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THE INFLUENCE OF CONTINUOUS CASTING AND EXTRUSION PROCESSES ON THE PROPERTIES AND STRUCTURE OF CuNi2Si ALLOY AND THE MORPHOLOGY OF THE Ni-Si PHASE PRECIPITATES

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Preliminary Note – Prethodno priopćenje

CuNiSi alloys are widely used in various mechanical and electrical applications. These group of materials, due to the phenomena of precipitation hardening, are able to obtain high mechanical properties with also relatively high electrical properties. In the article authors compare two different types of products, made from the CW111C alloy i.e. rods which were continuously cast on the horizontal laboratory casting set-up (low degree of structure refinement) and rods commercially extruded with high degree of structure refinement. The presented results of experimental work characterize the tested materials in terms of their chemical composition, mechanical and electrical properties depending on the manufacturing process, as well as reveal their structures and the effect of heat treatment on the morphology of the Ni-Si precipitates.

Keywords: CuNiSi alloy, continuous casting, extrusion, heat treatment, microstructure

INTRODUCTION

Materials based on CuNiSi alloys are widely used in many industries where high mechanical and electrical properties are required [1 - 4]. In the group of CuNiSi alloys, several grades can be distinguished that meet the above requirements, which depends mainly on the amount of alloy additions introduced to copper. In the article, tests were carried out on the CW111C alloy with a nominal chemical composition of CuNi2Si0.5, which is used i.e. for the load and current carrying overhead traction railway and tramway equipment [5 - 7]. CuNiSi alloys are characterized by high susceptibility to metal forming processes, especially in the process of forging, extrusion or rolling [1 - 2, 8 - 10]. The CW111C alloy is a material that can be heat treated in the processes of solutioning and aging. Products which are based on the CuNiSi alloy are most often manufactured in two typical technological routes, i.e. in the process of continuous casting with subsequent metal forming in the form of die forging or rolling and in the process of semi-continuous casting with subsequent hot extrusion into rods and following metal forming. The both mentioned alloy production paths which are based on the continuous casting process and the semi-continuous casting process with subsequent extrusion of the material, allow to produce semi-finished products with a diversified metal macrostructure and by that also different properties. For this reason, this article attempts to assess the impact of the macrostructure on the properties and morphology of the precipitates of the CW111C alloy rods after their heat treatment.

EXPERIMENTAL PROCEDURE

Research material

Experimental procedure included the use of CuNiSi alloy with a known chemical composition in the form of rods with a diameter of 18 mm. The amount of the main alloying additives present in the tested materials is given in Table 1. For all the tests and materials used within the scope of this article, chemical composition was tested and kept at the same level independently from the chosen rod production method i.e. horizontal continuous casting and extrusion process.

Table 1 **Chemical composition / wt. %**

Ni	Si	Fe	Cu
2,42	0,60	0,02	Rem

Heat treatment

The tests were carried out for three states of heat-treated materials, i.e. homogenized for 20 h with subsequent slow cooling in the furnace volume for approx.

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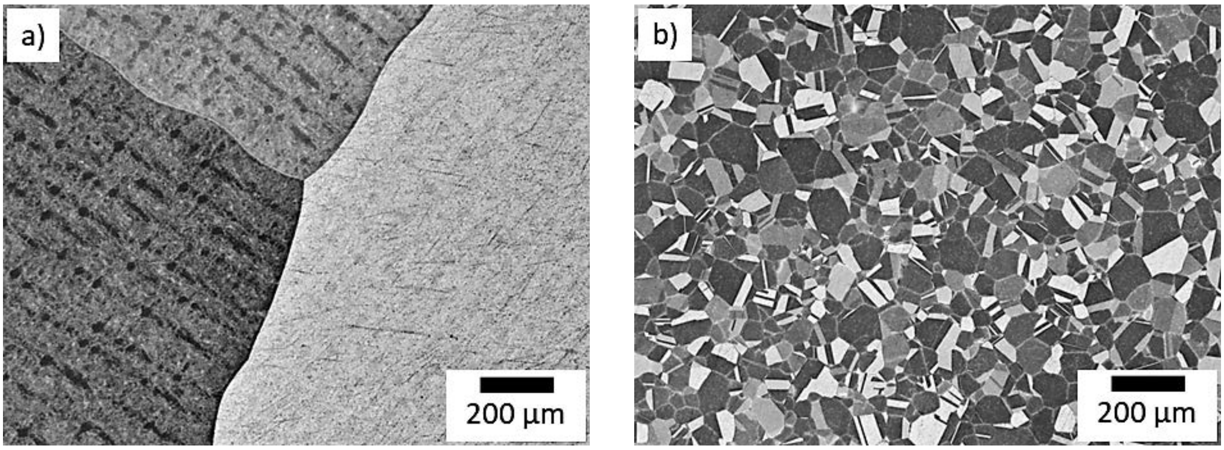

