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/IOC25538M
Original scientific paper

INFLUENCE OF TEMPERATURE AND ANNEALING TIME ON CHANGES OF THE MECHANICAL PROPERTIES OF THE CuFe1 ALLOY

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Abstract
This work includes experimental studies of the influence of thermomechanical processing regime on the mechanical properties of CuFe1 alloy, in the form of a wire Ø1,0 mm. The CuFe1 alloy was melted and homogenized in a medium-frequency induction crucible furnace, and casting was performed by the crystallization method above the melt using a casting machine. The resulting cast wire Ø8,0 mm was drawn on a multi-stage drawing machine according to a drawing plan identical to the Cu wire. Interphase annealing was performed at a temperature of 650 °C in a bell furnace with a protective nitrogen atmosphere for 1 hour. Final annealing of the samples was carried out at temperatures of 320, 400, 450, 500, 550, 650 and 800 °C for 1h and 0,5h. By combining temperatures and annealing times, the aim was to achieve a primarily appropriate elongation value (A ≥ 25 %) dictated by the exploitation conditions in which this wire is used. The results showed that the optimal conditions for the required mechanical characteristics of the material, primarily elongation, were achieved at an annealing temperature of 650 °C for a time duration of 0,5h.

***Keywords**: CuFe alloy, plastic processing, mechanical characteristics.*

1. INTRODUCTION

The wider application of Cu in industry is usually explained by its excellent physicochemical properties, electrical and thermal conductivity, corrosion resistance and ability to be processed in a plastic state. Depending on the area of application, pure Cu cannot meet all requirements in terms of mechanical properties, which is a problem for parts that work for a long time at elevated temperatures [1,2]. Therefore, its standard properties are corrected by alloying with appropriate metals, which in two-component or multi-component systems improve the existing properties of Cu [3].

Cu alloys with Fe are usually two- or multi-component alloys, so in addition to Fe they may also contain some common amounts of P and Zn, which are introduced primarily as agents for Cu deoxidation. Wang et al., indicate that the presence of Fe up to 5 wt% positively affects the mechanical properties of Cu alloys [4]. Due to the low solubility of Fe in Cu, an uneven distribution of the Fe phase occurs during the solidification of CuFe alloys, which leads to serious macrosegregation that deteriorates the performance of these alloys [5,6]. Therefore, CuFe alloy with relatively uniform composition and uniform structure, especially alloy with Fe content higher than 5 wt%, is difficult to prepare by traditional casting methods [4].

A higher Fe content has a negative effect on processing by deformation, both in cold and hot conditions, because after processing by deformation, the hardness and brittleness of Cu alloys increases. For the above reasons, Cu should be alloyed with strictly dosed amounts of Fe, in order to be viewed as a positive admixture that leads to the creation of materials with a very fine-grained structure, which, with properly selected thermomechanical processing regimes, improves the mechanical properties of these alloys.

The aim of this work is to determine the optimal thermomechanical regime for the production of wire from CuFe1 alloy, as well as to determine the optimal interphase annealing temperature. By understanding the dependence of the properties of the CuFe1 alloy on the degree of cold deformation and the time of interphase annealing, i.e. on the temperature of the interphase and final annealing, the manufacturer is enabled to select the optimal regime in order to obtain the predetermined properties of the final product.

2. EXPERIMENTAL

To obtain the CuFe1 alloy, electrolytic Cu and technically pure Fe (ARMCO Fe) were used. The charge calculation was made on a quantity of 100 kg.

