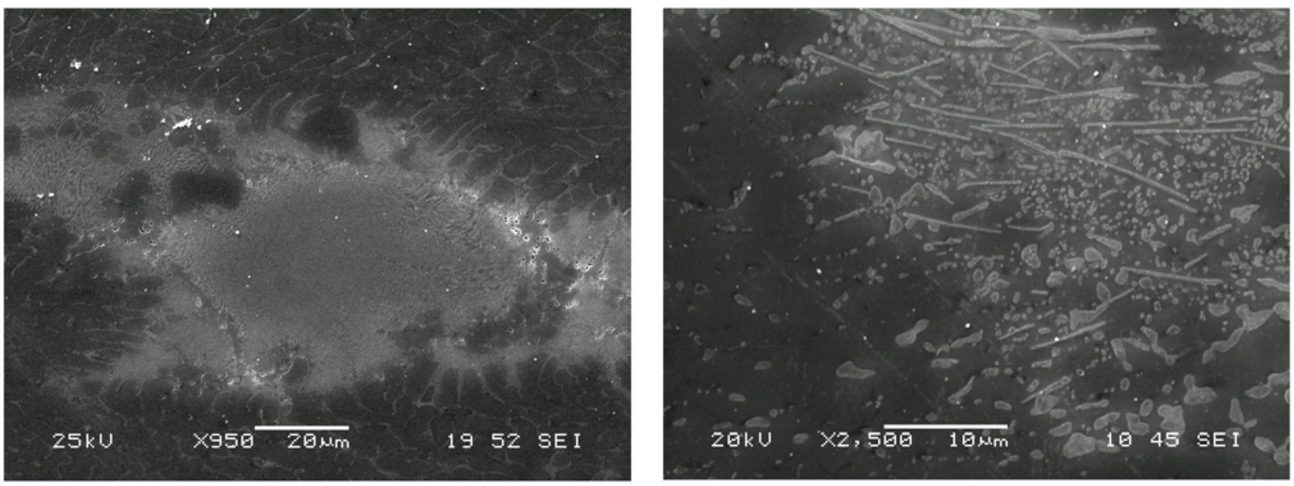
	Cu content, wt. %			
	0		0.25	
	Hard	Soft	Hard	Soft
CLS	97	68	130	93
Matrix near CLS	51	43	53	49
Surface	58	56	60	55

Figure 5 shows the grain structure of alloys at the thickness of 0.1 mm after soft anneal. According to the optical microscope images, Cu free alloy partially recrystallize and maintain cold worked grain structure whereas Cu added alloys are more likely to recrystallize during soft annealing compared to Cu free alloy.



(a) (b)

Figure 3. High magnification SEM images of centerline of Cu free alloy (a) as cast and (b) after homogenization.



(a) (b)

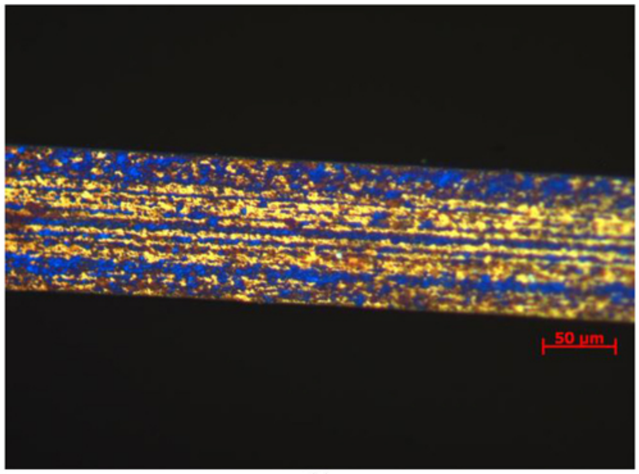
Figure 4. High magnification SEM images of centerline of 0.25 wt. % Cu added alloy (a) as cast and (b) after homogenization.

Mechanical properties of the alloys at the final thickness of 0.1 mm are presented in Table III. Although Cu added alloys are more prone to recrystallize during soft annealing, addition of Cu into 8xxx Al alloy results in improved mechanical properties at both hard and annealed states. Increase in Cu content in the alloy tends to increase the mechanical properties of as-rolled samples, however, after final annealing Cu added alloys exhibit similar tensile properties. On the other hand, it is interesting to note that Cu added alloys have higher tensile strengths even though they are in tendency of being recrystallized during soft annealing. This finding confirms that Cu improves the tensile strengths through solid solution hardening mechanism.