Figure 1 Macrostructures of samples after homogenization (I); a) rod produced in the continuous casting process, b) rod produced in the extrusion process

20 h (I), homogenized for 20 h with subsequent supersaturation into water (II) and homogenized for 20 h with supersaturation into water and following artificial aging at 500 °C for 5 h and subsequent free cooling at room temperature (III). Heat treatment of each of the above mentioned variants was carried out in a CZYLOK FCF22 resistance furnace. The samples subjected to heat treatment were annealed each time under graphite flakes cover in order to protect their surface against oxidation.

Material properties

Macrostructural analysis were carried out with the use of ZEISS stereoscopic microscope, model Stemi 305, on previously prepared metallographic specimens. The Hitachi SU-70 scanning microscope with the SE detector was used for microstructural observations and examination of the chemical composition of the precipitates. The EDX detector was used to analyse the chemical composition. Material properties tests included: analysis of electrical conductivity (γ), hardness (Vickers method - HV10) and strength properties (conventional yield strength - $R_{p0.2}$, tensile strength - R_m). All above mentioned research tests were carried out on samples of materials produced by two main productional paths and for all three states of their heat treatment. Electrical conductivity was determined on the basis of resistivity measurements using a Thomson bridge and the Bruster RESISTOMAT measuring unit, model 2304. The resistance measurements were performed with 100 mm measurement basis, at a stabilized temperature of samples at the level of 20 °C. The hardness of the materials was determined on the cross-sections of rods in accordance with EN ISO 6507-1:2018-05 on the basis of Vickers hardness measurement method with the use of Wilson Hardness Tukon 2500 automated hardness tester. Mechanical properties were determined in static uniaxial tensile test on samples in the form of rods with 50 mm measurement base with the use of Zwick Roell Z100 universal testing machine. Obtained results of all tests were presented as an average form calculated on the basis of at least ten measurements of the tested material property.

RESULTS AND DISCUSSION

Macrostructural analysis

The main variable between the tested materials was the method of their preparation, and thus their macrostructure. Figure 1 shows the macrostructure of a rod casted in a continuous process and a rod after casting and following extrusion. In both cases, the rods were subjected to the homogenization process in accordance with the covered scheme (I).

As observed, the crystallites in the casted rod take the form of non-axed (columnar) grains of large size and elongation, which is in accordance with the direction of casting process. Measurements of the grains on the longitudinal section showed that their length oscillated from 5 up to 10 mm. For this reason, there is only a few crystallites on the cross-section of the material, which is associated with a small number of grain boundaries. On the other hand, the crystallites observed in the extruded material take the form of fine equiaxed grains, the size of which does not exceed 135 µm, and often less than 50 µm. Regardless of the applied heat treatment, grain growth was not observed. Based on the above it was already assumed that in both compared materials, only the impact of the macrostructural effect will be visible on the material properties.

