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MANUFACTURING AND PROPERTIES OF CAST Cu-Ag ALLOYS DESIGNED FOR ELECTROTECHNICAL APPLICATIONS

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The results of the current paper present the research concerning the obtaining of Cu-Ag alloys with wt. % of silver ranging between 5 and 20 % using continuous casting process. The process parameters have been introduced. Selected results regarding physical and mechanical properties of the casts have been discussed. Strength coefficients describing the plastic deformation range of the Cu-Ag alloys have been calculated using Hollomon's equation. Additionally, in order to determine the influence of the temperature with Differential Scanning Calorimeter (DSC) on the electrical resistance, the values of temperature coefficients of resistance have been determined for all of the tested alloys.

Keywords: Cu-Ag alloys, chemical composition, DSC, mechanical properties, electrical properties

INTRODUCTION

Cu-Ag alloys due to high electrical conductivity of the copper matrix are widely used in many branches of technology related to the passage of the electric current [1]. Using axi-symmetric or profile wires to build electromagnet windings generating strong magnetic fields is just one of such applications in electrical engineering [2 – 3]. Cu-Ag sheets may as well be used to build the cores of Bitter electromagnets generating constant magnetic field [4 – 5]. In order to obtain high intensity of the electric current, and thus maximum magnetic field, the materials used to build the aforementioned cores require high electrical conductivity. On the other hand, high mechanical properties are required in order to transfer high Lorenz forces generated as a result of the magnetic field [6 – 7]. The ideal material for the manufacture of the electromagnet coil winding should combine the high mechanical properties of steel with the electrical conductivity of a superconductor or copper.

Obtaining the required level of mechanical and electrical properties at the same time is possible for instance using Cu-Ag alloys.

In terms of metallurgical synthesis, copper and silver form a solid solution with limited solubility on both sides of the phase-diagram with eutectic transformation at 779 °C with silver content of 71,9 wt. %. At the eutectic transformation temperature, the maximum solubility of silver in copper is 8 wt. %, whereas, the maximum solubility of copper in silver is 8,8 wt. %. Cu-Ag alloys with 5 wt. % of Ag solidifies above the eutectic transformation temperature. As a result mostly alpha phase (rich in copper solution of silver in copper matrix) exists in the alloy after solidification, however, if cooled down extremely slow a beta phase (rich in silver solution of copper in silver matrix) may also precipitate. The hypoeutectic Cu-Ag alloys with 10, 15 and 20 wt. % of Ag while solidifying form a fine grained eutectic matrix with crystals of alpha phase. The microstructure of said alloys may be described as alpha phase + (alpha + beta). The applied heat treatment (supersaturation and ageing) allows for both controlled and effective microstructure modifications through mutual precipitation reactions [8 – 9]. As a result during for instance wire drawing process the structure of the wires contains numerous, highly elongated fibers of almost pure silver in the almost pure copper matrix. Depending on the parameters of heat treatment and the amount of deformation applied the cross-section of the fibers may reach nanometric sizes [10 – 11]. It may result in significant increase in mechanical properties of the final product while maintaining its high electrical conductivity [12-15].

EXPERIMENTAL DETAILS

Cu-Ag alloys with 5, 10, 15 and 20 wt. % of Ag were obtained in the laboratory continuous casting process in the form of cast-rods of 9,5 mm in diameter. The stand consists of an induction furnace, a generator, an electronic control system, primary and secondary cooling systems as well as the cast-rod extracting system. Both crucible and crystallizer were produced using high quality isostatically pressed graphite. The alloying elements were oxygen free copper and silver granules with

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Table 1 **Chemical composition of rods all materials**

