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THE INFLUENCE OF HEAT TREATMENT AND PLASTIC DEFORMATION ON THE ELECTRICAL AND MECHANICAL PROPERTIES OF CuAg ALLOYS FOR THE CONSTRUCTION OF HIGH-FIELD BITTER TYPE ELECTROMAGNETS

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Cu-Ag alloys may be used in the form of sheets for the construction of bitter type magnets. The paper presents results of laboratory studies on obtaining of ingots from Cu-(1÷7wt.%)Ag alloys, solution treatment and aging and rolling process. Has been shown influence of different heat treatment and plastic deformation on the mechanical and electrical properties. The microstructural analysis of castings and sheets with the use of scanning electron microscopy (SEM) is also presented.

Keywords: Cu-Ag alloys, sheets, heat treatment, electrical conductivity, hardness, X-ray research

INTRODUCTION

The article presents a portion of research results concerning designing of new materials which might be used in the construction of Bitter electromagnets generating a strong magnetic field. Bitter type electromagnet (First design by F. Bitter in 1936) consists of metal discs and arranged spirally insulating spacers placed in a steel body strengthening the structure [1]. Currently used Bitter type electromagnets are mostly made of perforated, round, copper plates with a hole in the centre working with constant water cooling at 40-50 °C generating magnetic field of approx. 30 Tesla [2-3]. The holes in the sheet make it possible to effectively cool the electromagnet. High values of magnetic field generated by electric current of high intensity flowing through the electromagnet result in not only large amount of Joul's heat and but also irregular inducing of very high values of Lorentz forces which may lead to the destruction of the plates and thus the entire structure [4-5]. The material dedicated for plates manufacturing is expected to have high mechanical strength capable of transferring magnetic tensile forces and simultaneously of high electrical conductivity, allowing the electromagnet to obtain higher power limiting at the same time thermal effects [6-8].

Generating a magnetic field of higher value than currently obtained 30 Tesla may be possible either through the modification of electromagnet construction or using new materials with a higher than commonly used copper set of operational properties [9-11]. Such requirements may be met by plates made of e.g. Cu-Ag alloys due to both high mechanical and electrical properties achieved by these alloys but also a high fatigue, impact and heat resistance.

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EXPERIMENTAL DETAILS

The amount of silver alloy additive in copper alloys in hypoeutectic range and both the heat treatment and cold rolling parameters and their influence on the change of mechanical and electrical properties of the alloys were investigated. The following ingots were prepared: oxygen-free copper (Cu-OF) as reference material and four Cu-Ag alloys of nominal chemical composition: CuAg1; CuAg3; CuAg5, CuAg7. Metallurgical synthesis of Cu-OF and silver of high purity (99,99 wt. %) was conducted in a graphite crucible as it is hardly wettable by copper [12] at 1 230 – 1 250 °C in inert gas atmosphere. The obtained ingots were homogenized at 750 °C for 20 hours with further rapid cooling to achieve supersaturation. The supersaturated alloys were subjected to initial plastic deformation via cold rolling with the true deformation value of 0,22. The primary aging of the alloys (first stage) was conducted at 250 °C for 20 hours and the secondary aging (second stage) was conducted at 450 °C for 8 hours. The alloys were further subjected to the actual longitudinal cold rolling with accumulative true strain of 3,4. Analogical metal working process was conducted for Cu-OF ingot. Using SEM analysis of Cu-Ag alloys was conducted.

RESULTS AND DISCUSSION

The chemical composition analysis of the tested materials which confirms high purity of the obtained ingots was presented in Table 1.The influence of the heat treatment and metal working on the changes in hardness and electrical conductivity of Cu-Ag alloys was presented at Figure 1., a-e. Research was conducted on the samples in the as-cast state, after supersaturation, after initial deformation (cold rolling), after both the first stage and the second stage of heat treatment. The obtained in this state alloys were further subjected to target plastic deformation in the longitudinal cold rolling process.

