DOI: 10.5937/IOC25478Z *Original scientific paper*

EFFECT OF COPPER CONTENT ON PHASE FORMATION AND MECHANICAL RESPONSE OF Al–Cu ALLOYS

Biljana Zlatičanin[1a], Branislav Radonjić[1b]

[1] Faculty of Metallurgy and Technology, Cetinjski put bb, 81000 Podgorica, Montenegro
[1a] biljana@ucg.ac.me, 0000-0002-9659-3191
[1b] bradonjic@t-com.me, 0009-0005-8158-1023

Abstract

This study investigates the effect of Cu content (5–36 wt.%) on the microstructural evolution and mechanical behavior of Al–Cu alloys. Experimental results demonstrate that increasing Cu content promotes eutectic phase formation θ-Al_2Cu in as-cast microstructures, accompanied by a transition from dendritic to cellular dendritic grain morphology. Hypereutectic Al-Cu alloy is an ideal candidate for producing in situ composites because the multiphase structure that reinforced phases (θ-Al_2Cu phase) embedded in a flexible matrix eutectic phase can be directly achieved by casting. Al_2Cu is an intermetallic formed at the last stages of solidification.

***Keywords**: Al-Cu alloys, Brinell hardness, compression strength*

1. INTRODUCTION

Aluminium is the most abundant metal in the earth's crust. It makes up about 8% by weight of the earth's solid surface. Aluminium alloys with a wide range of properties are used in engineering structures. These properties can be largely modified by changing the alloy composition. Silicon, copper, zinc and magnesium are the most commonly used elements in aluminium alloying, which have sufficient solid solubility. In general, aluminium - copper alloys are used for many of the applications where higher strength is needed [1]. Currently, many types of Al-Cu alloys with different mechanical and technological properties are being produced. The most important factors shaping these properties include the content of alloying elements (mainly the addition of copper), as well as parameters of plastic forming and heat treatment [2].

In this paper, the effects of copper contents in the interval of 5 – 36wt.% on the mechanical properties of aluminium-copper alloy were examined. Namely, copper content in the standard alloys ranges up to around 5wt.% since the maximum solubility of copper in hard state, at eutectic temperature (548^{o}C) is 5,65wt.%. Alloys containing copper up to 36wt.% have been also tested, that is why a considerable eutectic phase appears in the microstructure. With standard alloys the primary α - super saturated solid solution crystalizes in a dendritic form. With higher copper contents, eutectic appears in the interdendritic space and between grains. Microstructure can be influenced by controlling technological parameters and by addition of titanium and boron in form of AlTi5B1 containing fine insoluble crystals of TiB_2 phase acting as nucleants, first for $TiAl_3$ phase, and further for the aluminium phase and/or of the α- super saturated solid solution [3].

2. EXPERIMENTAL

Al-Cu alloys with the compositions given in Table 1. were prepared in an electrical resistance furnace from 99.5% pure aluminium and 99.9 % pure copper. To study the variations in the mechanical properties with respect to copper content, special attention was given to an assessment of the different properties of the materials: hardness and determination of compression strength. Hardness of the samples has been measured by use of the Brinell method. Compression strength of the cast samples has been tested on a universal electronic tensile testing machine of $1x10^4$ kg.

Average size of samples was as follows: diameter D_o=10mm and height H_o=20mm. All of the tested samples have been fractured. Compression strength is measured in the moment of fracture.

