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RESEARCH ON THE INFLUENCE OF THE PROPORTION OF NICKEL AND SILICON ON THE MECHANICAL AND ELECTRICAL PROPERTIES OF CuNiSi ALLOYS

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The article presents research on the metallurgical synthesis of the CuNiSi alloy with a nickel content of 2,2 wt.% and silicon in the range of 0,8 – 1,3 wt.%. Each of the produced materials were subjected to the process of homogenization, solution heat treatment and artificial aging in order to improve the mechanical and electrical properties. Materials were directed to the chemical composition tests, Vickers hardness and electrical conductivity tests and also for microstructural tests with using scanning electron microscopy (SEM).

Keywords: CuNiSi alloy, chemical composition, aging, hardness, electrical conductivity

INTRODUCTION

CuNiSi alloys belong to the group of precipitation hardening alloys, fine and uniformly distributed separate Ni-Si strengthening phases takes place in the material's structure as a result of their heat treatment [1]. These alloys, due to their attractive mechanical, electrical and functional properties (high resistance to atmospheric corrosion, high resistance to stress and elevated temperatures, high rheological resistance, good machinability and susceptibility to plastic forming processes) are widely used in industry [2-4]. They are used e.g. in the railway industry for the production of various types of holder, fastening elements, clamps, electrical connectors, they are also used in the electronic industry for the production of semiconductor components or cooling system components in foundry system [5-7]. The alloy with the nickel concentration of 1,6-2,5 % and silicon 0,5-0,8 % is the most commonly used one [8-9]. CuNiSi alloys, depending on the content of alloying elements and their mutual proportions, differ in the properties that can be achieved. The temperature and time range of the supersaturation and aging processes which leads to the formation of the final properties of the material is closely related with the chemical composition of the alloy and its state of structure [10-12].

EXPERIMENTAL PROCEDURE

Process of the metallurgical synthesis of each of the four different CuNiSi alloys (2,2 % Ni, variable Si content: 0,8; 0,9; 1,1; 1,3 % Si) was started by melting the base metal in the laboratory resistance furnace heated to 1 250 °C. Copper was melted for about 45 minutes, and then appropriate amounts of alloy additions were introduced. One hour after the introduction of the first alloy addition, the crucible was removed from the furnace and left in air until full crystallization. Final result of the casting process were ingots with a diameter of ϕ = 40 mm, which were homogenized and supersaturated.

Samples were placed in a resistance furnace for 8 h at 900 °C. Samples subjected to homogenization treatment were cooled in the air after extraction from the furnace, while the samples subjected to supersaturation were cooled into water. The supersaturated samples were directed to artificial aging process, the materials were exposed to three different temperatures: 450, 500, 550 °C for a total time of 24 hours. Then, the materials were removed at 1 h intervals and after surface preparation, were directed for further testing. The alloys were tested for chemical composition on the SPECTROTEST spectrometer. CuNiSi samples in each of the material states (cast, after homogenization, supersaturation and aging processes) were tested in terms of mechanical and electrical properties. Hardness was measured using the Vickers method using an automated Tukon 2500 Wilson Hardness tester with a load of 10 kgf. The electrical properties of the alloys were tested using the Sigmatest 2 069/Foerster device using the eddy current method. In addition, materials after supersaturation and aging at 500 °C for 5 h were sent for microstructural tests conducted using the scanning microscope Hitachi SU-70 Scanning Electron Microscope (SEM).

RESULTS AND DISCUSSION

The results of the chemical composition measurements are shown in Table 1, the obtained results corre-

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Table 1 **Chemical composition research results of CuNiSi alloy / wt. %**

Material	Ni	Si	Zn	Fe	Pb	Mn	Cr	As	Cd	Cu
CuNi2,2Si0,8	2,18	0,76	<0,015	<0,008	<0,004	<0,004	<0,003	<0,003	<0,003	rest
CuNi2,2Si0,9	2,13	0,87	<0,015	<0,008	<0,004	<0,004	<0,003	<0,003	<0,003	rest
CuNi2,2Si1,1	2,13	1,08	<0,015	<0,008	<0,004	<0,004	<0,003	<0,003	<0,003	rest
CuNi2,2Si1,3	2,17	1,28	<0,015	<0,008	<0,004	<0,004	<0,003	<0,003	<0,003	rest

Table 2 **Vickers Hardness / HV10**

Material	Cast	Homogenized	Supersaturated
CuNi2,2Si0,8	129,5	133,4	51,5
CuNi2,2Si0,9	153	106,5	47,9
CuNi2,2Si1,1	181,6	115,6	50,1
CuNi2,2Si1,3	114,6	81,78	50,9

