A. BRUDNY, J. KULASA, B. CWOLEK, W. MALEC, B. JUSZCZYK

ISSN 0543-5846
METABK 61(3-4) 785-788 (2022)
UDC – UDK 669.35.6:621.74.04:66.065-678.5:621.9.015:620.18 =111

INFLUENCE OF THE CONTINUOUS CASTING PROCESS OF TIN-ZINC-LEAD BRONZE ON THE WEAR OF THE GRAPHITE CRYSTALLIZER

Received – Primljeno: 2021-10-30
Accepted – Prihvaćeno: 2022-03-25
Preliminary Note – Prethodno priopćenje

The research conducted in this paper concerns the influence of the continuous casting process of tin-zinc-lead bronze on the wear of the graphite crystallizer. Observations and testing of the external surface of the cast rods indicate their good quality, without casting defects. No excessive surface degradation was observed on the inner surface of the crystallizers after casting. It was assessed that the surface quality of the crystallizer would be acceptable for further use, despite stuck residue, mainly in the crystallization zone.

Keywords: bronze, continuous casting, graphite crystallizer, surface, structure

INTRODUCTION

One of the basic factors responsible for the production of high-quality rods in the continuous casting process are correctly selected casting conditions. Changing parameters such as casting speed and cooling water flow, apart from affecting the appropriate surface quality, affects mainly the microstructure, and thus the mechanical properties of the produced material [1, 2]. An important, but frequently ignored, factor in addition to properly selected casting parameters is the quality and kind of the used crystallizer. During the continuous casting process, especially of alloys containing aggressive elements, excessive wear of the graphite material occurs through the process of crystallizer surface degradation, consisting mainly of abrasive and erosive wear of mainly the internal part in the crystallization zone and directly behind it. Additionally, the casting process and the quality of the obtained castings are influenced by the crystallizer-cooler system, including the type of crystallizer geometry and its fitting with the cooling head through the efficiency of heat removal in the crystallization system. The better the surface quality of the crystallizer, the higher the casting efficiency. Increasing the efficiency of heat flow is possible by using crystallizers with high surface quality (low roughness) and properly matched to the crystallization system [3]. In addition to the properly selected crystallizer in terms of material and structure, an effective way to improve the heat removal effect in the crystallization zone is also to change the liquid inlet system to the cooler, which changes the liquid flow from laminar to vortex. The effect of swirling and the intensity of turbulence of the casting liquid in the crystallizer improves the homogeneity of the microstructure of the produced castings [4]. Crystallizers used in continuous casting of non-ferrous metals are made of graphite due to its self-lubricating properties, which eliminates the need for additional lubricants. Despite many advantages, graphite crystallizers are susceptible to oxidation and metal particles tend to stick to their surface. Thus, it is necessary to periodically regenerate crystallizers, but with the required high dimensional accuracy, the use of crystallizers after regeneration becomes impossible. The degradation of graphite consumables in a continuous casting line is mainly related to the chemical effect of liquid metal and high temperature. Crystallizers wear fairly quickly due to the friction between the surface of the crystallizer and the solidifying metal. In addition, crystallizers are also subject to mechanical wear, mainly during assembly in the crystallizer-cooler system, as well as in the initial stage of casting, due to inappropriate feeding of a starter bar into the crystallizer. Therefore, it is necessary to select an appropriate type of graphite material from which the crystallizer is made, strictly depending on the chemical composition of the cast alloy and the form of the cast product in order to extend the correct operation and life of a crystallizer. Using crystallizers made of inappropriately selected graphite materials generates high costs related to their frequent replacement with new ones, and thus the necessity to pause the production process and reassembling the crystallizer-cooler system. In the foundry of non-ferrous metals and their alloys, graphite products are also used for heating elements, crystallizers, and crucibles [5, 6]. As part of this work, laboratory scale tests were carried out to determine the influence of the process of tin-zinc-lead bronze continuous casting on the wear of graphite crystallizer. Most often, the crystallizers used for casting non-fer-

A. Brudny (anna.brudny@imn.gliwice.pl)
J. Kulasa, B. Cwolek, W. Malec, B. Juszczyk, Łukasiewicz Research Network – Institute of Non-Ferrous Metals, Gliwice, Poland

rous metals and their alloys are made of isostatically pressed graphite.

