The 56th International October Conference on Mining and Metallurgy
22-25 October 2025, Bor Lake, Bor, Serbia
www.ioc.tfbor.bg.ac.rs

DOI: 10.5937/IOC25482Z *Original scientific paper*

COMBINED EFFECT OF COOLING CONDITIONS AND Mg CONTENT ON THE MICROSTRUCTURE AND PROPERTIES OF Al-Cu15 Alloys

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Abstract

Results presented in this paper contribute to investigation of the cooling conditions and addition of magnesium on the microstructure of Al-Cu alloys. In this paper 4 samples were solidified by different cooling rates. The examined Al-Cu-Mg alloys contain intermediate phases $CuAl_2$ and $CuMgAl_2$ that appear in different quantities depending on the chemical composition and parameters of the technological process. With the addition of magnesium, the compressive strength and hardness of the aluminum-copper alloy increases.

Keywords*: Al-Cu alloys, Al-Cu-Mg alloys, cooling rate*

1. INTRODUCTION

Al-Cu alloy is widely used in aerospace and other fields due to its high tensile strength, elastic modulus, good fatigue performance, and corrosion resistance [1,2]. Interest in the Al-Cu15 alloys during last decades was due to the wide use of these alloys in diffrent industries. Depending on the casting conditions and alloy composition, microstructure, properties, and characteristics of the Al-Cu alloys will be different. The cooling rate affects the structure of as-cast alloys in a well-established manner, i.e. the grain size and the size of structure constituents (both primary and eutectic) decrease with the increase in cooling rate. A series of casting experiments were performed with binary Al-Cu alloys with varying cooling rates and cooling conditions [3]. This paper analyzes the influence of cooling rate and addition of Mg on the microstructure and properties of Al-Cu15 alloys.

2. EXPERIMENTAL

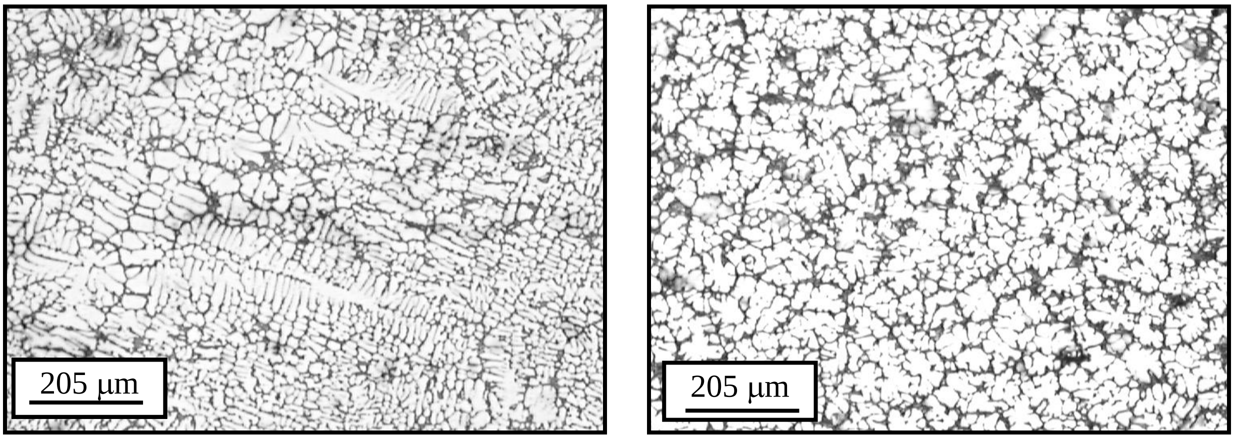
Experimental work can be divided in two phases. The first phase comprises of melting and casting of Al-Cu and Al-Cu-Mg alloys. Four samples were prepared by melting raw materials. The chemical composition (in wt. %) of the Al-Cu and Al-Cu-Mg alloys was specified by quantometery analysis and the results are reported in Table 1. The second phase includes characterization of cast samples by quantitative microstructure analysis. To study the variations in the mechanical properties with respect to cooling rate, the alloys were cast by conventional methods that include air or water-cooling. After applying different cooling methods, the hardness and compression strength were investigated. Hardness has been measured using the Brinell method. Compression strength of the samples has been determined on an electronic tensile testing machine of 10t.