Microstructural analysis

The microstructural studies showed the nature of the precipitates of the Ni - Si phase, which existence was previously confirmed by chemical composition analysis of visible precipitates. The homogenization process was aimed to eliminate any work hardening in order to achieve the primal macrostructure of the material which were initially dependent on the given production pro-

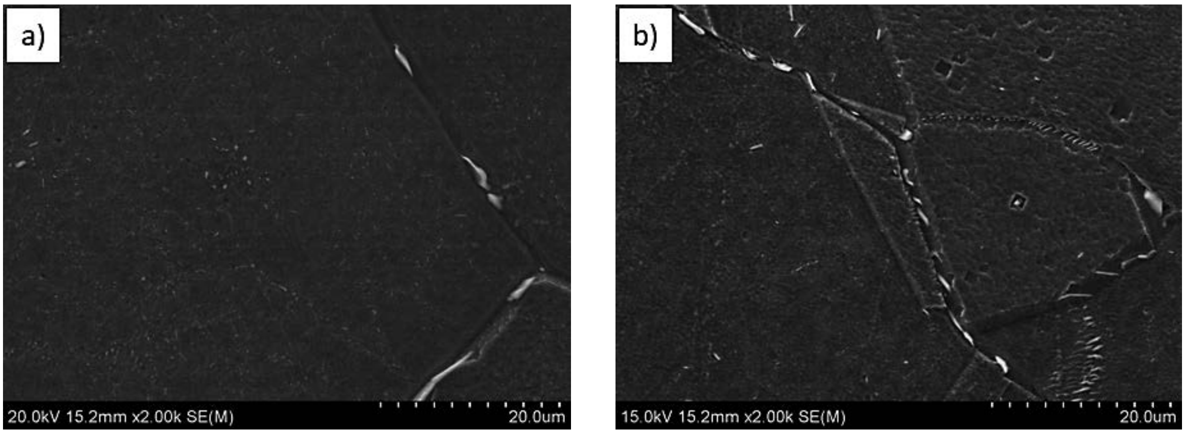

Figure 2 Microstructure of rods in I state; a) casted rod, b) extruded rod

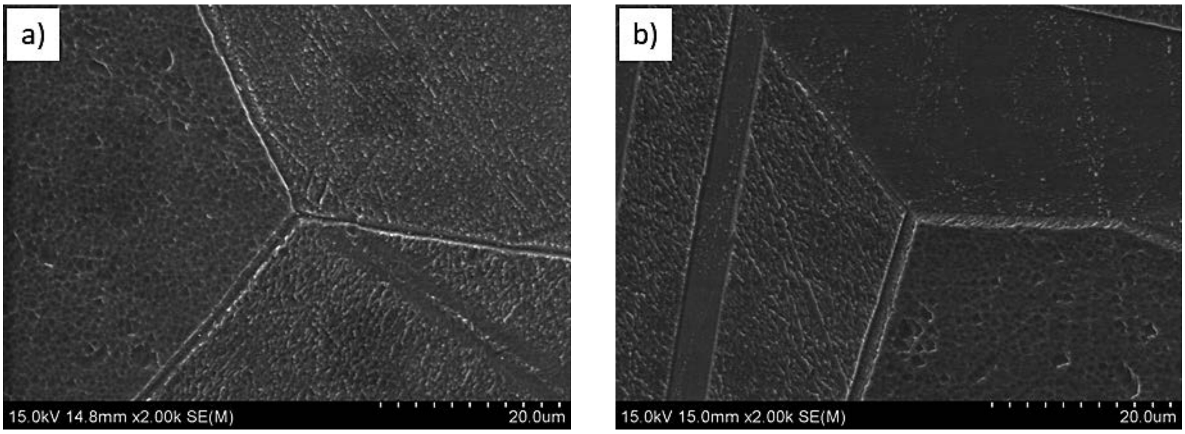

Figure 3 Microstructure of rods in II state; a) casted rod, b) extruded rod

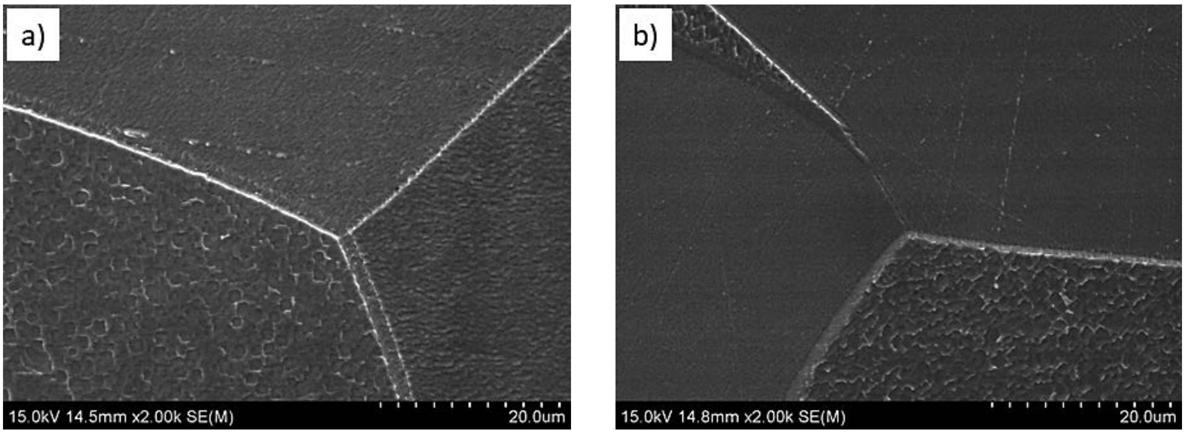

Figure 4 Microstructure of rods in III state; a) casted rod, b) extruded rod

cess. Figures 2, 3 shows a comparison of the microstructure of the CW111C alloy rods after casting and extrusion processes in different states of their heat treatment.

Analysis of presented microphotographs showed that heat treatment process in variant I results in the formation of primary precipitates at grain boundaries. In the case of cast bars, the precipitates are thread-like with a length of about 8 µm. Similar type of primary precipitates are observed for extruded rod after the same heat treatment conditions. However, in this case, observed precipitates are much smaller, ranging from 0,8 - 4 µm. These precipitates show a punctual character with a greater degree of dispersion at grain boundaries. The supersaturation of samples, carried out in accordance with variant II of heat treatment, allowed for almost complete dissolution of the primary precipitates. In the case of a casted rod, small residues of precipitates on grain boundaries were observed, but they do not exceed 0.6 µm. On the other hand, no residues of primary precipitates were observed on the extruded rod sample, which is related to their complete dissolution in the matrix volume after the sample was supersaturated in water. The application of the third heat treatment procedure results in the presence of small Ni - Si phase precipitates on grain boundaries. In the case of samples that were casted, their size did not exceed 1 µm, while in the sample that was being extruded, precipitations were not larger than 0,2 µm..

Mechanical and electrical research results