EXPERIMENTAL PROCEDURE

Graphite used for crystallizers should have high hardness and mechanical resistance. During the tests of casting rods from the CuZn5Sn5Pb2 grade alloy, a crystallizer made of R4550 grade isostatically pressed graphite material was selected for evaluation, the selected properties of which are presented in Table 1 [7].

Table 1 **R4550 grade graphite material properties [7]**

Typical properties	Units/	Values
Average grain size	µm	10
Bulk density	g/cm^3	1,83
Open porosity	Vol, %	10
Medium pore entrance diameter	µm	1,8
Coefficient of permeability (ambient temperature)	cm^2/s	0,06
Rockwell hardness HR $_{5}$ / $_{100}$		90
Resistivity	µΩm	13
Flexural strength	MPa	60
Compressive strength	MPa	130
Dynamic modulus of elasticity	MPa	11,5 x 103
Thermal expansion (20 – 200 °C)	K^{-1}	4,2 x 10^{-6}
Thermal conductivity (20 °C)	Wm^{-1}K^{-1}	105
Ash content	ppm	20

During the continuous casting trials, one of the process parameters, the feed forward, was gradually increased while maintaining the reverse feed rate and the time of standstill at a constant level. The remaining parameters were adjusted to maintain approximately constant temperature of the metal bath and the temperature of the crystallizer (the flow of water cooling the system). Ø15 mm rods were cast in two strands. The continuously cast material was visually assessed to be good with no surface defects. For further macro and microstructure studies, samples of the cast rod were taken at the beginning and the end of the casting process.

RESULTS AND DISCUSSION

Analysis of the surface of used crystallizers

The used crystallizer was tested after a 16-hour casting process of the CuZn5Sn5Pb2 alloy on a ConCasTech MINI SCC laboratory line for continuous casting. The chemical composition results of this alloy are shown in Table 2.

Table 2 **Chemical composition of CuZn5Sn5Pb2 rods/ wt.%**

Cu	Zn	Sn	Pb	Ni	Fe	P	S
Bal.	5,24	4,55	2,68	0,42	0,15	0,020	0,018

The study of the surface analysis of the direct contact between metal and graphite was carried out together with a microanalysis of the chemical composition of a two-strand crystallizer made of isostatically pressed R4550

Figure 1 View of the used R4550 grade graphite crystallizer

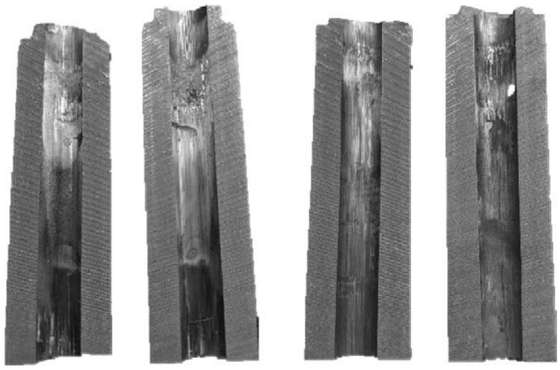

Figure 2 View of the cross-section of strands 1 and 2 of the R4550 grade crystallizer

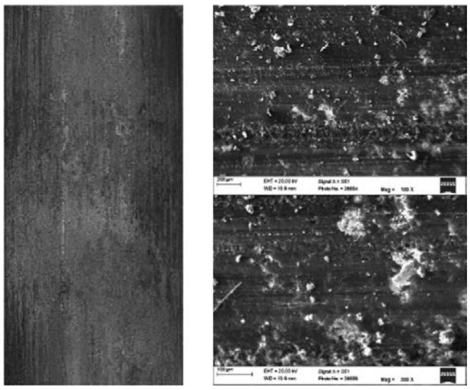

Figure 3 Surface analysis – part 1, strand 1

grade material using a Zeiss Evo MA10 scanning electron microscope (SEM) equipped with SE, BSE and Energy Dispersive Spectroscopy (EDS) SDD Quantax XFlash® 5010 Bruker detectors. The study of the analysis of the surface of the crystallizer walls which have contact with liquid metal was one of the elements of assessing the wear of the crystallizer exposed to temperature, liquid metal, and the aggressive air atmosphere. The test results for the crystallizer on which the CuZn5Sn5Pb2 alloy rods were cast are shown in Figures 1 ÷ 6.

