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STUDIES ON MAGNESIUM ADDITION TO COPPER PRODUCED IN THE CONTINUOUS CASTING PROCESS AND ANALYSIS OF MECHANICAL, ELECTRICAL AND STRUCTURAL PROPERTIES OF OBTAINED CASTS

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Preliminary Note – Prethodno priopćenje

Article presents the effect of magnesium addition to copper in the range of 0,02 – 0,5 wt. %. on the mechanical, electrical and structural properties of obtained materials. All analysed alloys were produced by horizontal continuous casting set-up in the form of 9,5 mm rods. Obtained Cu-Mg alloys were next tested for their as-cast properties via Vickers hardness analysis, electrical conductivity measurements and macrostructure observations in both cross and longitudinal section. The aim of the research was to verify the influence of the magnesium content on the properties of selected Cu-Mg alloys, which are dedicated to use in overhead railway system for contact wires and catenaries.

Keywords: continuous casting, copper Cu-Mg alloys, mechanical properties, structural properties, electrical conductivity

INTRODUCTION

Copper, due to its high electrical properties which is the highest right after silver, is commonly used in power systems in various branches of the economy. Unfortunately, pure copper is not characterized by a high set of mechanical properties, which is why it is most often used as an alloy in combination with other elements. An example of such materials is a group of Cu-Mg alloys were Mg is up to 0,7 wt. %, which are characterized by higher mechanical properties with a slight decrease in electrical conductivity, compared to pure copper [1-3]. Copper-magnesium alloys are used in the automotive industry as contacts and electrical wires. Furthermore, Cu-Mg alloys are also used as contact wires and catenaries in overhead railway traction systems - especially for high-speed rail. Based on the literature analysis, it appears that copper-magnesium alloys are characterized by high strength up to 520 MPa with an electrical conductivity of about 38 MS/m (for CuMg0.5 type alloy). These materials also show significantly lower wear through abrasion by pantograph contact strips and high corrosion resistance when used in railway systems. Copper alloys are often produced in production processes based on vertical or horizontal continuous casting processes, in which rods or bars are produced for further metal forming processing. The continuous casting process enables the production of castings of any diameter and length, which is beneficial from the railway application point of view [4-8]. As part of the work presented in the article, the continuous casting process of copper with different content of magnesium addition was analysed in terms of mechanical, electrical and structural properties differences of the obtained castings.

EXPERIMENTAL PROCEDURE

As part of the work covered by the presented article, research was carried out on continuous casting process in order to obtain rods made of various Cu-Mg alloys with a targeted diameter of 9,5 mm, along with a comprehensive analysis of their properties, whose nominal chemical compositions are presented in Table 1.

Table 1 **List of copper alloys produced on the continuous casting line**

id.	Targeted chemical composition / wt. %	
	Cu	Mg
1	99,98	0,02
2	99,95	0,05
3	99,8	0,2
4	99,5	0,5

The horizontal continuous casting process was carried out on laboratory set-up equipped with carbon components of melting and crystallization system i.e. crucible and crystallizer (see Figure 1).

Metallurgical synthesis done during continuous casting process of individual Cu-Mg alloys was carried out analogically for all selected materials. The input

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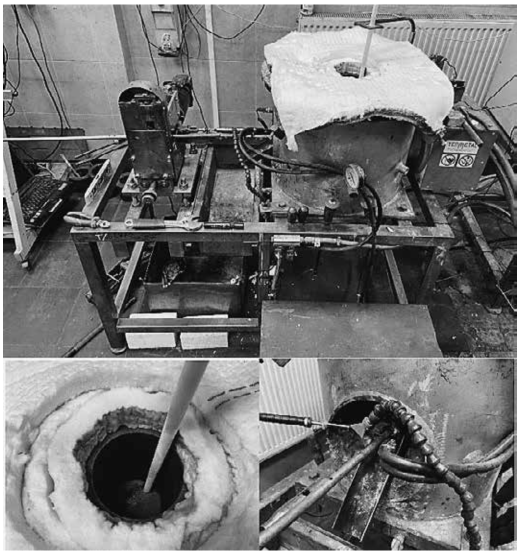