Fe was in strip form, while Cu was cut from the cathode of controlled chemical composition in plate form. The melting was carried out in a medium-frequency induction crucible furnace under a layer of charcoal which has role to protect the melt from the influence of oxygen. The addition of Cu was carried out in smaller portions, and after complete melting at a temperature of about 1150 °C, intensive mixing was carried out with a graphite rod. To eliminate the gas present in the melt, a small amount of "logos" degasser was added. The next stage of melting included the addition of Fe, which had been previously heated to a temperature of 250 °C. Fe was added in small portions with intensive stirring until completely dissolved in the melt. Casting was performed by the crystallization method above the melt using a casting machine. The obtained cast wire with a diameter of Ø8,0 mm was drawn on a multi-stage drawing machine with an output of Ø1,0 mm. The draw was carried out according to passages plan identical to the Cu wire. Interphase annealing was performed at a temperature of 650 °C in a bell furnace with a protective nitrogen atmosphere for 1h. After cooling, the wire with a diameter of Ø1,8 mm was drawn to a final dimension of Ø1,0 mm.

The final annealing was performed with the aim of achieving the appropriate condition of the alloy through a combination of temperature and annealing time. The main goal of this research is to achieve primarily the appropriate elongation ($A \geq 25$ %) dictated by the exploitation conditions in which the wire is used.

Since it is known that soft-annealed materials possess good mechanical and physical properties with a fine-grained structure, the aim was to achieve complete recrystallization by combining annealing time and temperature, while avoiding the appearance of coarsening of the structure. The samples were annealed at temperatures of 320, 400, 450, 500, 550, 650 and 800 °C with annealing times of 1h and 0,5h. To fix the structures obtained at these temperatures, the samples were cooled in water, after which mechanical tests were performed.

3. RESULTS AND DISCUSSION

The results of testing the mechanical properties of CuFe1 alloy are given in Tables 1 and 2, and the diagrams of the dependence of mechanical properties on annealing temperature are shown in Figures 1 and 2.

The presence of Fe in the alloy (1 wt%) refines the structure and delays the recrystallization of Cu, which leads to an increase in mechanical properties [7,8]. It is known that grain size, which is a significant factor in defining mechanical properties, depends not only on the degree of deformation, but also on the height of the annealing temperature, annealing time, and the cooling rate after annealing.

Table 1. Values of mechanical properties of CuFe1 alloy after one-hour annealing

No.	Sample state	Annealing time, (h)	T, (°C)	R_m, (MPa)	$R_{p\,0,2}$, (MPa)	A, (%)
1	Hard deformed	/	/	481,0	463,0	2,0
2	annealed	1	320	435,0	427,0	5,0
3	annealed	1	400	402,0	383,0	7,5
4	annealed	1	450	330,0	213,0	21,0
5	annealed	1	500	323,0	206,0	23,5
6	annealed	1	550	317,0	192,0	25,0
7	annealed	1	650	308,0	157,0	28,5
8	annealed	1	800	273,0	150,0	30,0

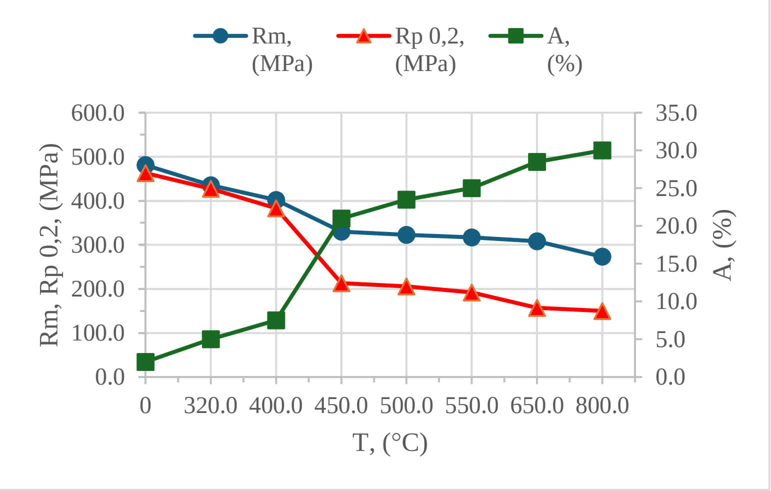

Figure 1. Dependence of the mechanical properties of CuFe1 alloy on temperature, for 1h of annealing

Since the recrystallization temperature of pure copper is 200 °C [2] it is logical that the presence of Fe will increase the recrystallization temperature, therefore the experiment plan included the lowest annealing temperature being 320 °C and the highest 800 °C.