Elements	Element content / wt %			
	CuAg5	CuAg10	CuAg15	CuAg20
Ag	4,91	9,88	15,03	19,92
Cu	rest	rest	rest	rest
Element content / ppm				
As	0,37	0,29	0,43	0,35
Bi	0,09	0,14	0,11	0,14
Se	0,13	0,09	0,12	0,16
Mn	0,09	0,12	0,11	0,08
Zn	2,59	2,82	2,96	2,66
Pb	0,98	0.86	0,78	0,85
Sb	0,83	0,75	0,72	0,81
Sn	0,09	0,07	0,11	0,09
Te	0,18	0,13	0,16	0,18
Fe	2,97	2,63	2,64	2,94
Ni	1,89	1,75	2,04	1,95
S	3,57	3,92	3,11	3,71
P	1,48	1,84	1,94	1,74
Si	1,33	0,97	1,11	0,96
O_2	8	13	11	13

purity of 99,99 wt. %. In order to prevent oxidation of the alloy a graphite powder was used to cover the liquid metal in the crucible and additionally, a protective nitrogen gas was supplied during the process inside of the crucible and around the crystallizer. During the continuous casting process the temperature of the liquid metal was ranging between 1 200 and 1 280 °C depending on the alloys, and the solidified bars immediately in front of the crystallizer had the temperature between 150 and 190 °C. The temperature of the cast rod before coiling them did not exceed 50 °C thanks to the secondary cooling system. For each 4 mm of cast feed there was 1 s of standstill needed for the liquid metal to flow into the crystallizer. The mechanical and physical properties of rods in the as-cast state were thus determined. The chemical composition was provided by Quality Testing Division of KGHM. The density of the alloys was determined using the basic Archimedes principle by measuring the mass of the samples in water and air while knowing their density in the temperature of measurement. The determination of the phase transformation temperature and heat was possible using thermodynamic tests on Differential Scanning Calorimeter DSC Q2000 made by TA Instruments. The electrical conductivity was determined using Burster RESISTOMAT® model 2304 resistance measurement Thomson bridge. For the conversion of resistance to be accurate in 20 °C additional research was performed to establish the temperature coefficient of resistance, which determines the effect of temperature on the rate of resistance change of the alloys. Strength properties were obtained using Zwick Z100 testing machine with maximum load of 100 kN and materials hardness was determined using Nexus 3001 hardness tester which implements the Brinell's method of hardness measurement.

RESULTS AND DISCUSSION

In Table 1 the results of chemical composition analysis of the obtained alloys was presented, which shows the presence of other than copper and silver elements (impurities), however, the total amount did not exceed 30 ppm. The DSC thermographs of the tested alloys were presented at Figure 1, based on which the melting and solidification points as well as the thermal effect of these phenomena were determined. The influence of Ag content on the density of the alloys was presented at Figure 2.