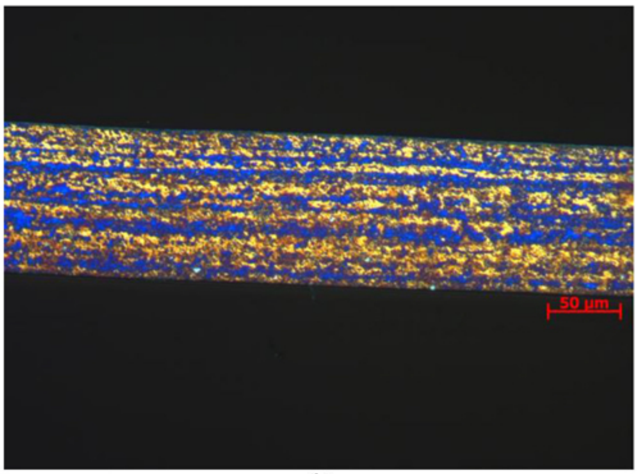
Change in open circuit potential (OCP) values for Cu free and Cu added alloys are shown in Fig. 6. It was observed that Cu added alloys have more noble OCPs as compared to that of the Cu free alloy and among the Cu added alloys, the one containing 0.25 wt. % of Cu has much more noble OCP. It was reported that Cu in solid solution enhances the corrosion performance of Al [7], therefore more noble OCP values of Cu added alloys can be attributed to presence of Cu in solid solution.

Table III. Mechanical properties of the alloys at the final thickness.

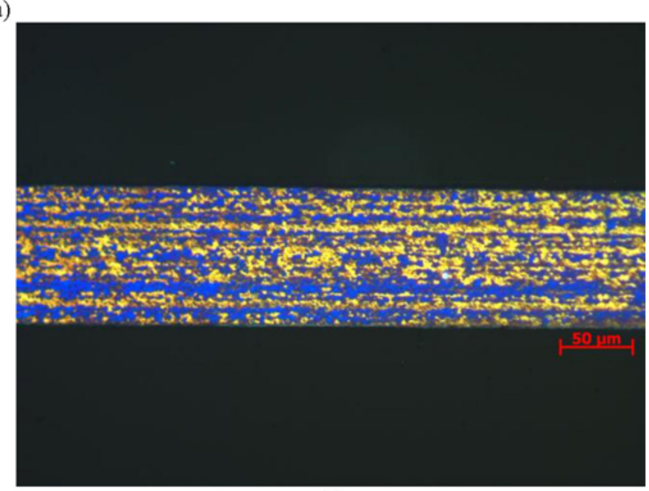
	Cu content, wt. %					
	0		0.17		0.25	
	As rolled	Soft	As rolled	Soft	As rolled	Soft
Yield Strength, MPa	148	109	184	116	226	115
Tensile Strength, MPa	200	127	270	142	312	141
Elongation (A100), %	6.0	18.3	7.4	19.9	4.5	13.1
Erichsen, mm	4.3	8.2	4.7	9.2	3.5	9.2



(a)



(b)



(c)

Figure 5 Grain structures of alloys at a thickness of 0.1 mm after annealing (a) Cu free, (b) 0.17 wt. % and (c) 0.25 wt. % Cu added alloys.

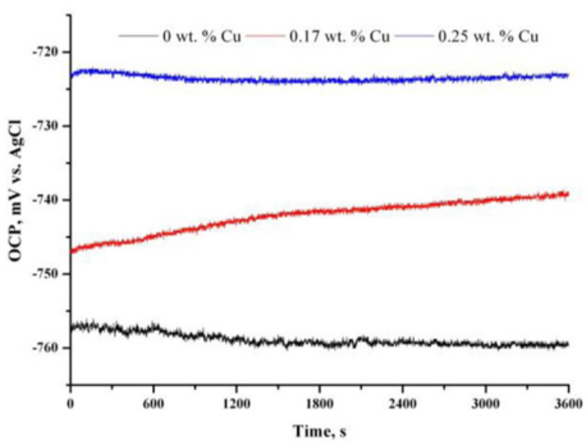


Figure 6. Change of OCP values with respect to time for alloys.

Conclusions

The results of this study can be summarized as follows:

The centerline structures of Cu free and Cu added alloys at as-cast state and after homogenization anneal have similar chemical compositions and morphologies. Homogenization anneal, leads to eutectic centerline structure transforms into spherical and needle like particles. No significant chemical composition differences between the eutectics and needle like intermetallic particles as well as spherical intermetallic particles were detected by EDS analyses.

Addition of Cu into 8xxx alloy suppresses the formation of smaller grains during homogenization anneal. In contrast to as-cast state, Cu added alloys exhibit coarser grains after homogenization heat treatment retaining the same grain structure as in the as cast condition.

CLS of the alloys have remarkably higher hardness. Upon homogenization anneal, overall hardness of the alloys tend to decrease. This observation is more obvious in the centerline when compared with other regions of the cross section of the samples. In general, Cu addition enhances the hardness values of the alloys.

Cu addition facilitates the recrystallization during final annealing.

Although Cu added alloys are more likely to recrystallize during final annealing, they possess superior tensile strengths and Erichsen values when compared to those of Cu free alloy. This observation suggests that Cu improves the mechanical properties through solid solution hardening mechanism.

Cu addition into AlFeMnSi alloy provides more noble OCP values indicating that Cu is in the solid solution.

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