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

Type of sample		%Fe	%Si	%Ti	%Cu	%Zn	%Al
Al-Cu5	0%Ti	0.11	0.07	0.000	5.90	0.054	93.86
	0.02%Ti	0.11	0.07	0.023	4.44	0.050	95.31
	0.08%Ti	0.12	0.07	0.094	4.34	0.050	95.33
	0.15%Ti	0.12	0.07	0.195	6.38	0.053	93.19
	0.25%Ti	0.11	0.07	0.276	4.28	0.049	95.22
Al-Cu36	0%Ti	0.15	0.07	0.000	36.46	0.091	63.22
	0.02%Ti	0.14	0.08	0.027	36.22	0.094	63.44
	0.08%Ti	0.15	0.08	0.111	35.54	0.089	64.03
	0.15%Ti	0.14	0.07	0.202	35.35	0.090	64.14
	0.25%Ti	0.14	0.08	0.345	35.57	0.091	63.78

3. RESULTS AND DISCUSSION

Copper has been the most common alloying element almost since the beginning of the aluminium industry, and a variety of alloys in which copper is the major addition, were developed. In the binary aluminium-copper system, the aluminium-rich terminal solid solution is in equilibrium with the intermetallic phase θ, which has approximately the formula Al_2Cu, although some solid solubility exists. The Brinell hardness and the compression strength are shown in Table 2 and 3.

Table 2. Hardness of the investigated alloys with different amounts of titanium

Type of sample		HB_1	HB_2	HB_3	HB_4	$HB_{average}$
Al-Cu5	0%Ti	52.5	56.1	57.5	56.1	55.55
	0.02%Ti	60.5	62.1	59.0	57.5	59.77
	0.08%Ti	62.1	63.7	64.3	67.3	63.92
	0.15%Ti	62.4	63.7	64.7	64.9	64.35
	0.25%Ti	63.6	64.9	64.9	67.5	65.22
Al-Cu36	0%Ti	180.0	178.0	185.0	179.0	180.50
	0.02%Ti	193.0	195.0	189.0	195.0	192.50
	0.08%Ti	194.0	197.0	202.0	197.0	197.50
	0.15%Ti	202.0	207.0	202.0	207.0	205.50
	0.25%Ti	204.0	211.0	204.0	211.0	207.50

The changes in chemical composition of the alloy cause changes in the structure that are reflected in the Brinell hardness and the compression strength. The hardness of the modified alloy is higher than the hardness of the alloy without any modification treatment. By increasing the content of titanium, compression strength also increases.

Table 3. Compression strength of the investigated alloys with different amounts of titanium

Type of sample		$F_{P0.2}$ (N)	$R_{P0.2}$ (N/mm^2)	F_{PM} (N)	R_m (N/mm^2)	d_P (%)	Y_P (%)
Al-Cu5	0%Ti	6600	84.08	24800	315.92	39.70	50.59
	0.02%Ti	7000	89.17	26000	331.21	36.99	46.18
	0.08%Ti	8000	101.92	37600	478.98	35.12	43.27
	0.15%Ti	8080	102.93	37640	479.49	22.73	25.79
	0.25%Ti	8200	104.46	37720	480.51	21.72	24.48
Al-Cu36	0%Ti	31000	394.90	42800	545.22	2.04	2.06
	0.02%Ti	38000	484.07	45800	583.44	1.02	1.02
	0.08%Ti	39400	501.91	52800	672.61	0.85	0.85
	0.15%Ti	40800	519.74	52840	673.12	0.68	0.68
	0.25%Ti	40800	519.74	52920	674.14	0.68	0.68

In Al-Cu alloys, strengthening takes place with the precipitation of the intermetallic Al_2Cu phase. The present intermetallic phases can be determined by determination of the chemical composition using EDS analysis. Typical EDS spectra of θ-phase and α-phase are shown in Figure 1 and 2. The chemical compositions matched the stoichiometric composition of Al_2Cu, and was confirmed by EDS analysis. In Al–Cu alloys, higher Cu content increases the volume fraction of θ (Al_2Cu) precipitates; their size is mainly controlled by cooling rate and aging conditions, not just copper content. In the Al–Cu system, the intermetallic compound Al_2Cu forms during the binary eutectic reaction: L → α-Al + Al_2Cu (at ~548°C, ~33wt.% Cu in the eutectic). When the local liquid composition reaches the eutectic composition at the solid–liquid interface, the eutectic reaction occurs, producing a mixture of α-Al and Al_2Cu. The Al_2Cu may appear in blocky or lamellar forms depending on solidification conditions.

