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ISSN 0543-5846
METABK 62(3-4) 397-400 (2023)
UDC – UDK 669.3:621.771:620.18:537.311.3:620.17=111

THE EFFECT OF THE ROLLING PROCESS ON SELECTED PROPERTIES OF MAGNESIUM COPPER WITH MICROADDITIVES

Received – Primljeno: 2023-03-03
Accepted – Prihvaćeno: 2023-04-25
Original Scientific Paper – Izvorni znanstveni rad

The article presents the results of rolling magnesium copper castings with microadditives of P, Al, Ti, and Zr. The castings were made in the process of static casting into rods with a diameter of 20 mm. The obtained castings were shaped with a 3 % draft into bars of square cross-section and rolled on a shape mill with 20 % drafts on average. Mechanical properties were determined in a static tensile test at selected degrees of plastic deformation (57,2 %, 76,9 % and 91,3 %). At the final stage of cold working of the wire rods with a total draft of 91,3 %, the microstructure and electrical conductivity were examined. The research indicates a strong influence of microadditives on the strengthening of castings in the rolling process and their electrical conductivity.

Keywords: copper alloy, rolling, macrostructure, electrical conductivity, mechanical properties

INTRODUCTION

Rapid development of the economy, especially in the field of energy and microelectronics, has resulted in a dynamic expansion of new technologies and an increase in demand for products made of copper and copper alloys. Research conducted at this time have created new possibilities in the field of creating desired sets of functional properties of products and semi-finished products that can be successfully used for utility purposes. This phenomenon has influenced the increase in the production of semi-finished products and products made of copper and its alloys more than twice over the last twenty years [1].

Due to the high electrical and thermal conductivity of copper as well as its corrosion resistance and good plasticity, it is used, among others, for power and telecommunication cables, winding wires, etc. In turn, pure copper sheets and strips are used in the production of printed and integrated circuits.

Main requirements of alloy copper relate to electrical and thermal conductivity as well as tensile strength and stability of these properties under operating conditions. Their value is usually shaped by alloying additives, heat treatment and plastic working. Modelling of product characteristics by adding additives usually takes place at the initial stage of alloy production. Depending on the properties of the alloying elements added and their amounts in the cast alloy, appropriate casting techniques (static, semi-continuous, continuous) as well as appropriate materials and tools should be used [1 - 4].

Strengthening of the alloys is achieved by heat treatment and/or plastic working. The mechanisms shaping their microstructure and, indirectly, their properties include solid solution strengthening, precipitation hardening or strain hardening. In the case of cast materials, there are many possibilities of shaping the microstructure. Of course, other factors that may affect the usability of the products must also be taken into account. For example, copper alloys used for resistance welding caps require the structure to meet specific specifications. Too much fineness will cause faster recrystallization, and too little will cause faster zinc diffusion. Therefore, it is important to conduct research on microadditions in copper alloys [5 - 10].

The article presents the results of cold rolling tests of magnesium copper alloys with microadditives, such as magnesium, zirconium, titanium, aluminium, and phosphorus. It indicates their strong influence on the strengthening and electrical properties of copper-based alloys.

Table 1 **Chemical composition of cast bars / wt. %**

Casting / wire rod number	Chemical composition / % wt.					
	P	Al	Ti	Zr	Mg	Cu
1	-	0,009	-	-	0,023	rest
2	-	-	-	0,003	0,023	rest
3	-	0,025	-	-	0,083	rest
4	-	0,022	-	-	0,033	rest
5	-	0,023	0,034	-	0,049	rest
6	-	0,022	-	-	0,059	rest
7	0,075	-	-	-	0,253	rest
8	0,078	0,173	-	-	0,254	rest
9	0,026	0,181	0,122	-	0,262	rest
10	0,143	-	-	-	0,613	rest
11	0,079	0,180	-	-	0,688	rest

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EXPERIMENTAL PROCEDURE

Material

The input material for rolling and further tests were cast bars / ingots produced in the static casting process, was conducted at a temperature of 1200 °C – 1250 °C. The bars were cast into the cast iron mould. In the test cycle, 11 samples (casts) were made. Their chemical composition was tested - Table 1. In Table 1, the order of the castings was arranged from the lowest magnesium content (casting 1) to the highest (casting 11).

