G. KIESIEWICZ, P. KWAŚNIEWSKI, W. ŚCIĘŻOR, K. FRANCZAK,
M. SADZIKOWSKI, S. KORDASZEWSKI

ISSN 0543-5846
METABK 62(3-4) 464-466 (2023)
UDC – UDK 539.417-621-75:621-426:669.3.721:620.17:537.311.3=111

RESEARCH ON Cu-Mg CASTINGS COLD DRAWING PROCESS AND ANALYSIS OF MECHANICAL AND ELECTRICAL PROPERTIES OF OBTAINED WIRES

Received – Primljeno: 2023-03-01
Accepted – Prihvaćeno: 2023-04-25
Preliminary Note – Prethodno priopćenje

The aim of the conducted research works which are presented in the article was to determine the mechanical and electrical properties of Cu-Mg wires obtained in cold drawing process with total deformation at the level of 95 %. Base material for the research was obtained with the use of continuous casting process which allowed to produce CuMg0.02, CuMg0.05 and CuMg0.5 cylindrical rods with 9,5 mm diameter which were next cold drawn up to 1,97 mm diameter. After the cold drawing process Vickers hardness measurements along with static tensile test and electrical conductivity analysis were performed in order to determine the evolution of castings properties as a result of the applied cold deformation.

Keywords: cold drawing, wire, Cu-Mg alloys, mechanical properties, electrical conductivity

INTRODUCTION

Nowadays, extensive research work is being carried out all around the world to develop new types of copper-based alloys in order to improve mechanical, electrical and exploitational properties of those materials in order to improve their performance. An example of such works are the studies presented in [1], concerning the effect of rare-earth metals addition of the copper alloys on the refinement of the microstructure and the resulting improvement in plasticity and increase in mechanical properties. Another example of this type of research are the results presented in [2] concerning the possibility of obtaining high mechanical and electrical properties of fibre composites with a copper matrix and the addition of niobium. In order to increase the functional properties of copper, the addition of Mg is also used, which in various proportions allows to increase the various proportions allows to increase the mechanical properties of copper [3-6]. This type of alloy is currently used for high strength and high electrical applications i.e. for contact wires and catenaries in high speed railway applications, where it is produced by cold drawing process to desired shape [7-8]. The main goal of conducted and presented research work is to determine the mechanical and electrical properties of CuMg0.02, CuMg0.05 and CuMg0.5 castings which were next subjected to the cold drawing process. The implementation of the planned works makes it possible to determine the evolution of mechanical and electrical properties as a result of performed cold metal forming, at the same time allowing to determine the values of critical mechanical and electrical properties of finished products.

G. Kiesiewicz (e-mail: gk@agh.edu.pl), P. Kwaśniewski, W. Ściężor, K. Franczak, M. Sadzikowski, S. Kordaszewski - AGH University of Science and Technology, Faculty of Non-Ferrous Metals, Cracow, Poland

EXPERIMENTAL PROCEDURE

All materials prepared for detailed mechanical and electrical properties were initially prepared on laboratory scale, first by horizontal continuous casting process with induction heating and with the use of graphite crucible and crystallizer (R4550 grade graphite). Metaling temperature was set at the level of 1220 °C**.** After the melting process and further performed alloying of magnesium to copper, chemical composition was verified in order to obtain following Cu-Mg alloys: CuMg0.02, CuMg0.05, CuMg0.5 in form of rods with 9,38 mm diameter. After casting all materials were subjected to cold drawing process with total deformation at the level of 95,7 % which allowed to obtain final Cu-Mg wires with 1,97 mm diameter through 17 individual draw steps as presented in Table 1.

