University of Belgrade
Technical Faculty in Bor,
Mining and Metallurgy
Institute Bor

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PROCEEDINGS

Editors:
Ljubiša Balanović
Dejan Tanikić

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PREFACE

On behalf of the Organizing Committee, it is a great honor and pleasure to welcome all esteemed participants of the 54th International October Conference on Mining and Metallurgy (IOC 2023), scheduled to take place at the picturesque Bor Lake, Serbia, from October18th to 21st 2023.

The collaborative efforts of the University of Belgrade, the Technical Faculty in Bor, and the Mining and Metallurgy Institute Bor have meticulously organized this year's IOC. Our focus remains unwavering on showcasing the latest research findings and advancements in geology, mining, metallurgy, materials science, technology, environmental protection, and other engineering disciplines. Our primary objective is to foster a dynamic environment where academics, researchers, and industry professionals can come together to share their knowledge, experiences, and innovative ideas while exploring opportunities for collaborative research endeavors.

Our conference agenda is rich and diverse, encompassing plenary sessions, engaging invited lectures, technical presentations, enlightening oral and poster sessions, informative technical tours, a diverse exhibition, and memorable social gatherings. At the heart of this event lies our strong commitment to sustainable development within the mining and metallurgy sector. We are dedicated to exploring ecologically conscious methodologies, responsible resource extraction practices, and cutting-edge technologies that reduce the industry's environmental impact and enhance the well-being of local communities.

The conference proceedings comprise 129 papers authored by individuals from universities, research institutes, and industries in 22 countries. We are proud to welcome participants from Bosnia and Herzegovina, Bulgaria, Canada, China, Croatia, Germany, Greece, India, Iran, Kazakhstan, Libya, North Macedonia, Montenegro, Morocco, Romania, Russia, Slovakia, South Africa, Spain, Turkey, United States, and, of course, Serbia.

We are excited to host the 8th International Student Conference on Technical Sciences (ISC 2023) as part of IOC 2023. This event offers students from Serbia and the wider region a unique chance to showcase their research and discuss the future of their fields with experts.

We sincerely thank the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia for their generous financial support. In addition, we express our profound gratitude to all our sponsors, exhibitors, and friends of the Conference for their contributions and unwavering support for playing a pivotal role in ensuring the success of IOC 2023.

We would like to express our heartfelt thanks to all authors, committees, reviewers, speakers, and chairpersons for their invaluable contributions in shaping IOC 2023.

We look forward to welcoming you to the 55th International October Conference on Mining and Metallurgy (IOC 2024), which will be held in October 2024.

On behalf of the 54th IOC Organizing Committee,

Prof. dr Ljubiša Balanović

TABLE OF CONTENTS

Plenary Lectures

Invited Lectures

Conference Papers

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EFFECT OF CASTING SPEED ON TENSILE STRENGTH, ELONGATION AND MICROSTRUCTURE OF CONTINUOUS CAST COPPER WIRE

Srba Mladenović[1], Bojan Novaković[2], Ivana Marković[1], Uroš Stamenković[1]

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Abstract

The present work presents the characterization of oxygen-free copper wire and examines the influence of the casting parameters on its properties. It was found that these parameters could improve the mechanical properties of samples. Also, this investigation showed that there are plenty of possibilities for improving the quality of cast wire cast by UPWARD continuous casting technology..

***Keywords**: Continuous casting, copper, wire, properties*

1. INTRODUCTION

The continuous casting technology has been intensively used from the middle of the 20th century, when big volumes of standardized products have to be produced. The main advantages of this technology are: energy saving, mass and a continuous quality production, decreased production costs, simplified production scheduling, more compact production lines.

There is a different variants of this technology regarding mould type, arrangement of mould and furnace, as well as drawing direction. Today, we have a wide variety of mould systems. Special types of casting procedures have been developed, such as the low head casting (LHC) and the electromagnetic casting (EMC) [1,2]. Nonferous metals and alloys, are often continuous cast using vertical (upward or downward) or horizontal processes to produce round billets for subsequent extrusion, forging or wire drawing.
In 1998 Rautomead introduced an upwards vertical casting process to produce 8mm dia. oxygen-free copper rod (C10200) directly from Grade A copper cathode feedstock (Cu-CATH-1) using a single electrically-heated graphite crucible furnace. This was a novel process when first introduced in the senses that it produced an oxygen-free copper wire rod cast directly at 8mm [3,4].
The aim of this paper is to investigate the impact of the casting parameters on mechanical properties of copper wire casted by Rautomead UPWARD continuous casting technology.

2. EXPERIMENTAL

All the measurements and metallographic analysis was performed on samples of Cu-OF copper wire rod obtained by continuous casting. The samples were taken from wire rod obtained on a RS 2200 machine for continuous casting. The machine is basically a single electrically-heated graphite crucible furnace. The graphite crucible is large enough to permit whole cathode sheets to be fed into the melt chamber and to accommodate two separate chambers linked by a submerged bottom transfer port. Rod withdrawal is vertically upwards through water-cooled graphite dies immersed in the liquid copper. The whole rod withdrawal carriage is arranged to move up and down and to maintain a constant immersion depth of the casting dies. On figure 1. the schematic presentation of the machine is presented.