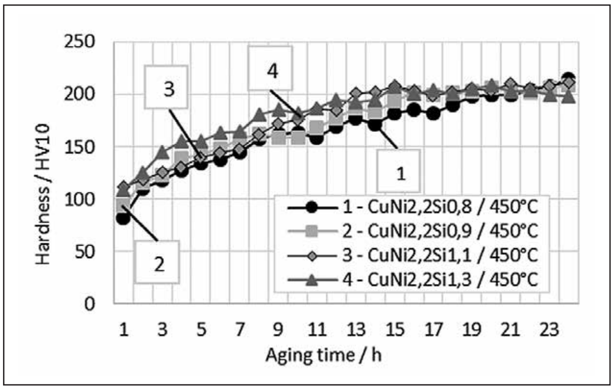

Figure 1 Vickers hardness of CuNi2,2Si0,8-1,3 after aging at 450 °C

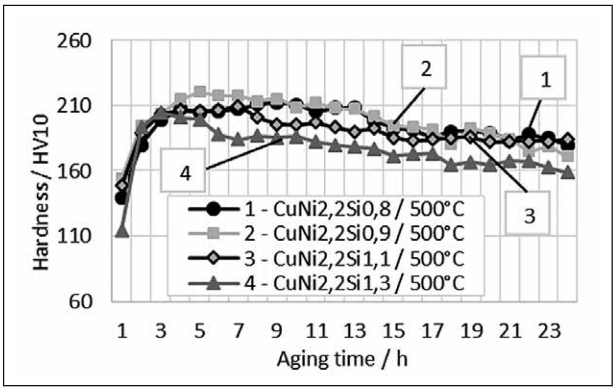

Figure 2 Vickers hardness of CuNi2,2Si0,8-1,3 after aging at 500 °C

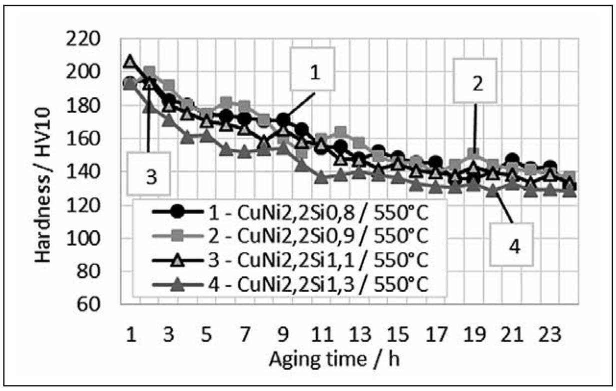

Figure 3 Vickers hardness of CuNi2,2Si0,8-1,3 after aging at 550 °C

spond with high accuracy to the expected level of alloy additions, and the level of impurities, especially from the group of heavy metals is at an acceptable level. Table 2 shows the hardness results for materials in as cast state and after homogenization and supersaturation treatment. Figures 1-3 present the results of hardness test of materials subjected to artificial aging for 24 hours. CuNiSi alloy with 2,2 % nickel addition and the variable content of the silicon shows an increase in hardness with the increasing Si addition in the alloy in the as cast state. Hardness of the alloys ranges from 129,5 HV10 for CuNi2,2Si0,8 to 181,6 HV10 for CuNi2,2Si1,1, the exception to this dependence is the alloy with the highest nickel content, its hardness is slightly lower (114,6 HV10). It is worth nothing that for the CuNi2,2Si0,8, unlike the others alloy, the hardness of the material slightly increased after homogenization compared to its hardness in as cast state. All analysed alloys show a similar level of hardness after supersaturation, ranging from 47,9 to 51,5 HV10.

Comparing the aging characteristics of the CuNi2,2Si alloy with different silicon content and carried out at the temperature of 450°C, a linear increase in hardness with the heat treatment time is noticeable, higher hardness level is reached by alloys with a higher silicon content. It is worth noting that the increase in hardness for each of the alloys is significant and amounts to approx. 100 HV10 in the aging time range from 1 to 24 h.

Analysing the aging characteristics at 500 °C, a significant increase in hardness is visible in the first 4 hours of treatment, after this time there is a decrease in mechanical properties of all alloys with increasing the aging time. Optimal aging time at 500 °C is 3-8 hours, higher hardness level is shown for alloys with the lower addition of nickel (0,8-0,9 %). At the aging temperature of 550°C, a decrease in alloy hardness is observed after 1-2 hours from the start of heat treatment, these alloys have a maximum hardness of approx. 200 HV10.

The obtained results of the electrical properties measurements of the alloys are shown in Table 3, the aging characteristics of the alloys, depending on the temperature process, are shown in Figures 4-6.

CuNiSi alloy with 2,2 % of nickel addition and a variable content of silicon shows a decrease in electrical properties with increasing Si content, both in the as cast state as well after heat treatment.