By analyzing the diagram of the dependence of mechanical properties on temperature, at a constant annealing time of 1h (Figure 1), it can be concluded that with increasing annealing temperature, the values for R_m and $R_{p0.2}$ decrease, while the values for A increase. In the initially annealed samples at temperatures of 320 and 400 °C, the values for R_m, $R_{p0.2}$ and A did not change drastically compared to the hard state (cold deformed), which indicates incomplete recrystallization. Complete recrystallization occurred at higher temperatures, which caused a more intense drop in strength and an increase in elongation.

To see how much the annealing time affects the change in mechanical properties, annealing was performed at temperatures of 550, 650 and 800 °C for 0,5h (Table 2). The temperature selection was made based on the previous experiment, and the criterion was that $A \geq 25$ %.

Table 2. Values of mechanical properties of CuFe1 alloy after half an hour annealing

No.	Sample state	Annealing time, (h)	T, (°C)	Rm, (MPa)	$R_{p\,0,2}$, (MPa)	A, (%)
1	hard deformed	/	/	481,0	463,0	2,0
2	annealed	0,5	550	320,0	168,0	25,5
3	annealed	0,5	650	308,0	160,0	28,5
4	annealed	0,5	800	279,0	150,0	30,0

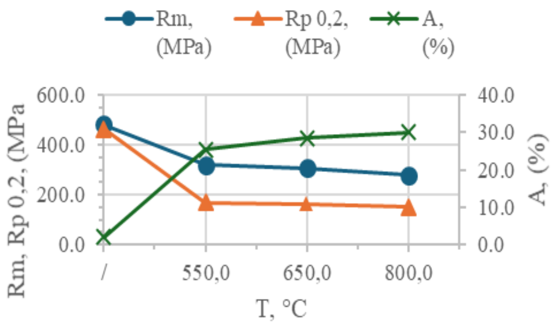

Figure 2. Dependence of mechanical properties of CuFe1 alloy on temperature, for 0,5h of annealing

With both variants of annealing, there is no significant difference in the obtained values for R_m, $R_{p0,2}$ and A, but there is in relation to the relevant data given in the literature for pure copper [9]. This difference is a consequence of the Fe presence, which significantly affects changes in mechanical and structural properties. Since Fe dissolves very little in Cu, it is present in the alloy in the form of dispersed α-Fe particles, and on their size and distribution depend the mechanical properties of the alloy. By increasing the temperature and extending the annealing time, it leads to significant coarsening of this particles, which is why shorter time and optimal annealing temperature are recommended. The results showed that the required elongation was obtained at a temperature of 550 °C and a time of 0,5h, which represents the lower limit. Due to the safety factor in the industrial conditions of exploitation of this alloy, an annealing temperature of 650 °C and an annealing time of 0,5h were adopted as the optimal thermal regime.

4. CONCLUSION

Based on the performed tests and the obtained results, the following can be concluded: At lower annealing temperatures (320 °C and 400 °C), the values of mechanical properties did not change drastically compared to the cold deformed state, which indicates incomplete recrystallization; Complete recrystallization occurred at higher annealing temperatures, which caused a more intense drop in tensile strength (R_m) and yield strength ($R_{p0,2}$), and an increase in elongation (A); Optimal conditions for the required mechanical characteristics of the CuFe1 alloy were achieved at an annealing temperature of 650 °C, in a duration of 0,5 h.

ACKNOWLEDGEMENTS

The research presented in this paper was done with the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, with the funding of the scientific research work at the University of Belgrade, Technical Faculty in Bor, according to the contract with registration number 451-03-137/2025-03/200131.

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