After cold drawing, hardness measurement were done on the samples prepared from each drawing stage of drawing process. Wilson-Hardness Tukon 2500 hardness tester was used for the analysis. The tests were carried out using the Vickers method with a load of 10 kgf. For every sample 5 indentations were made on the cross section of the wire from which the arithmetic mean was calculated and presented in the article. The next stage of work included the resistance measurements, which were carried out using RESISTOMAT model 2304 by Burster, using the Thomson bridge method. Measurement base during the tests was 100 mm, while the tests

Table 1 **Parameters of cold drawing process used to obtain CuMg0.02, CuMg0.05 and CuMg0.5 wires**

Draw no.	Die working diameter	Total deformation / %	True strain
0	9,38	-	-
1	8,70	13,97	0,15
2	8,00	27,26	0,32
3	7,30	39,43	0,50
4	6,65	49,74	0,69
5	6,05	58,40	0,88
6	5,25	68,67	1,16
7	5,00	71,59	1,26
8	4,55	76,47	1,45
9	4,15	80,43	1,63
10	3,78	83,76	1,82
11	3,44	86,55	2,01
12	3,14	88,79	2,19
13	2,86	90,70	2,38
14	2,61	92,26	2,56
15	2,37	93,62	2,75
16	2,16	94,70	2,94
17	1,97	95,59	3,12

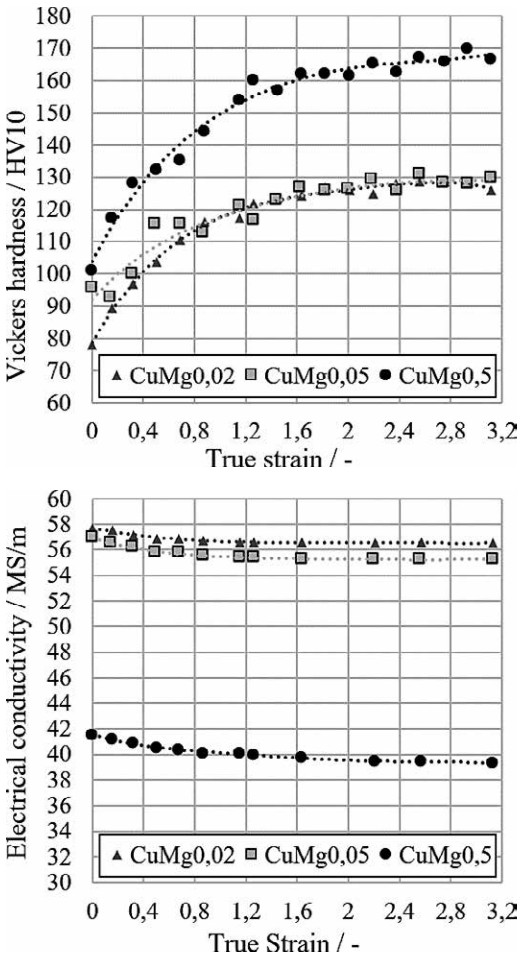

Figure 1 Vickers hardness and electrical conductivity research results for all Cu-Mg materials at all staged of cold drawing process from 9,38 mm to 1,97 mm diameter.