Artificial aging of the CuNi2,2Si alloys carried out at the temperature of 450 °C contributes to an increase in electrical properties along with the treatment time, this increase is greater for alloys with lower Si content

Table 3 **Electrical conductivity / MS/m**

Material	Cast	Homogenized	Supersaturated
CuNi2,2Si0,8	13,3	12,89	11,76
CuNi2,2Si0,9	12,45	10,88	10,38
CuNi2,2Si1,1	11,76	10,53	9,46
CuNi2,2Si1,3	8,67	8,34	8,29

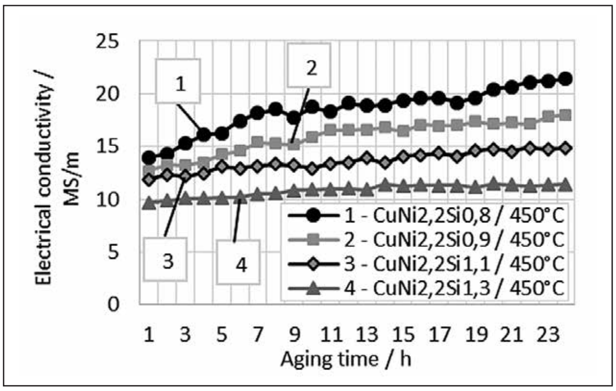

Figure 4 Electrical conductivity of CuNi2,2Si0,8-1,3 after aging at 450 °C

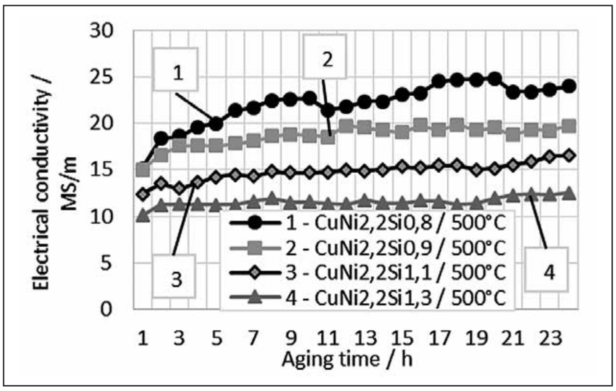

Figure 5 Electrical conductivity of CuNi2,2Si0,8-1,3 after aging at 500 °C

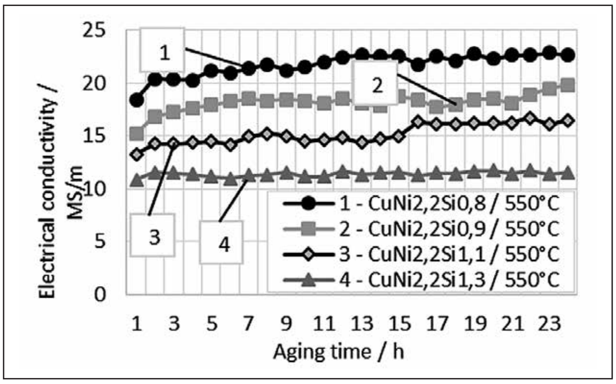

Figure 6 Electrical conductivity of CuNi2,2Si0,8-1,3 after aging at 550 °C

(0,8-0,9 %). Alloys are characterized by higher electrical conductivity and its higher increase for lower content of silicon addition, the highest electrical properties are shown for the CuNi2,2Si0,8 alloy. Similar relationship is observed for the aging process carried out at 500 °C and 550 °C, the highest electrical properties has CuNi2,2Si0,8 alloy (up to 25 MS/m).

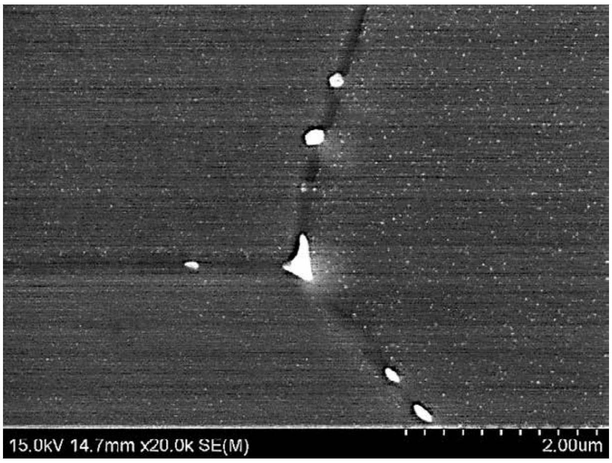

Figure 7 Microstructure of CuNi2,2Si0,8 after aging at 550 °C / 5h (SEM)