Research of material properties is a direct reflection to their heat treatment analysis. The results of electrical and mechanical properties for all materials in various states of their heat treatment are presented in Tables 2, 3.

Table 2 **Electrical and mechanical properties of casted rods**

State	γ / MS/m	HV10	$R_{p0,2}$ / MPa	R_m / MPa
I	23,29	148	282	394
II	12,13	65	68	229
III	26,43	231	498	507

Table 3 **Electrical and mechanical properties of extruded rods**

State	γ / MS/m	HV10	$R_{p0,2}$ / MPa	R_m / MPa
I	24,84	147	461	490
II	12,35	71	99	297
III	26,13	217	580	664

Obtained results indicate that electrical properties oscillate at a similar level between identical states of heat treatment for products obtained through different production methods. The analysis of mechanical properties research results shows that there is some noticeable variation, which is related to the given macrostructure (size of grains) and the accompanying precipitates. The greatest difference in ultimate tensile strength (R_m) between the two types of samples is observed for the precipitate-strengthen material (state III). The differentiation between both materials reaches almost 160 MPa, which proves a very large influence of macrostructure and presence of secondary precipitates on the work hardening level of the metal.

CONCLUSIONS

On the basis of all obtained test results, it was concluded that, regardless of the manufacturing technological process used for the production of CW111C alloy, the homogenization of the material results in the formation of Ni - Si precipitates at grain boundaries, which potentially can be the source of cracks during following metal forming processes. The precipitates in the cast material are much larger than in the case of extruded products. Supersaturation of the material after homogenization allows for the majority of the alloy additions to be retained in the matrix, which limits the occurrence of precipitations at grain boundaries. The above mentioned macrostructural effect correlates to the mechanical properties, significantly increasing them in the case of material with small grain sizes, i.e. extruded material. The conducted research did not reveal secondary precipitates, which forces the use of more advanced observation techniques (TEM) to be done in the future.

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