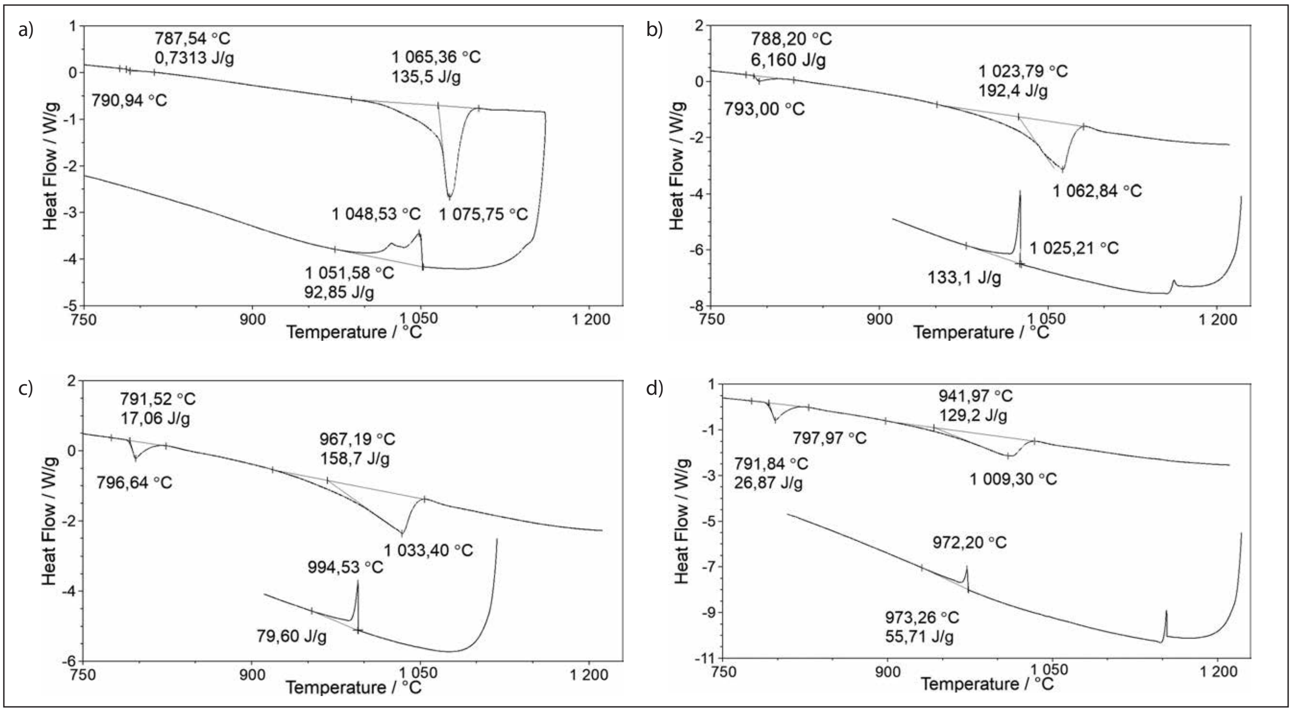

Figure 1 Thermographs of tested alloys: a) CuAg5, b) CuAg10, c) CuAg15, d) CuAg20