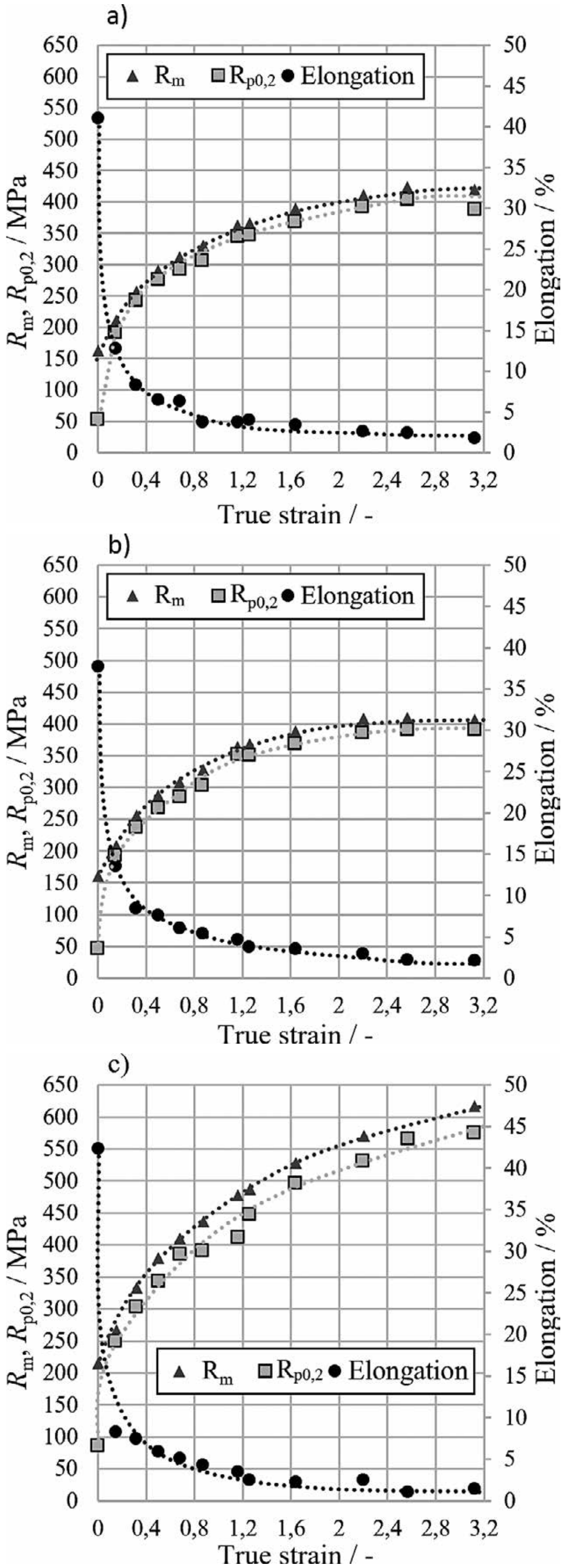

Figure 2 Work-hardening curves obtained in cold drawing process of previously casted rods: a) CuMg0.02, b) CuMg0.05 and c) CuMg0.5 alloys

were carried out at a ambient temperature of 22 °C. Last tests carried out as part of this article included the static tensile test, which used to evaluate tensile strength (R_m), yield strength ($R_{p0.2}$) and elongation (A_{100}). The tests were carried out on a Zwick/Roell Z100 materials testing machine and measurement base for all samples were 100 mm.

RESULTS AND DISCUSSION

Research results of Vickers hardness and electrical conductivity measurements were presented for all three copper magnesium materials in figure 1 below in the form of cumulative characteristics.

Analysis of all obtained research results for CuMg0.02 alloy shows that wires made out of this material exhibit an electrical conductivity starting from 57,6 MS/m and decreasing to 56,5 MS/m at the end of the drawing process. At the same time and the Vickers hardness is increasing from 78 up to 129 HV10 which is 65 % more. The ultimate tensile strength of wires, as it was shown in Figure 2a, is in the range of 163 up to 420 MPa. The yield strength of the material, which was determined with the use of traditional graphic method for all samples, is at the range of 52 to 410 MPa. The elongation of tested wires is decreasing as an effect of strain hardening from 41 to 1,8 %.

In the case of wires made out of CuMg0.05 alloy, their electrical conductivity decreases from 56,9 to 55,2 MS/m which is 3 % less. Material with addition of 0,05 wt. % of magnesium to copper exhibits the Vickers hardness values from 92 to 131 HV10. Static tensile test which allowed to obtain $R_{p0,2}$, R_m and elongation characteristics presented for CuMg0.05 alloy in Figure 2b shows that the yield strength of samples ranges from 41 up to 392 MPa. Ultimate tensile strength is at the level of 161 MPa at the beginning of the cold drawing process (as-cast state) to approx. 410 MPa for wires with 95 % of deformation through applied through cold working process. The elongation value decreases form initial 37,7 % to 2,1 %.