Table 1 **Chemical composition of the ingots / ppm**

Elements	Element content / wt %				
	Cu-OF	CuAg1	CuAg3	CuAg5	CuAg7
Ag	11,5	1,02	3,04	4,95	7,04
Element content / ppm					
Bi	0,12	0,13	0,19	0,17	0,16
Pb	0,86	0,64	0,52	0,44	0,51
Sb	0,82	0,63	0,37	0,37	0,77
As	0,38	0,55	0,44	0,34	0,43
Fe	1,41	2,10	1,96	1,25	1,69
Ni	1,43	1,51	1,15	1,13	1,07
Sn	0,29	0,32	0,34	0,3	0,35
Zn	1,28	1,54	1,22	1,21	1,32
Cd	0,01	0,01	0,03	0,04	0,03
Co	0,04	0,03	0,03	0,04	0,03
Cr	0,04	0,07	0,11	0,06	0,07
Mn	0,03	0,03	0,11	0,09	0,05
P	0,32	1,27	0,32	1,24	0,78
Se	0,11	0,10	0,15	0,12	0,14
Si	0,22	0,61	1,34	0,89	1,32
Te	0,13	0,18	0,22	0,15	0,21
S	1,35	2,23	2,30	2,48	1,98
O_2	2,8	8	10	7	9

Cu-Ag alloys are characterised by limited solubility in the solid state of both silver in copper and copper in silver. Through multi-stage heat treatment and metal working of the ingots in appropriately selected conditions (time of homogenization, supersaturation and aging) it was possible to effectively modify the microstructure of the alloys. The first stage of heat treatment (250 *°C/*20h) resulted in precipitating of numerous, fine silver particles, while the second stage of heat treatment (450 °C/8h) contributed to their growth thus most of silver precipitated from the solution. After heat treatment of hypoeutectic Cu-Ag alloys (below 7,9 wt.% of Ag) the microstructure consisted of the copper matrix containing unprecipitated silver and precipitations reach in silver containing small amounts of unprecipitated copper. This phenomenon causes a large increase in hardness of the obtained alloys with high level of electrical conductivity remaining.