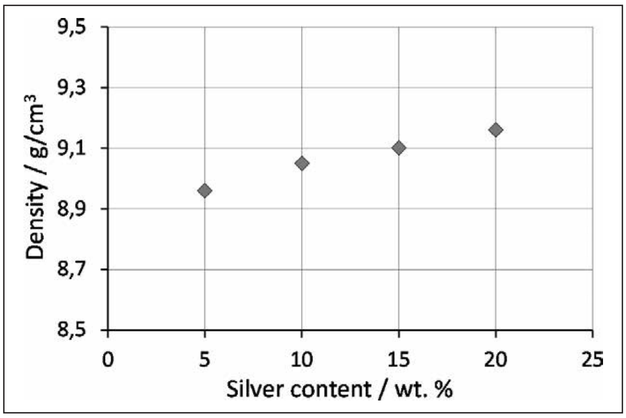

Figure 2 The influence of the Ag content on density

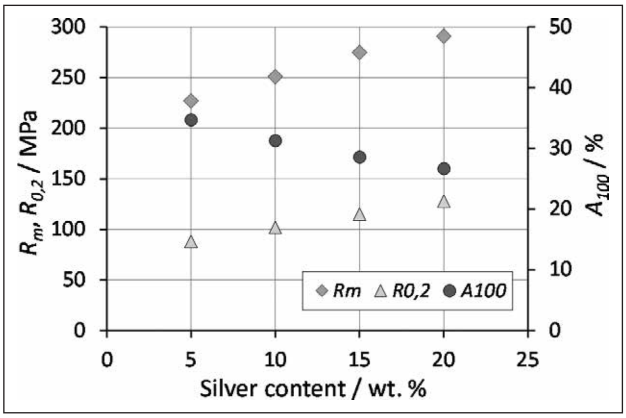

Figure 3 The influence of the Ag content on strength properties

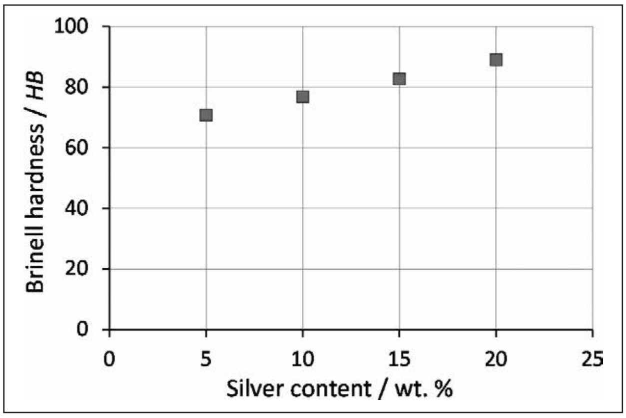

Figure 4 The influence of Ag content on hardness

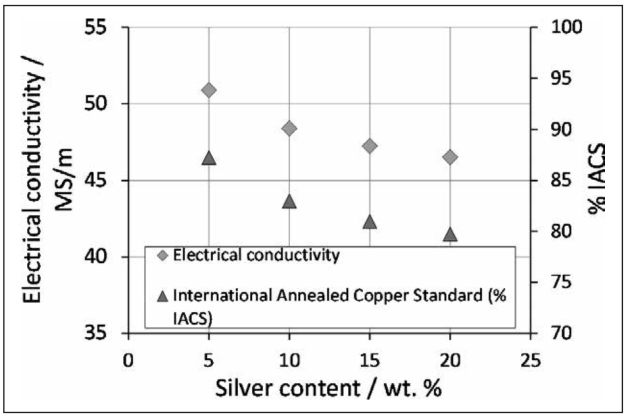

Figure 5 The influence of Ag content on electrical conductivity

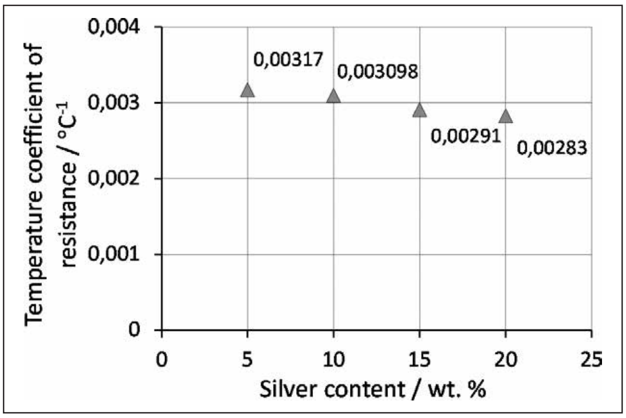

Figure 6 The influence of Ag content on the temperature coefficient of resistance

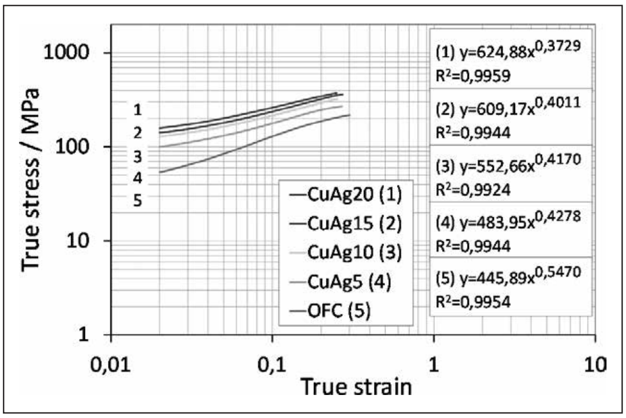

Figure 7 Characteristics of strengthening of Cu-Ag alloys determined in the tensile test and Hollomon's equation

As presented there is a quasi-linear dependance regarding the density and the Ag content of the alloys. Figure 3 and 4 present the influence of the Ag content on the evolution of mechanical properties of the tested Cu-Ag alloys. The values presented at the graphs are the average values obtained using the proper standards. Figure 5 presents the electrical conductivity results and Figure 6 shows the influence of the amount of Ag in the alloy on the temperature coefficient of resistance of the cast-rods. As reference, the values for the oxygen free copper were also provided. Among the tested temperature range (20 – 100 °C) and the Ag content (5 – 20 wt. %) the wires obtained from the cast-rods in the as-cast state the changes in the temperature coefficient of resistance show linear characteristics. Figure 7 presents the strengthening characteristics of Cu-Ag alloys in the as-cast state determined in the uniaxial tensile test based on the Hollomon's equation with the same characteristics obtained for oxygen free copper in the as-cast state as reference.

CONCLUSIONS

On the basis of the conducted research and results analysis the following may be concluded:

Cu-Ag alloys obtained in the continuous casting process are characterized with homogeneous chemical composition and both mechanical and electrical properties. The tested alloys show significantly higher strengthening potential than pure copper. The proper heat treatment parameters (super-saturation and aging) may allow for effective change of microstructure towards controlled precipitation of silver from copper. It may further increase the mechanical properties. The electrical conductivity will increase due to the intentional precipitation of alloy additive from the matrix. The combination of precipitation and strain hardening of Cu-Ag alloys may consequently result in the obtaining of materials of very high mechanical and electrical properties required by some applications in the field of electrical engineering.

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Note: The translator responsible for English language: Paweł Strzępek, Kraków, Poland