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GRAPHITE CRYSTALLIZER AND ITS SURFACE QUALITY AS A FACTOR AFFECTING THE COPPER CONTINUOUS CASTING PROCESS

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Pure copper is one of the best conducting metals among known materials, making it the first choice for wires and microwires. However, before subjecting to metal working, the material is being manufactured in the continuous casting lines. The experimental study conducted in laboratory conditions proved that the external surface quality, and thus the contact quality with the cooling system is being responsible for the worsening or improving of the heat transfer and therefore the temperature of the crystallizer itself. The conducted study might function as sort of a guideline for the industrial process.

Keywords: copper, graphite, continuous casting, crystallization, temperature distribution

INTRODUCTION

Electrical energy is one of the resources in today's world which consumption increases drastically every year [1]. Its transmission is usually conducted with the use of copper or aluminium wires and cables which origin comes most often from continuous casting lines. Pure copper in ETP grade is usually hot rolled after c sting into the final form of wire rod, whereas oxygen free copper is casted directly into a cast rods [2-6]. Continuous casting processes of copper and copper alloys are usually conducted with the use of graphite crucibles and crystallizers as they are not wettable by copper, have self-lubricating properties and hardly diffuse into each structure, thus guaranteeing high quality of the obtained materials [7-10]. The reason for this is also an excellent thermal conductivity of graphite which is responsible for heat transfer from the crystallizing metal to the cooling system providing great efficiency of the process. By these means it makes the crystallization system the most important part of the casting furnace [11-14]. Other research works have proven that the power received by the crystallizer from the solidifying material is determined by the chemical composition, temperature of the liquid metal, the size of the cast, the feed and standstill of the process and by that the temperature of the crystallizer during the process [15,16]. However, the impact of the surface roughness of the crystallizer and quality of contact with the cooling system, and its influence on the temperature distribution has not been widely discussed empirically which is the focus of this paper.

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EXPERIMENTAL PROCEDURE

The conducted research was divided into two main parts, numerical simulations with the use of finite element method and empirical verification of the obtained results in the actual laboratory conditions. The numerical simulations took into account 4 various qualities of the crystallizer with Ra 0,2 µm, 0,65 µm, 1,25 µm and 5 µm which should reflect extremely good surface quality, good surface quality, commercial surface quality and extremely bad surface quality. The temperature of the cast rod was set to ~850 °C and the velocity of the cooling medium was set to 0,3 l/min. The temperature mapping showing distribution of heat were generated and with measuring points the temperature of the crystallizer and cast rod after the cooling system were measured. After the analysis of the obtained results empirical verification of the process in laboratory conditions was conducted. The assembly consisting of inserted in the crystallizer copper cast rod and the cooling system with thermocouples is presented at Figure 1. The cast rod was insulated and the induction coil responsible for the heating of the cast rod was placed around it as presented at Figure 2.

The empirical verification was conducted with analogical cooling medium velocity and additional slower (0,1 l/min) and faster (0,5 l/min) velocities were applied. The thermocouples measured the temperature of the crystallizer in three places (beginning, middle and end) and the temperature of the cast rod after exiting the cooling system. Analogically like in the case of the numerical simulations the cast rod temperature was increased to ~850 °C.

RESULTS AND DISCUSSION

The first part of the conducted research were computer simulations conducted with Ansys software. The

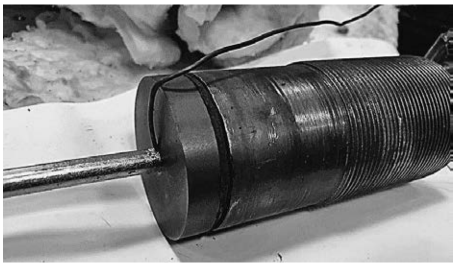

Figure 1 Crystallizer with an inserted cast rod and visible cooling system and thermocouples

Figure 2 The view of the induction coil during the increasing temperature of the cast rod

results of the Finite Elements Method (FEM) simulations were presented at Figures 3 – 6.

Based on the obtained results it is clearly visible that as the surface roughness increases the temperature of the cast rod increases as well with simultaneous decrease of the temperature of the cooling medium. This suggests that as the quality of contact worsens so does the amount of heat received from the system by the cooling medium. From the obtained temperature distribution mapping it is visible that with the best surface quality the temperature of the cast rod after the cooling system is ~40 °C and with the worse surface quality the temperature increases to over 60 °C which suggests a huge impact of the quality of contact on the obtained results.