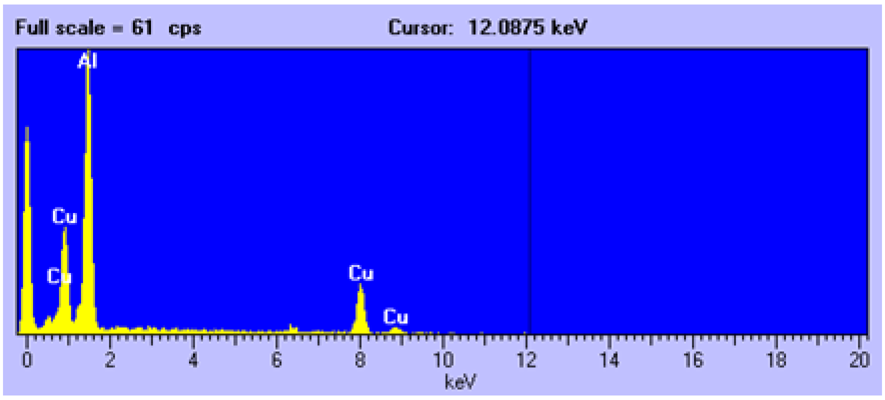

Figure 1.EDS microanalysis of Al_2Cu phase

In as-cast Al–Cu alloys, the microstructure typically consists of primary α-Al and the intermetallic Al_2Cu (θ) phase, arranged as a eutectic mixture in an Al-rich matrix. The Al_2Cu phase often forms along α-Al grain boundaries, with morphologies ranging from continuous networks to isolated sectored plates, depending on composition and cooling rate.

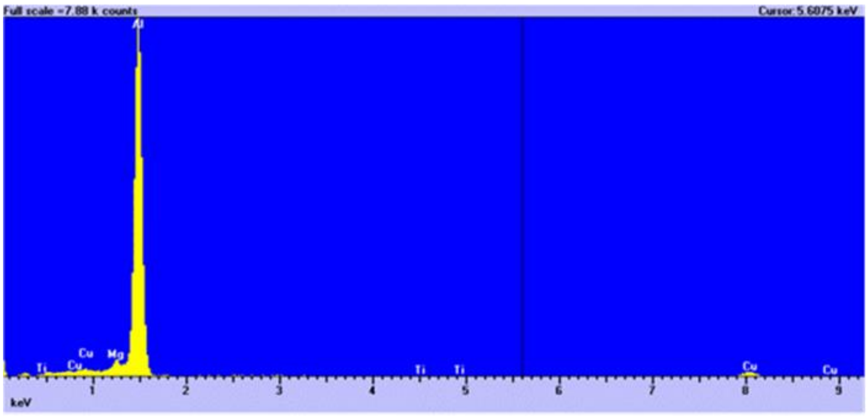

Figure 2. EDS microanalysis of α-phase

4. CONCLUSION

From the obtained data the following conclusions can be drawn: The compression strength and hardness of Al-Cu alloy increases with the increase in Cu content. When the Cu content increases from 5wt.% to 36wt.% the strength increases by 40%, and hardness increases over 220%. In Al-Cu alloys, copper content is critical because the temperature-dependent solubility of Cu in aluminum enables heat treatment; through precipitation hardening, this allows control and enhancement of mechanical properties. In Al–Cu alloys, higher Cu content increases the potential hardening effect, with the θ (Al_2Cu) phase playing a central role in precipitation strengthening.

REFERENCES

[1] H. Rashed, E. Ashrafi, A. Hasan, Mater. Trans., 64 (1) (2023) 177-183.
[2] B. Płonka, K. Żyłka, K. Remsak, M. Rajda, J. Zdunek, D. Moszczyńska, ACME, 24 (8) (2024) 8-17.
[3] B. Zlatičanin, B. Radonjić, S. Đurić, B. Jordović, B. Stojanović, Mater. Technol., 36 (1-2) (2002) 49-51.