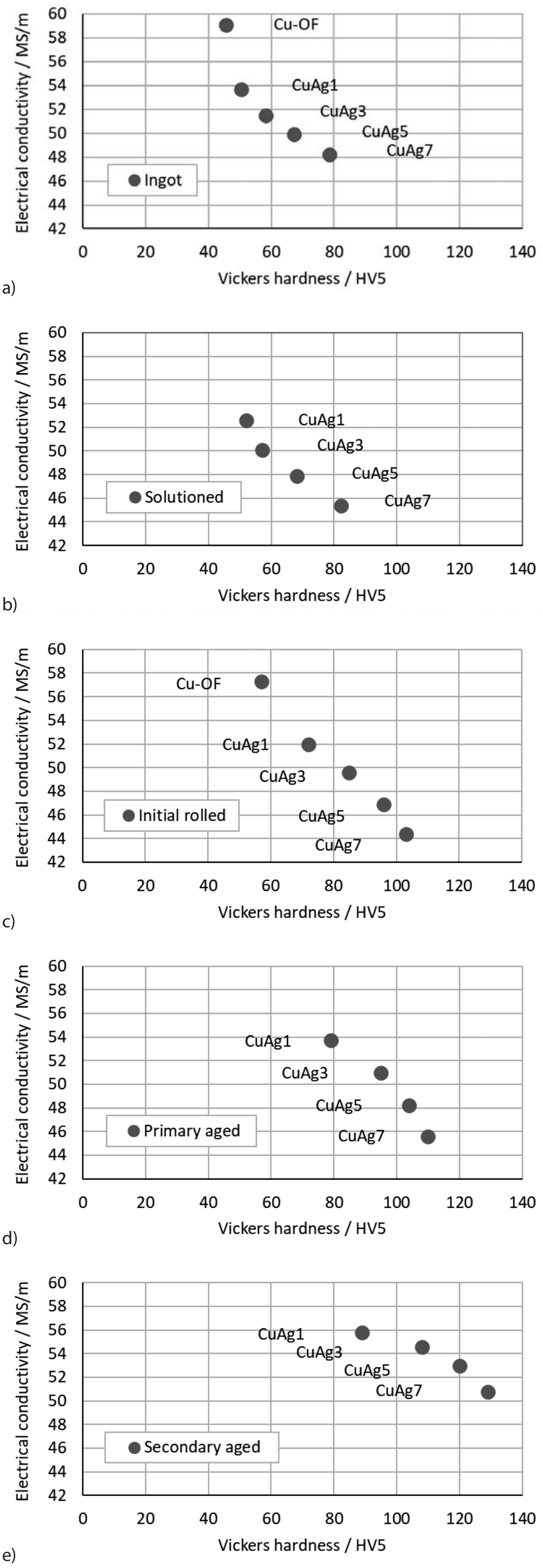


Figure 1 The influence of heat treatment and deformation on hardness and electrical conductivity of Cu-Ag alloys: a) as-cast state b) supersaturated c) initial metal working d) primary heat treatment e) secondary heat treatment

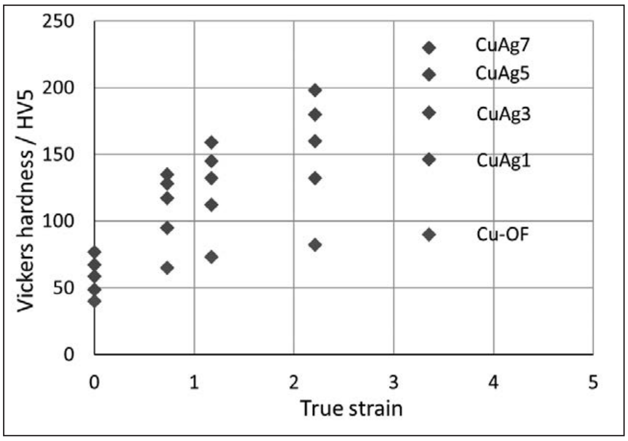


Figure 2 The influence of amount of cold rolling deformation on the change of Vickers hardness of Cu-Ag alloys

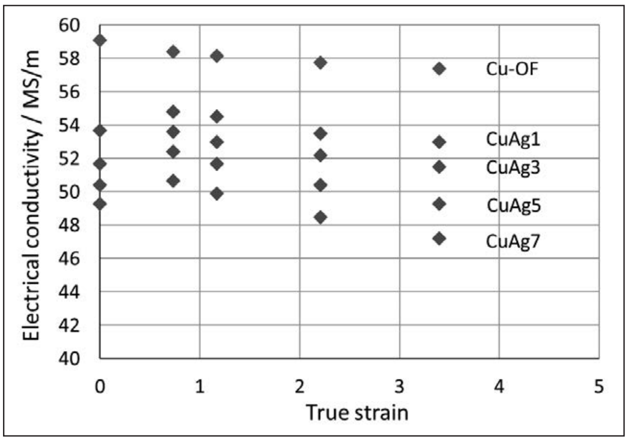
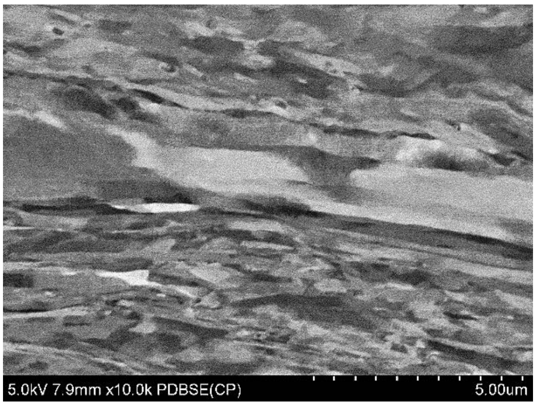
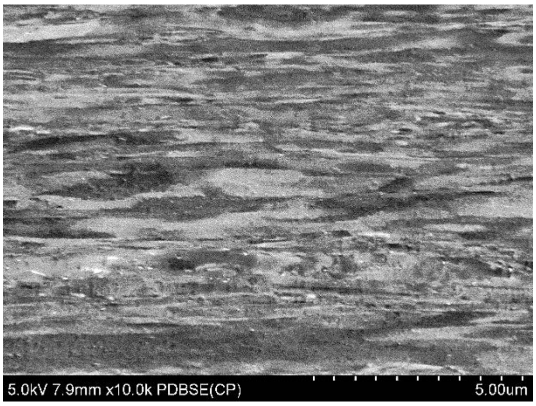