Table 1. Chemical composition of the investigated alloy (in wt.%).

Type of sample	%Fe	%Si	%Ti	%B	%Cu	%Zn	%Mg	%Al
Al-Cu15	0.13	0.07	0.000	0.000	14.25	0.062	0.00	85.48
Al-Cu15-Mg1	0.15	0.07	0.002	0.000	14.30	0.080	1.139	84.23

3. RESULTS AND DISCUSSION

The effects of different process parameters during the solidification of the AlCu and AlCuMg alloys were examined. The changes in the microstructure were caused mainly by the different cooling rates of the sample. It is well known that the cooling rate plays an important role in the refinement of metal structures. Increasing the cooling rate is an effective way to change the morphology of an intermetallic. Number of primary grains is one of the most important factors for determining the quality of castings. The final grain density in the casting depends on the nucleation process at the beginning of solidification. Figure 1 shows the microstructures of Al-Cu15 alloy obtained after different cooling rates. The microstructures consists of dendrites and the interdendritic eutectic. For Al-Cu15 alloys, in both cooling rates, equilibrium eutectic is formed during solidification. Figure 2 shows the microstructure of Al-Cu15-Mg1 alloy obtained after a higher cooling rate (water cooled). From the presented figure, it can be concluded that the higher cooling rate along with the Mg addition, produced finer grains. The two present phases in the microstructure are the primary phase (alpha solid solution) and the secondary phases.



a) b)

Figure 1. Microstructure of Al-Cu15 samples with different cooling rates: a) air-cooled, b) water-cooled

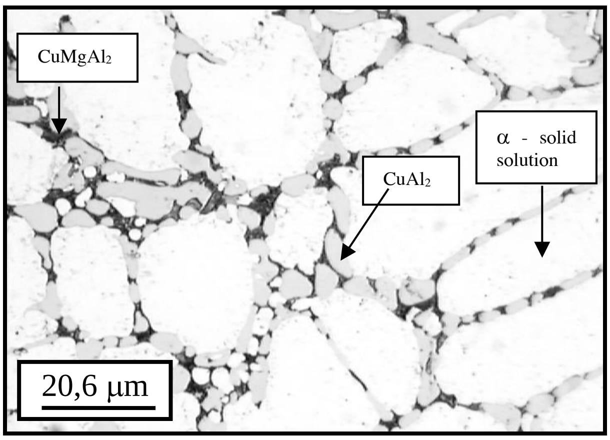


Figure 2. Microstructure of Al-Cu15-Mg1 sample (water-cooled)

Fast cooling rate facilitated the grain refinement. The sizes of the grains for the Al-Cu15 alloy decreased from 810.48 μm (air-cooled) to 560.08 μm (water cooled). For the Al-Cu15-Mg1 alloy grain size decreased from 233.37 μm (air-cooled) to 160.08 μm (water-cooled) after which, a fine uniform grain structure was obtained, as shown in figure 2. Also, addition of magnesium to the aluminum-copper alloy, decreased the mean value of the grain size, from 810.48 μm (air-cooled) to 233.37 μm (air - cooled) and produced a finer, more uniform microstructure.