Research methodology

The chemical composition of tested material was measured on the SPECTROMAXx spark emission spectrometer – Table 1. The static tensile test was carried out on the Instron 100 kN universal testing machine. Electrical conductivity was measured by the eddy current method on a Resistomat 2504 (1 000 mm) instrument. Microstructural studies were performed on the Olympus GX71F metallographic microscope.

Procedure of research

All samples were rolled on a shape mill. The number of passes in the rolling process was set to 13 passes according to the procedure presented in Table 2. The size of the unit drafts ranged from 15 to 22 %. The exception was the first draft, the value of which was 3,7 % and was intended to change the shape of castings from round to square. The initial surface area of the semi-finished products before the rolling process was 314 mm^2. After all the passes, the surface area was reduced to 27,4 mm^2. Samples were taken on selected passes (total draft 57,2 %, 76,8 %, and 91,3 %), and a tensile test was performed.

Microstructure tests were conducted on selected samples (wire rod 4 and 7). The castings were tested on longitudinal- and cross-sections in the area of the center of the samples and on their edges.

Table 2 **Drafts scheme**

Rolling pass number	Cross section / mm^2	Unit draft / %	Total draft / %
0	314,0	0	0
1	302,5	3,7	3,7
2	251,5	16,9	19,9
3	196,6	21,8	37,4
4	164,0	16,6	47,8
5	134,3	18,1	57,2
6	110,8	17,6	64,7
7	87,6	20,9	72,1
8	73,0	16,7	76,8
9	58,2	20,2	81,5
10	47,9	17,6	84,7
11	40,4	15,8	87,1
12	34,2	15,4	89,1
13	27,4	19,8	91,3

RESULTS AND DISCUSSION

Table 3 shows the results of the tensile strength tests after the rolling process with a total draft of 57,2 %. The lowest value of the tensile strength Rm = 347 MPa (A = 9,4 %) is characteristic of wire rod number 4 and the highest value - wire rod number 8 (Rm = 416 MPa, A = 5,8 %). The remaining value of the tensile strength is within the mentioned range.

Table 4 presents the test results obtained in the static tensile test of castings after a total draft of 76,8 %. The value of the Rm coefficient for the tested samples is between 309 MPa (A = 0,4 %) for casting number 10 and 502 MPa (A = 2,2 %) for wire rod number 3.

Table 3 **Mechanical properties of wire rods after total draft of 57,2 %**

Wire rod number	Draft / %	Rm / MPa	A / %
1	57,2	369	6,5
2		358	7,5
3		402	2,3
4		347	9,4
5		350	8,5
6		377	8,6
7		352	1,0
8		416	5,8
9		412	4,5
10		351	0,7
11		368	1,2

Table 4 **Mechanical properties of wire rods after total draft of 76,8 %**

Wire rod number	Draft / %	Rm / MPa	A / %
1	76,8	398	7,5
2		396	7,6
3		502	2,2
4		396	8,4
5		420	5,6
6		419	4,8
7		396	1,5
8		472	4,8
9		470	6,9
10		309	0,4
11		490	0,9

In the case of testing mechanical properties in the static tensile test of castings with a total draft of 91,3 % (Table 5), the values of the tensile strength Rm are in the range of 421 MPa (A = 3,1 %) for wire rod number 1 and 580 MPa. (A = 1,6 %) for wire rod number 3. For wire rods (castings) number 7 and 10, due to the physical damage of the sample during rolling, a static tensile test was not performed. Figures 1 and 2 show the change of mechanical properties depending on the casting being rolled. The relation (change) was calculated according to formula 1. Figures 1 and 2 show the change of mechanical properties depending on the casting being rolled. The relation (change) was calculated according to formula 1.

Table 5 **Mechanical properties of wire rods after total draft of 91,3 %**

Wire rod number	Draft / %	Rm / MPa	A / %
1		421	3,1
2		433	4,3
3		580	1,6
4		424	3,5
5		460	5,7
6	91,3	451	5,5
7		-	-
8		512	3,6
9		500	4,1
10		-	-
11		505	4,4

$$Change\,/\,\% = -100 \cdot \left(\frac{x-y}{x} \right) \qquad 1$$

where, $x = R_m; A \ \ for\ 57,2\%\ draft,$

$y = R_m; A \ \ for\ 91,2\%\ draft$

The lowest increase in the Rm (by 14 %), with elongation (by 52 %), is for wire rod number 1 containing a aluminium addition of 0,009 % by mass and magnesium – 0,023 % by mass. The highest increase in Rm by 44 % (a decrease in elongation, A by 30 %), was recorded for wire rod number 3, indicating its greatest strengthening in terms of total drafts between 57,3 % and 91,3 %.