The wear analysis of the tested crystallizer was carried out in two areas:

- part 1 of the crystallizer - the area where the solidified metal leaves the crystallizer,
- part 2 of the crystallizer - the area where the metal starts to solidify.

In part 1, due to the occurring greater friction of the metal against the walls of the crystallizer, the presence of numerous metal traces rubbed onto the surface of the graphite material was observed.

The surface analysis showed the presence of stuck zinc and lead residue as well as other alloying elements

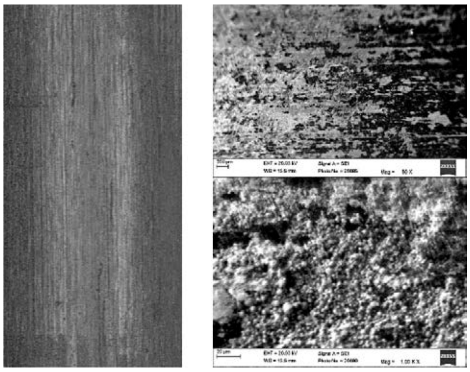

Figure 4 Surface analysis – part 2, strand 1

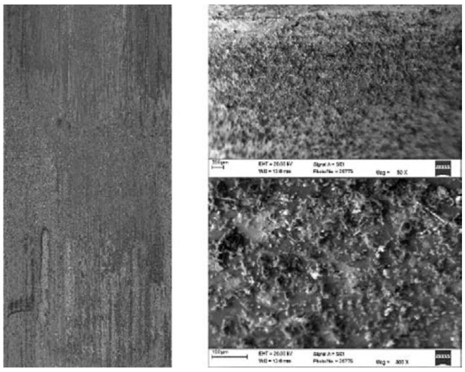

Figure 5 Surface analysis – part 1, strand 2

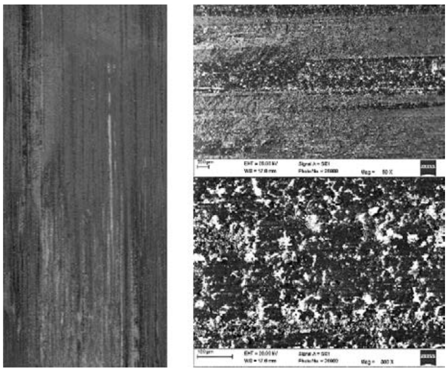

Figure 6 Surface analysis – part 2, strand 2

of the cast material (copper, tin) on the surface of the crystallizer. These analyses are illustrative as they concern only a specific area or point on the tested sample.

As a result of the analysis of the internal surface of the crystallizer, the effects of wear can be observed, i.e., wear of the internal part due to metal-graphite friction, and burn-out due to high temperature and the presence of oxygen.

Macro and microstructure of continuously cast rods

The results of the macrostructure analysis of the cast rods are shown in Figure 7, and the microstructure in Figures 8, 9. No internal casting defects were observed for any of the tested samples. Depending on the place of sampling for testing (the beginning or the end of the casting process), and thus depending on the parameters of the casting process, a different macrostructure of the material of the cast rod was observed, which is obviously related to the change in the casting speed and cooling intensity. The increase in cooling intensity results in a gradual change in the direction of growth of the columnar crystals, and then the appearance of periodic changes related to the casting cycle.

Cast materials have a multiphase microstructure where the basic structural component is a solid solution of tin and zinc in copper. In the microstructure, there are lead precipitations located in the interdendritic spaces and at the grain boundaries, and the precipitations of the $\alpha + \delta$ eutectoid, also present in the interdendritic spaces. The characteristic relief of the surface of the specimens after etching is related to the strong dendritic segregation typical of Cu-Sn alloys.