Under industrial conditions, in standard aluminium-copper alloys a dendritic grain structure is typical. In the binary aluminium-copper system, the aluminium-rich solid solution phase is in equilibrium with the intermetallic compound θ, which has approximately the formula $CuAl_2$, although some solid solubility exists. The addition of magnesium allows the formation of more intermetallic compounds, such as $CuMgAl_2$, $CuMg_4Al_6$, CuMgAl and $Cu_6Mg_2Al_5$. Magnesium is added to strengthen the solid solution. The addition of 1 wt.% magnesium to aluminum alloys sharply increases the strength of the alloy. In Al-Cu15-Mg1 alloys, $CuAl_2$ phase and $CuMgAl_2$ phase are dominant [3]. This is in agreement with the fact that the addition of Mg tends to increase the formation of the $CuMgAl_2$ phase (Figure 2). The dominant strengthening phase in the tested AlCu15Mg1 alloys is the $CuMgAl_2$ phase. The addition of Mg to the alloy causes the deposition of a fine $CuMgAl_2$ phase when compared to the case of the alloy without Mg.

In this study the mechanical properties like compressive strength and hardness of both air-cooled and water-cooled cast specimens were tested and the results were compared (Tables 2 - 4). Increases in hardness and compressive strengths of the water - cooled cast specimen have been encountered from the present work. This result reveals that increase in cooling rate leads to enhancement of the mechanical properties. The maximum hardness increases for air-cooled samples from 89.7 BHN for the alloy with Al-15wt.%Cu to 146.0 BHN for the alloy Al-15wt.%Cu-1wt.% Mg. At room temperature, the strength increases for water-cooled samples from 491.72 MPa for the alloy with Al-15wt.%Cu to 673.7 MPa for the alloy Al-15wt.%Cu-1wt.% Mg.

Table 2. Hardness of the investigated alloys

Type of sample	$HB_{average}$, water-cooled	$HB_{average}$, air-cooled
AlCu15	90.0	89.7
AlCu15Mg1	148.0	146.0

Table 3. Compression strength of the investigated alloys (air-cooled samples)

Type of sample	$F_{P0.2}$ (N)	$R_{P0.2}$ (N/mm^2)	F_{PM} (N)	R_m (N/mm^2)	δ_P (%)	Ψ_P (%)
Al-Cu15	14800	188.54	38600	491.72	31.05	37.18
Al-Cu15-Mg1	17520	223.18	43800	557.96	24.43	28.02

Table 4. Compression strength of the investigated alloys (water-cooled samples)

Type of sample	$F_{P0.2}$ (N)	$R_{P0.2}$ (N/mm^2)	F_{PM} (N)	R_m (N/mm^2)	δ_P (%)	Ψ_P (%)
Al-Cu15	16800	214.01	40000	509.55	27.15	31.67
Al-Cu15-Mg1	19200	264.9	52800	673.7	19.94	22.24

The addition of magnesium to the Al-Cu15 alloy significantly increases the hardness (HB). The most important contribution of magnesium is in increasing strength. We found that 1wt.% of magnesium increases the strength by about 50 MPa for air-cooled samples and by about 180 MPa for water-cooled samples. As the magnesium content increases, the compressive strength and hardness of the aluminum-copper alloy also increases. In FCC metals such as aluminum, grain refinement contributes to strengthening, though generally less strongly than in BCC metals. In Al–

Mg alloys, Mg primarily strengthens through solid solution hardening, while in Al–Mg–Si and related systems, precipitation (e.g., Mg_2Si) plays a key role in enhancing strength.

4. CONCLUSION

The aim of this research was to investigate how addition of 1wt.%Mg to the Al-Cu alloy affect the solidification process, development of microstructure and mechanical characteristics of Al-Cu-Mg alloys. With the Mg addition the strength of Al-Cu alloy increases by 10% for air-cooled samples and by about 35% for water-cooled samples, and hardness increases by 60%.

The microstructure and mechanical properties of cast products are greatly influenced by the cooling rate during their solidification. It is evident that the increase in cooling rate improves the compression strength for 20% for the cast Al-Cu15-Mg1 alloy. The grain size decreases with increasing cooling rate, and the hardness and strength increase correspondingly. In addition, higher cooling rates produced a finer primary α-phase.

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