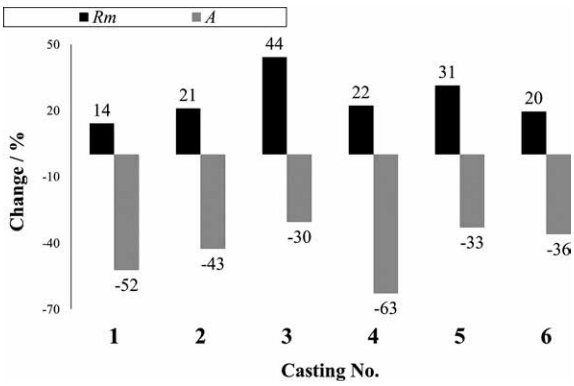

Figure 1 Change in mechanical properties calculated according to formula 1 for wire rod number from 1 to 6

Microstructure tests were carried out on selected wire rods number 4 and 7 with a total draft of 57,2 %, 76,8 % and 91,3 %. The results of the observations are shown in Figures 3 - 6.

An interesting fact is the increase in plasticity in sample 11, however, this issue requires additional research and in-depth analysis. In both presented cases, an increase in grain refinement was observed along

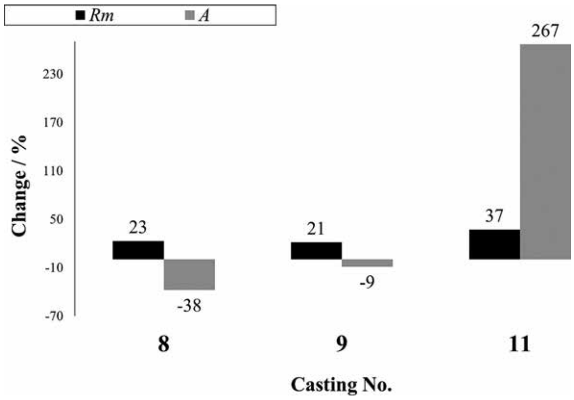

Figure 2 Change in mechanical properties calculated according to formula 1 for wire rod number 8, 9 and 11

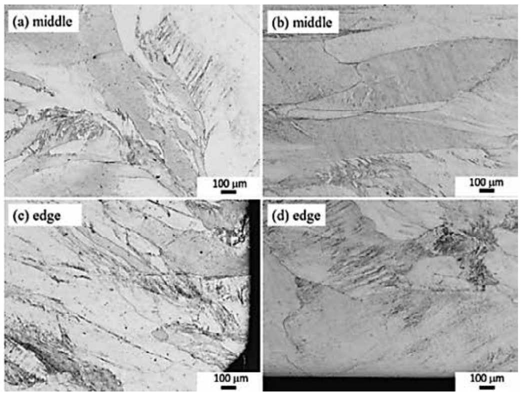

Figure 3 Microstructure of wire rod number 4, total draft 57,2 %, a, c - cross section, b, d - longitudinal section

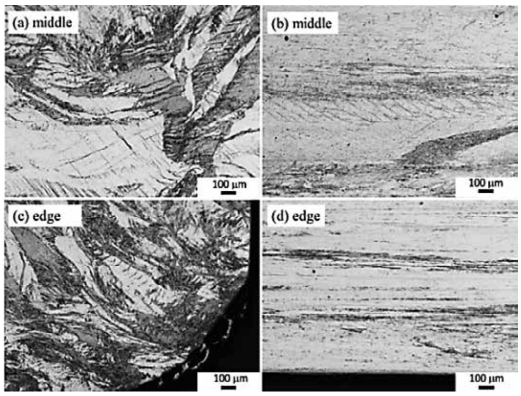

Figure 4 Microstructure of wire rod number 4, total draft 91,3 %, a, c - cross section, b, d - longitudinal section

with an increase in deformation. The grain size distribution gradient shows greater grain size refinement at the edges of the sample compared to its centre. Examination of the longitudinal section shows grain elongation in the direction of rolling. In the case of casting number 7, with a total draft of 91,3 %, delamination of the material was observed in the middle part of the wire rod.