Microstructure tests, carried out for a batch of rods obtained from continuous casting trials, and carried out

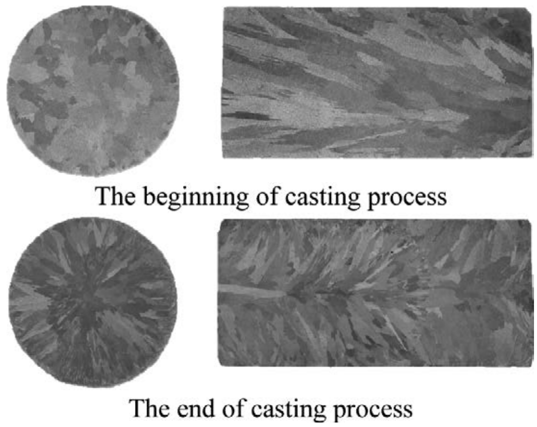

Figure 7 The macrostructure of continuously cast rods

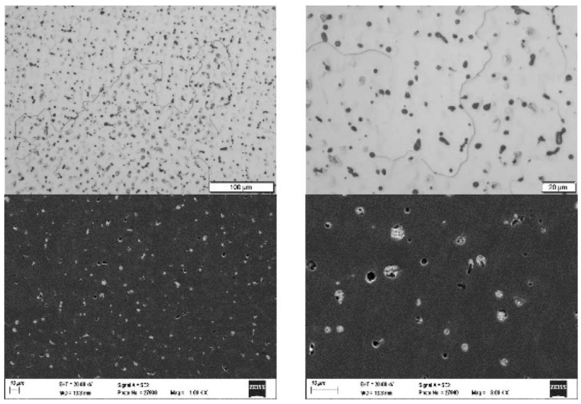

Figure 8 The microstructure on the rod cross-section - the beginning of the casting process

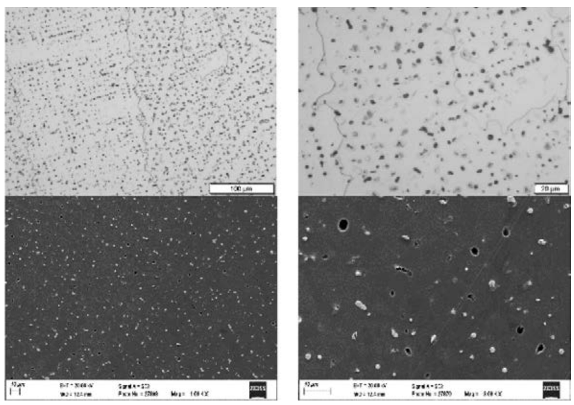

Figure 9 The microstructure on the rod cross-section - the end of the casting process

by the observation methods of light microscopy and scanning electron microscopy with numerous EDS analyses, were related to an attempt to assess the impact of excessive wear of the crystallizer on the possible occurrence of impurities and internal defects in the cast material.

Surface analysis of the cast rods

The surface of the rods was free from casting defects, such as misruns, tears. Periodic traces, related to the casting cycle, of light and dark grey colour and different intensity were observed (Figures 10, 11).

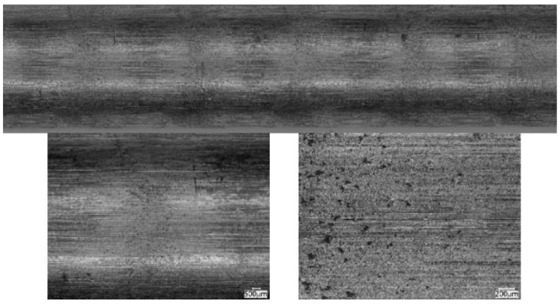

Figure 10 Surface analysis of a continuously cast rod - the beginning of the casting process

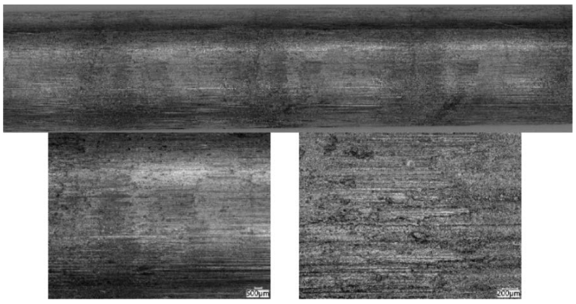

Figure 11 Surface analysis of a continuously cast rod - the end of the casting process

The EDS microanalysis of the surface of the cast rods indicates the presence of large amounts of carbon on the surface in the form of graphite residue from the crystallizer rubbed onto it, numerous sweating, mainly lead, and less often stuck residue with a high tin content.