Figure 3 The influence of amount of cold rolling deformation on the change of electrical conductivity of Cu-Ag alloys

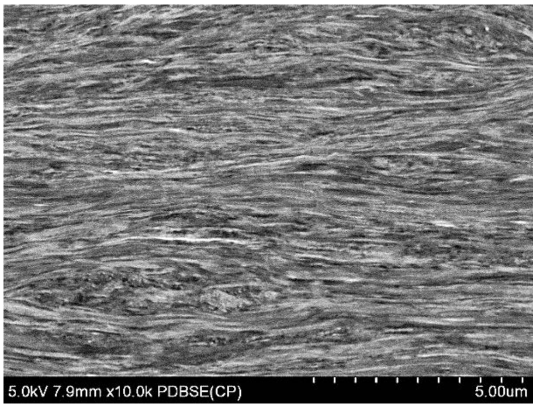
Second stage of heat treatment contributed to not only significant increase in hardness but also electrical conductivity of all tested Cu-Ag alloys. It should be noted that the higher the silver content in the alloy the higher the measured hardness values prior their plastic cold deformation. As it may be noticed when analysing Figures 2 and 3 silver precipitation due to high amount of plastic deformation causing strong deformation and structural defects thus creating a reinforcing phase, which significantly increases their strength properties. The tested materials show quasi-linear increase of hardness even after strong deformation. At the same time, the elongated grains of copper and silver occurring alternately at the entire volume forming a kind of parallel connections system of two excellently conductive materials which despite strong plastic deformation do not lose significantly their electrical conductive properties. Due to the very large amount of grain boundaries and high plastic deformation as the amount of silver increases the decrease of electrical conductivity is faster. When analysing SEM images of the obtained Cu-Ag alloys sheet samples presented at Figure 4 it is visible that the high amount of plastic deformation contributed to elongation of silver precipitates resulting from heat



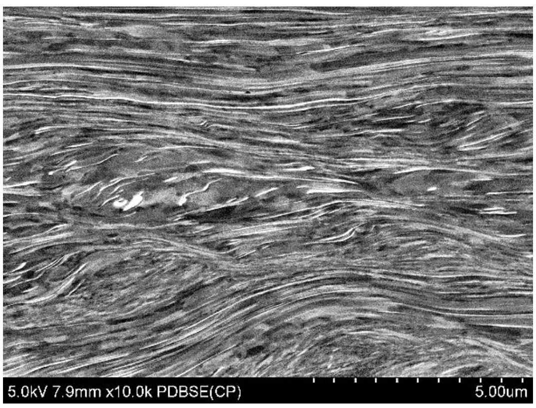
a) Longitudinal-section of CuAg1 at the rolling direction



b) Longitudinal-section of CuAg3 at the rolling direction



c) Longitudinal-section of CuAg5 at the rolling direction



d) Longitudinal-section of CuAg7 at the rolling direction

Figure 4 SEM analysis of the Cu-Ag alloys after plastic deformation with accumulative true strain of 3,4 on the longitudinal-section at the rolling direction treatment and metal working of the alloy. The microstructure at the longitudinal-section of the obtained sheets consists of numerous thin, highly elongated silver fibres (almost entirely made of copper with residual copper, white areas) visible against almost entirely copper matrix (dark areas).

CONCLUSIONS

The experimental research on microstructure and properties shaping of Cu-Ag alloys was presented. Based on the obtained results a significant influence of multistage heat treatment on not only microstructure but also mechanical and electrical properties of Cu-Ag alloys was proven. The appropriate modification of the cast structure made it possible through cold rolling to obtain sheets with high mechanical and electrical properties. The obtained results indicate the possibility of manufacturing Bitter's electromagnets with Cu-Ag plates which are characterised with more favourable operational parameters and functional properties than materials used for their construction up until now.

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