Figure 1 Laboratory line for horizontal continuous casting process used for the metallurgical synthesis and casting of Cu-Mg alloys

material were copper in the form of a cathode and scrap copper granulates mixed with a 1:1 ratio. Magnesium in appropriate amounts was added to liquid copper in it pure metallic form. After the metallurgical synthesis liquid metal was heated up to 1220 °C and homogenized for 5 minutes. The continuous casting process itself was carried out under following constant conditions: casting speed (feed/standstill) - 4 mm / 2 s, cooling fluid flow in primary cooling system – 0,4 to 0,5 l/min and the use of additional secondary cooling of the casting after crystallization. Cu-Mg rods obtained by above mentioned process were next subjected to mechanical, electrical and structural properties analysis. Mechanical tests were carried out by measuring the hardness and determining the tensile strength of samples. The hardness measurements were carried out with the use of Vickers method and HV10 scale on Tukon 2500 hardness tester. The tensile strength of individual alloys was determined in static tensile test on Zwick/Roell Z100 testing machine. The electrical conductivity measurements were carried out using the Burster Resistomat 2304 device and final macro-structural analysis was carried out on bars in both cross and longitudinal section.

RESULTS AND DISCUSSION

Figure 2 presents casted rods made of CuMg0.02, CuMg0.05, CuMg0.2 and CuMg0.5 which were next subjected to further properties analysis. Mechanical properties of the obtained materials are presented in Table 2 and Figure 3 showing that the hardness of the alloy increases with the increase of Mg content in copper. In particular, depending on the amount of Mg additive, the hardness increases from 67 HV10 for the CuMg0.02 alloy to 89 HV10 for the CuMg0.5 alloy. Similarly, the tensile strength of materials also increases with the amount of Mg, i.e. for the CuMg0.02 alloy is at the level of 160 MPa, while for the CuMg0.5 alloy it is 218 MPa.

Figure 2 Exemplary pictures of the obtained rods: a) CuMg0.02, b) CuMg0.05, c) CuMg0.2, d) CuMg0.5

Table 2 **Mechanical properties of Cu-Mg alloys in their as-cast state**

Material	Hardness / HV10	R_m / MPa
CuMg0,02	67	160
CuMg0,05	73	187
CuMg0,2	82	202
CuMg0,5	89	218

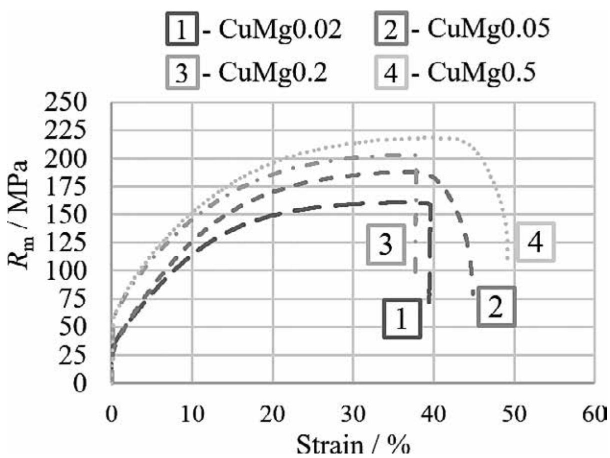

Figure 3 Stress-strain curves obtained in static tensile test for all casted Cu-Mg alloys

Analysis of electrical conductivity research results presented in Table 3 and Figure 4, shows that along with the increase of magnesium content in the chemical composition of the alloy, the electrical conductivity decreases. For the CuMg0.02alloy, the electrical conductivity is 58,3 MS/m, while for the CuMg0.05 alloy it drops down to 57,2 MS/m. Further increase of magnesium content to the level of 0.2 wt. % and 0.5 wt. % reduces its conductivity to the level of 51,3 MS/m and 39,5 MS/m, respectively.

The last stage of research included macrostructural analysis on the cross-section and longitudinal section of the obtained castings. Figures from 5 to 8 show the macrostructures of all individual materials. Analysis of above mentioned photographs allows to observe that all materials are characterized by a structure that is classic for this method of casting. The elongated grains are arranged in the direction of heat reception. In addition,

Table 3 **Electrical properties of Cu-Mg alloys in their as-cast state**

Material	Electrical conductivity / MS/m	IACS / %
CuMg0,02	58,3	100,5
CuMg0,05	57,2	98,6
CuMg0,2	51,3	88,4
CuMg0,5	39,5	68,1