The technical parameters of the machine such as withdrawal temperatures, cooling water temperature at the inlet of the coolers, inlet pressure of the cooling water, outlet pressure were the same trough out the process. Also, the operating parameters of the furnace: temperature, pressure of shielding gas nitrogen at the inlet, nitrogen pressure in the furnace space and nitrogen flow were constant and have same impact on the final results.

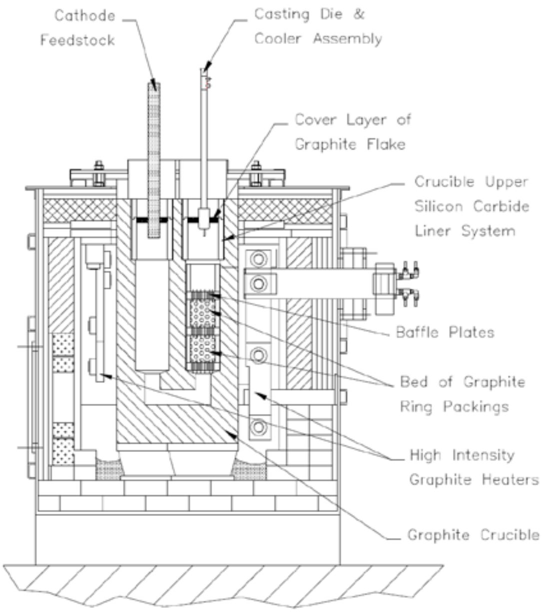


Figure 1 - Section Through Model RS2200 Upwards Vertical Continuous Casting Machine

The main casting parameters that have the influence on microstructure and consequently mechanical properties are:

- Cooling water flow rate.
- Casting speed.
- Pull distance.
- Melt temperature.
- Withdrawal system.
- Continuous casting direction.
- Super cooler size.
- Casting die materials.

In this paper the effect of casting speed was examined. The values of all others parameters are maintained constant during the investigation.

The samples for mechanical testing and for metallographic analysis were prepared according the appropriate standards.

Tensile test was performed on the universal Carl Frank Germany, model 81221 machine where the tensile strength (MPa) of the material as well as ductility in terms of elongation percentage of the copper samples were determined. Samples for microstructural observations were cut with a clean sharp hacksaw. After the sample is sectioned to a convenient size, samples were then ground by using coarse abrasive paper (Grade No. 120) and subsequently 250, 360, 500, 800, 1200, 1500. 2000. Then, the samples were polished on a cloth with a diamond suspension and lubricating solution. In the chemical etching process, nitric acid and distilled water were used. The microstructures were imaged on a Carl Zeiss Jena Epytip 2 metallographic microscope.

3. RESULTS AND DISCUSSION

In table 1. the representative copper samples gated by specific casting speed which were analyzed are presented.

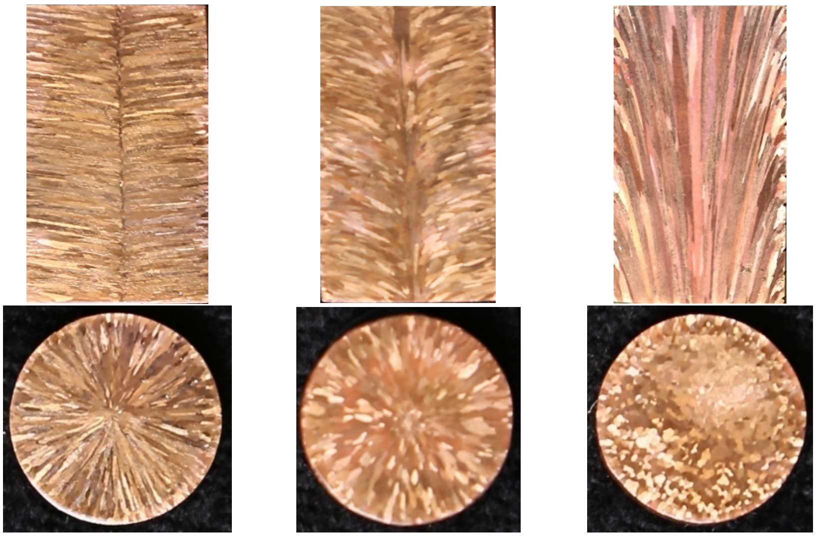
Table 1 - OFCu samples tested in this research.

Samples	Rod dia. (mm)	Met. temp (°C)	Water flow rate (l/min.)	Water tem. inlet (°C)	Water tem. outlet (°C)	Casting speed (kg/h)
1.1	12,7	1185	33	32	41,2	100
1.2	12,7	1185	33	32	38,8	80
1.3	12,7	1185	33	32	36,5	60
1.4	12,7	1185	33	32	34,7	40
1.5	12,7	1185	33	32	32,8	20

In this research the casting speed is presented as physical measurement of the as cast rod over the specify time e.g kg/h. Investigation has been performed with five different casting speeds. The results of the mechanical investigations are presented in table 2. and on figure 3. the structure of grains for different samples is presented.