Figure 7 shows the results of electrical conductivity tests with a total draft of 91,3 %. Wire rod number 5 had the lowest electrical conductivity, 25,51 MS/m. The highest, 52,10 MS/m, was for wire rod number 2.

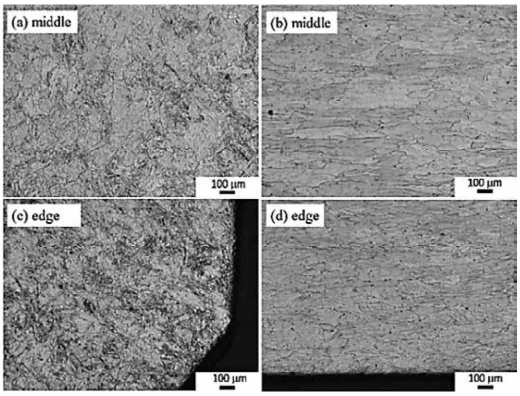

Figure 5 Microstructure of wire rod number 7 total draft 57,2 %, a, c - cross section, b, d - longitudinal section

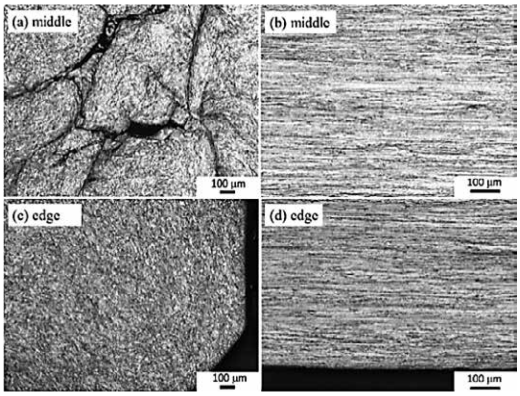

Figure 6 Microstructure of wire rod number 7 total draft 91,3 %, a, c - cross section, b, d - longitudinal section

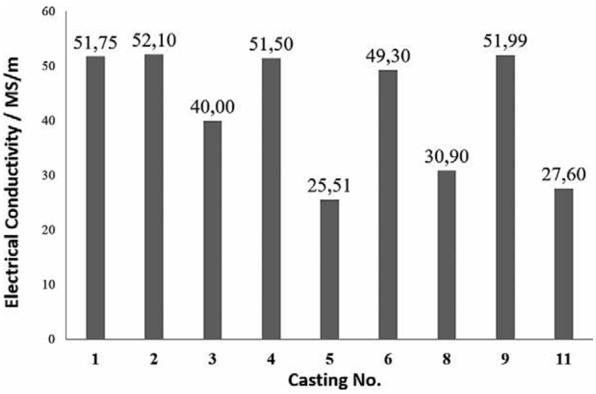

Figure 7 Electrical conductivity depending on chemical composition, total draft 91,3 %

CONCLUSIONS

A large influence of microadditives on the final properties of castings after plastic working (the rolling process) was found. Depending on the amount of microadditives and their type in rolled castings, various values of material properties were obtained and the following conclusions were formulated:

- The technology presented in the article allows to get selected good quality magnesium copper-based wire rods obtained in the static casting process.
- Wire rod number 3 with the composition of 0,025 % Al, 0,83 % Mg, and Cu the rest has the highest hardening level after applying the total draft of 91,3 % (the highest coefficient Rm = 580 MPa), while the lowest (Rm = 421 MPa) occurs in wire rod number 1 with a mass chemical composition of 0,009 % Al, 0,023 % Mg, and Cu the rest.
- The highest mechanical properties were recorded in the sample containing the highest content of magnesium and the addition of Al in the amount of 0,025 % by mass. (casting No. 3) it caused an increase in the Rm coefficient to 580 MPa with a simultaneous decrease in elongation to 1,6 %. The electrical conductivity has also been reduced to 40 MS/m.
- The presence of Ti together with Al (wire rod 5) and Al and P (wire rod 8 and 11) as well as Al alone (wire rod 3) causes a decrease in electrical conductivity.

Acknowledgments

The research was carried out as part of the CuMag+ project financed by the National Centre for Research and Development under the TECHMATSTRATEG III program (TECHMATSTRATEG-III/0002/2019-00)

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