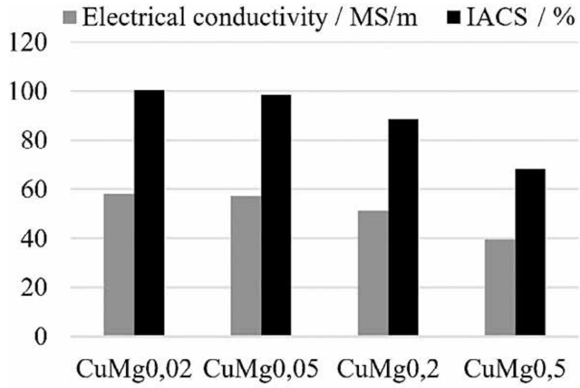

Figure 4 Electrical properties graphical representation for all casted Cu-Mg alloys

with the Mg content increase, a noticeable decrease in the average grain size in the material structure is being observed.

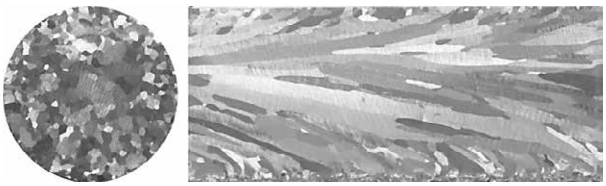

Figure 5 CuMg0.02 alloy macro-structure

Figure 6 CuMg0.05 alloy macro-structure

Figure 7 CuMg0.2 alloy macro-structure

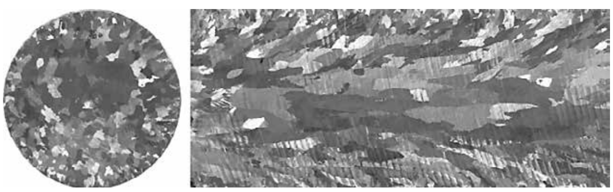

Figure 8 CuMg0.5 alloy macro-structure

CONCLUSIONS

Based on the conducted research, following conclusion have been taken:

- the horizontal continuous casting process enables the production of Cu-Mg alloys with the addition of magnesium up to 0,5 wt. % in a controlled way,
- casted materials are characterized by an increase in mechanical properties in accordance with an increase in the magnesium content, i.e. maximum hardness of 89 HV10 and maximum R_m of 218 MPa for the CuMg0.5 alloy,
- as the magnesium content in copper increases, the electrical conductivity of materials decreases from 58,3 MS/m for the CuMg0.02 alloy to 39,5 MS/m for the CuMg0.5 alloy,
- studies of the Cu-Mg alloys macrostructure shows that along with the increase of Mg content in copper, a structure with smaller grains is formed, which is beneficial from the point of view of potential following metal forming processing.

Acknowledgments

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REFERENCES

[1] J. R. Davis, Copper and copper alloys, ASM International Handbook, Materials Park, OH, USA (2001)
[2] K. Maki, Y. Ito, H. Matsunaga, H. Mori, Solid-solution copper alloys with high strength and high electrical conductivity, Scripta Materialia 68 (2013), 777-780
[3] K. Franczak, P. Kwaśniewski, G. Kiesiewicz, M. Zasadzińska, B. Jurkiewicz, P. Strzępek, Z. Rdzawski, Research of mechanical and electrical properties of Cu-Sc and Cu-Zr alloys, Archives of Civil and Mechanical Engineering 20 (2020) 28, 20-28
[4] EN 50149:2012, Railway applications – Fixed installations – Electric traction – Copper and copper alloy grooved contact wires, (2012)
[5] 01-3/ET/2008, Przewody jezdne profilowane Iet-113, PKP Polskie Linie Kolejowe S.A., Warszawa, PL (2008)
[6] M. Nairn, Continuous casting of copper magnesium conductor alloys, WAI Interwire Conference, Atlanta, GA, USA (2013)
[7] Gorsse, S. Ouvrad, B. Goune, M. Poulon-Quintin, Microstructural design of new high conductivity - High strength Cu-based alloy, J. Alloys Compd. 633 (2015), 42–47
[8] Z. Rdzawski, W. Gluchowski, J. Stobrawa, J. Sobota, Effect of rare-earth metals addition on microstructure and properties of selected copper alloys, Archives of metallurgy and materials 59 (2014) 641-648

Note: The translator responsible for English language: Andrzej Mamala, Krakow, Poland