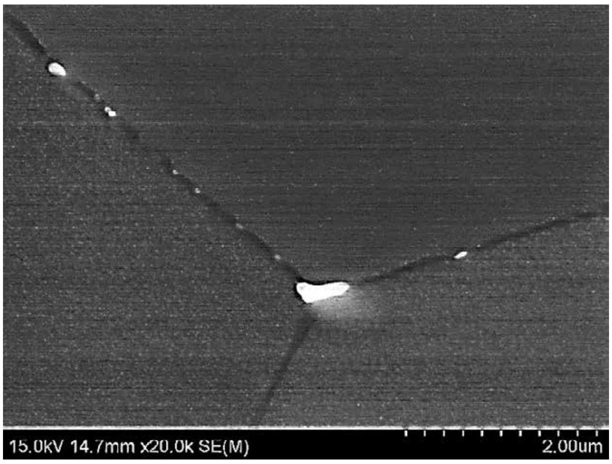

Figure 8 Microstructure of CuNi2,2Si0,8 after aging at 550 °C / 5h (SEM)

Figures 7-10 presents results of microstructural research on CuNiSi alloys after supersaturation and aging at 500 °C for 5 h. Microstructures of CuNiSi alloys after the precipitation hardening process made on the SEM microscope are differ depending on the silicon amount in the alloy. For the alloys with lower Si content mainly elongated primary precipitates are visible, while for the alloy with higher silicon content (CuNi2,2Si1,1 and

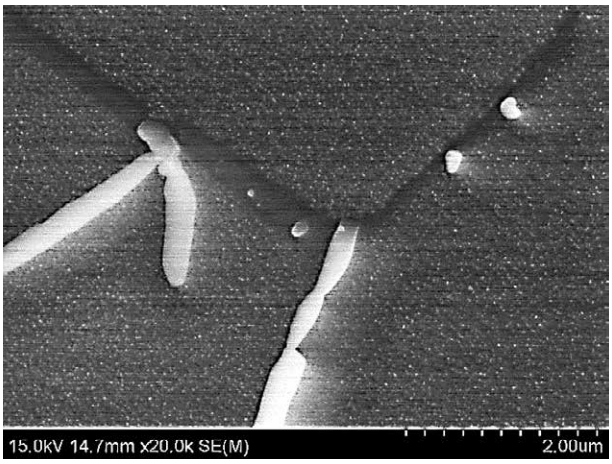

Figure 9 Microstructure of CuNi2,2Si1,3 after aging at 550 °C /5 h (SEM)

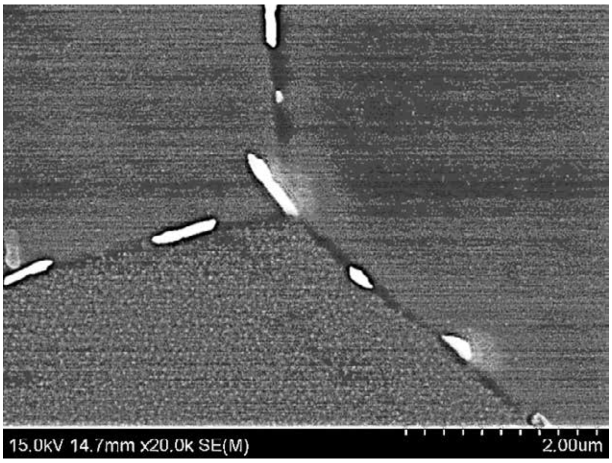

Figure 10 Microstructure of CuNi2,2Si1,3 after aging at 550 °C /5 h (SEM)

CuNi2,2Si1,3) there is more visible - resulting from heat treatment - numerous fine precipitates.

CONCLUSIONS

Precipitation hardening CuNiSi alloys with 2,2 % nickel content and various amounts of silicon have a great possibilities to control their properties through the mutual proportion of alloy additives and heat treatment conditions. On the basis of the carried out research it can be seen that both the time and temperature of artificial aging, as well as the silicon content have a strong influence on the final electrical and strength properties of the alloy. Therefore, it is possible to control the final properties of the alloy in terms of its intended use and production requirements. Based on the conducted tests, the best set of properties has the alloy with the lowest nickel content CuNi2,2Si0,8, aging process at 500 °C results in a significant increase in hardness already within the first 4 hours of heat treatment, reaching the optimum in the range of 3 to 8 hours (approx. 210 HV10). In addition, this alloy shows the highest electrical conductivity at each of the aging temperatures. The highest given artificial aging temperature (550 °C) already in 2 h of heat treatment allows to obtain electrical conductivity of the material above 20 MS/m (at 500 °C it takes 6 h of aging process). With higher Si content in the alloy it can be seen more fine precipitates in the microstructure, which were observed with using scanning electron microscopy.

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