Table 2 - Tensile strength and average elongation percentage

Samples	Rod dia. (mm)	Met. temp (°C)	Water flow rate (l/min.)	Water tem. inlet (°C)	Water tem. outlet (°C)	Casting speed (kg/h)	Ten. st.. N/mm^2	Aveage elon. %
1.1	12,7	1185	33	32	41,2	100	184,3	42,5
1.2	12,7	1185	33	32	38,8	80	188,2	42,0
1.3	12,7	1185	33	32	36,5	60	191,2	39,5
1.4	12,7	1185	33	32	34,7	40	196,4	38,0
1.5	12,7	1185	33	32	32,8	20	150,8	27,5



100 kg/h 60 kg/h 20 kg/h

Figure 3 - Grain structure of samples (cross and longitudinal section)

The reason for this improvement of specified mechanical properties is because the casting speed affects the structure formation during solidification. This parameter actually has effect on the cooling condition, which results in making it possible to obtain a structure with finer grains. Figure 3 shows cross and longitudinal sections of continuously cast rods at three different casting speeds. For all samples, except for sample 1.5, an increase in tensile strength was observed with a decrease of casting speed. It was also found that the casting speed could improve the elongation of samples from 27,5% to 42,5%. The change in tensile strength and elongation with the change in cast speed are shown in figure 4.

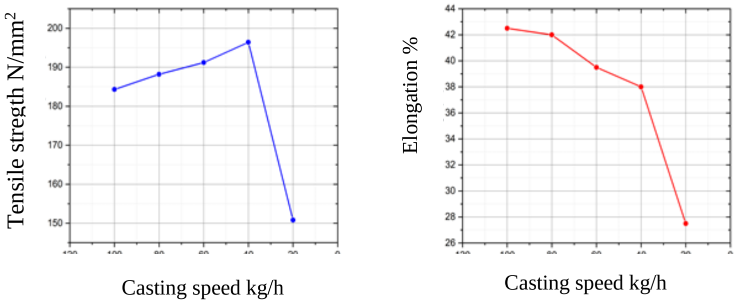
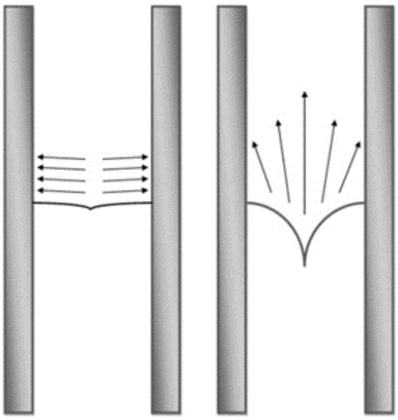


Figure 4 - Tensile strength and elongation percentage of the samples

With maximum casting speeds, the high-temperature liquid metal enters the low-temperature zone at high speed. During the standstill, at the contact of the liquid metal and the inner walls of the graphite mould matrix, a large number of crystallization centers are simultaneously created on the entire contact surface. Most of the heat is dissipated through the walls of the graphite mold. The crystals grow simultaneously parallel to each other and normal to the longitudinal axis, i.e. normal to the casting direction. A very small part of the heat is additionally removed via the already formed wire, which causes a very slight slope of the orientation of the crystal downwards, towards the liquid metal (sample 1.1.). By reducing the casting speed, there are changes in the direction of heat dissipation. The amount of heat that is removed through the walls of the graphite mold decreases, and the heat removal through the hardened copper in the casting direction increases. This causes an even greater change in the angle of inclination and direction of crystal growth (sample 1.3). Most of the heat is dissipated through the wire in the direction of casting, which causes crystal growth parallel to the longitudinal axis of the wire and in the direction opposite to the direction of casting. The picture in Figure 5. illustrates, very nicely, the process of heat dissipation in a concrete case.



a) b)

Figure 5 - The scheme of heat dissipation, a) max. cast speed, b) min. cast speed

Also, with an increasing of the casting speed, the grain structure tends to become finer. Smaller grains have greater ratios of surface area to volume, which means a bigger ratio of grain boundaries, which presents a more obstacles for dislocations. The more grain boundaries that occur, the higher the strength of the copper rod samples.

4. CONCLUSION

The effect of casting speed, on the mechanical properties of continuous cast copper wire were investigated. Some important conclusions can be drawn:

- We can influence the quality of the wire with casting speed change.
- With casting speed change the direction of heat dissipation also change.
- The greater casting speed brings more cristalization centers formation, grains are smaller and their orientation are normal to the casting direction. That brings to the increasing of the elongation.
- By reducing the speed, it is possible to obtain a structure with larger crystals whose orientation is parallel to the longitudinal axis of the cast wire, which leads to an increase in tensile strength.

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