CONCLUSION

The conducted trials of continuous casting of CuZn-5Sn5Pb2 alloy rods in laboratory conditions allowed to obtain good quality material.

Observations and tests of the external surface of the cast rods indicate their good quality, without casting defects. Only cyclical changes in the form of discoloration and traces of carbon from the crystallizer rubbed onto the metal are visible on the surface.

The conducted research indicates the presence of local lead and tin enriched areas, which is a typical phenomenon for this type of alloys prone to segregation.

The structural tests of the cast rods showed a macrostructure typical for continuously cast materials, its character corresponding with the casting parameters used. The presence of internal defects on a macroscopic scale was not observed. The rod microstructure is typical of cast materials, dendritic, with a solid solution matrix based on α copper with strong dendritic microsegregation and α + δ eutectoid regions and lead particles present in the interdendritic spaces. No significant amounts of contamination, cracks or microshrinkages were observed.

No excessive surface degradation was observed on the inner surface of the crystallizer after casting.

It was assessed that the surface quality of the crystallizer would be acceptable for further operation, despite stuck metallic residue, mainly in the crystallization zone. In the place of abrasions of the crystallizer as a result of the casting process, the occurrence of stuck metallic residue did not lead to a deterioration of the quality and changes in the dimensions of the cast rods.

Acknowledgements

The research was carried out as part of the project: Techmatstrateg (TECHMATSTRATEG2/408701/2/NCBR/2019) co-funded by the National Centre for Research and Development.

REFERENCES

[1] P. Strzępek, A. Mamala, M. Zasadzińska, P. Noga, M. Sadzikowski, The Influence of the Continuous Casting Conditionson the Properties of High-Strength Two-Phase CuMg Alloys, Materials, 13 (2020) 21, 4805, DOI: 10.3390/ma13214805

[2] M. Zasadzińska, T. Knych, B. Smyrak, P. Strzępek, Investigation of the Dendritic Structure Influence on the Electrical and Mechanical Properties Diversification of the Continuously Casted Copper Strand, Materials, 13 (2020) 23, 5553, DOI: 10.3390/ma13235513

[3] P. Kwaśniewski, P. Strzępek, G. Kiesiewicz, Sz, Kordaszewski, K. Franczak, M. Sadzikowski, W. Ściężor, A. Brudny, J. Kulasa, B. Juszczyk, R. Wycisk, M. Śliwka External Surface Quality of the Graphite Crystallizer as a Factor Influencing the Temperature of the Continuous Casting Process of ETP Grade Copper, Materials, 14 (2021), 6309, DOI: 10.3390/ma14216309

[4] Y. Han, Y. Xiao, A.Y. Zhang, F. Liu, E.L. Yu, Y. Gao, Study on influence of lateral liquid feeding into crystallizer on solidification process of copper billets, International Journal of Heat and Mass Transfer, 125 (2018), 104-115, https://doi.org/10.1016/j.ijheatmasstransfer.2018.04.068.

[5] V. E. Bazhenov, A. V. Koltygin, Yu. V. Tselovalnik, A. V. Sannikov, Determination of Interface Heat Transfer Coefficient between Aluminum Casting and Graphite Mold, ISSN 1067-8212, Russian Journal of Non-Ferrous Metals, 58 (2017) 2, 114-123.

[6] K. Franczak, P. Kwaśniewski, K. 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, DOI: 10.1007/s43452-020-00035-z

[7] https://www.sglcarbon.com/pdf/SGL-Datasheet-SIGRAFINE-R4550-EN.pdf

Note: The translator responsible for English language: Małgorzata Krystowska, Gliwice, Poland.