The research results for CuMg0.5 alloy shows that it has an electrical conductivity in the range of 39,2 to 42,6 MS/m. It has the lowest electrical conductivity of all tested materials and also significantly lower than pure ETP grade copper. The Vickers hardness of the alloy was measured to be in the range of 101 to 170 HV10, which is on the other hand the highest value from all tested materials. The R_m value (see Figure 2c) of the CuMg0.5 material has significantly increased from 215 to 616 MPa. The yield strength ranges from 86 to 575 MPa, and the elongation which started at 42,4 %, dropped down to 1,4 %.

CONCLUSIONS

Research works obtained and presented in this article allowed to formulate following conclusions:

- the highest electrical conductivity value, in as-cast state, of 57,6 MS/m was obtained for alloy with the lowest amount of magnesium addition which is CuMg0.02. On the other hand the lowest conductance has the CuMg0.5 alloy at the level of 42,6 MS/m, also in as-cast state, which is around 26% less. Cold drawing process for both CuMg 0.02 and CuMg0.05 alloys resulted in 2-3 % decrease in electrical conductivity and for CuMg0.5 this decrease was even higher at the level of approx. 8 %,
- the highest value of Vickers hardness was measured for CuMg0.5 alloy which after cold drawing process was at the level of 170 HV10. Both CuMg0.02 and CuMg0.05 alloys have hardness in analogical temper at the level of approx. 130 HV10 which is 23,5 % lower,
- R_m for CuMg0.02 and CuMg0.05 alloys in their cold-worked temper equals successively 410 and 420 MPa. The $R_{p0,2}$ of both above mentioned materials is 392 and 410 MPa which is in both cases no more that 5 % difference as of R_m respectively. Indisputably the highest mechanical properties were obtained for CuMg0.5 with 616 MPa for R_m and 575 MPa for $R_{p0,2}$ which is more less 30 % more than for other two materials.

Acknowledgments

The research results were achieved as part of TECHMATSTRATEG-III/0002/2019 project "Innovative technology of production of wired materials based on Cu-Mg alloys with special performance properties for working in high and variable mechanical, electrical and thermal loads" financed by the National Centre for Research and Development in Poland.

REFERENCES

[1] 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) 2, 641-648

[2] W. Głuchowski, Z. Rdzawski, J. Stobrawa, K. Marszowski, Microstructure and properties of Cu-Nb wire composites, Archives of Metallurgy and Materials 59 (2014) 1, 35-40

[3] HuiYa Yang, ZiChao Ma, ChenHui Lei, Liang Meng, YouTong Fang, JiaBin Liu, High strength and high conductivity Cu alloys: A review, Science China Technological Sciences 63 (2020), 2505–2517

[4] G.J. Liu, S.S. Jia, S.H. Hong, J.W. Lim, Y.F. Zhu, K. Mimura, M. Isshiki, Corrosion resistance of dilute CuMg alloys at elevated temperature, Corrosion Science 51 (2009) 3, 463-468

[5] Yun-xiang Tong, Si-yuan Li, Dian-tao Zhang, Li Li, Yufeng Zheng „High strength and high electrical conductivity CuMg alloy prepared by cryorolling" Transactions of Nonferrous Metals Society of China 29 (2019) 3, 595-600

[6] P. Rodríguez-Calvillo, N. Ferrer, J.M. Cabrera „Analysis of microstructure and strengthening in CuMg alloys deformed by equal channel angular pressing" Journal of Alloys and Compounds 626 (2015), 340-348

[7] F. Kiessling, R. Puschmann, A. Schmieder „Contact lines for electric railways" Publicis, Munich, GE (2001)

[8] Guo Zhen, Yongseok Kim, Li Haochuang, Jae-Mean Koo, Chang-Sung Seok, Kiwon Lee, Sam-Young Kwon „Bending fatigue life evaluation of Cu-Mg alloy contact wire" International Journal of Precision Engineering and Manufacturing 15 (2014), 1331–1335

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