The computer simulations were further verified in laboratory conditions with a wider spectrum of variables in terms of the additional velocities of the cooling medium. The results concerning the temperature of the

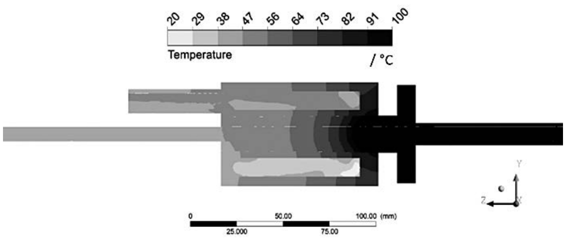

Figure 3 The crystallizer with surface roughness of Ra 0,2 µm / °C

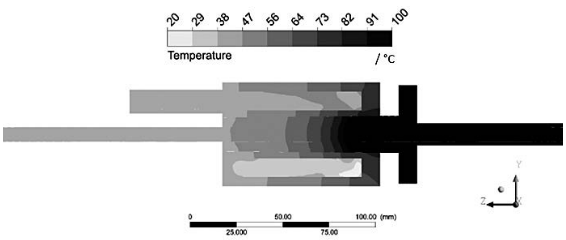

Figure 4 The crystallizer with surface roughness of Ra 0,65 µm / °C

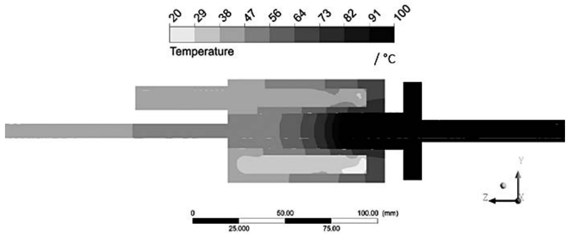

Figure 5 The crystallizer with surface roughness of Ra 1,25 µm / °C

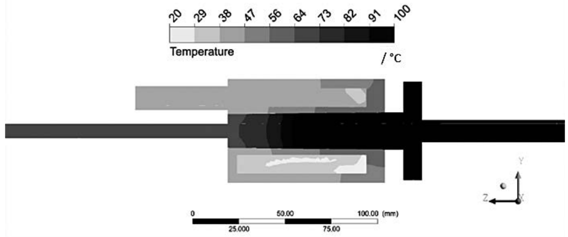

Figure 6 The crystallizer with surface roughness of Ra 5 µm / °C

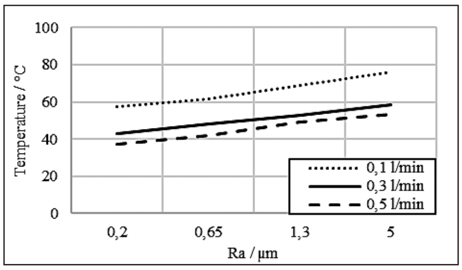

Figure 7 The evolution of the cast rod temperature after exiting the cooling system

cast rod after exiting the cooling system are presented collectively at Figure 7.

The increase of the cast rod temperature is clearly visible at Figure 7 regardless of the applied velocity of the cooling medium and confirms the results obtained in the FEM simulations. Other quantified temperatures were collectively presented in Table 1. The influence of the cooling medium velocity was expected and the obtained results confirm that it has a significant impact on the crystallization system and therefore the temperature distribution in the process. Based on the obtained results it may be stated that the surface roughness of the crystallizer and therefore the quality of contact with the cooling system has a considerable influence on the heat transfer in the process. The temperature of the cast rod increases from 57,62 °C to 76,19 °C with cooling medium velocity 0,1 l/min, from 42,78 °C to 58,5 °C with cooling medium velocity 0,3 l/min and from 37,17 °C to 53,09 °C with cooling medium velocity 0,5 l/min. In each of the cases the temperature increased along with the temperature of the crystallizer regardless of the measuring point. The proposed method may simulate the actual continuous casting parameters and function well as a test of heat transfer as it shows the changes in the crystallization system.

CONCLUSIONS

Taking into consideration the obtained FEM simulations, empirical research results and conducted calculations, the following may be stated:

Table 1 **Collective data of the empirical research conducted with the laboratory assembly**

Ra / µm	Velocity of the cooling medium / l/min	Crystallizer - beginning / °C	Crystallizer - middle / °C	Crystallizer - end / °C	Cast rod after cooling system / °C
0,2	0,1	163,72	79,90	53,14	57,62
0,65	0,1	174,74	78,82	58,02	61,40
1,3	0,1	171,17	87,03	65,53	69,05
5	0,1	190,89	88,87	70,12	76,19
0,2	0,3	142,66	62,38	35,90	42,78
0,65	0,3	159,04	63,46	41,10	48,12
1,3	0,3	150,34	67,38	45,88	52,83
5	0,3	168,69	68,01	49,42	58,50
0,2	0,5	133,80	56,25	30,08	37,17
0,65	0,5	151,47	56,54	33,73	42,01
1,3	0,5	144,26	60,53	40,95	48,91
5	0,5	162,54	61,78	42,88	53,09

The proposed methodology proved to be a fine simulation of the continuous casting process as it showed the temperature distribution and changes in the crystallization system.

The surface roughness of the crystallizer and therefore the quality of contact with the cooling system is an important factor influencing the heat transfer, the temperature and thus the quality of the obtained cast rod. As the roughness increases and the quality worsens the crystallizer and cast rod temperature increases significantly (by even 50 %).

The obtained results were confirmed both with the use of finite element method simulations and empirical research simulating the actual continuous casting process.

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Note: The translator responsible for English language: Andrzej Mamala, AGH University of Science and Technology, Kraków, Poland