BASIC MECHANICAL PROPERTIES INFLUENCED BY DRAWING TECHNOLOGY OF COPPER WIRES

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Abstract

In the industrial field that manufactures products, which are used in electrical installations, copper is an essential part in terms of the use of materials. Due to excellent electrical and thermal properties compared to other metallic materials, copper is mainly used for the manufacture of electrical conductors of various cross-sections depending on the area of application, from small electronics to high-voltage conductors. In the manufacturing process, copper is subject to strict operating conditions, especially in terms of chemical purity, in order to ensure the required mechanical and electrical properties. The copper conductors which are subject of this study are made by cold drawing technology. In this production process, the input semi-finished product is a copper rod with a circular cross-section. This copper rod is formed by various number of dies which ensure the final diameter of the wire. The passage of wire through the individual dies during drawing has a disadvantageous influence and reveals an uneven distribution of strain intensity for the drawn material and causes the changes of mechanical properties along the wire cross-section [1]. Despite the various advantages of this manufacturing process, the drawing of wires leads to a reduction in plasticity, especially in the case of multiple drawing. Wires lose their strength due to the high presence of residual stresses that have arisen after pulling, which can negatively affect their function under operating conditions [2]. The above mention structural and mechanical changes are the subject of this study. The knowledge of this experiment can be beneficial for applications of mechanically loaded electrical conductors.

Keywords: cold drawing, mechanical properties, copper wire, reinforced structure, tensile test

1 Introduction

Copper, thanks to excellent electrically conductive properties, is used for the production of electric conductors with different diameters for high voltage installations. The resulting diameter of these conductors is provided by the cold drawing technology. During the drawing process, the copper wire is plastically deformed due to a number of factors related to the drawing technology, such as the approach angle of the drawing die, the drawing speed and the number of dies. The move of the wire through a series of cone dies causes the cross-section to be reduced to the desired dimension with respect to the further use of the wire in working conditions. The stress-strain characteristics of the precursor blank are important due to the wire drawing technology. In the paper was shown that the edge reinforcement caused by the production of the wires affects their stress-strain characteristics and fracture properties [3].

2 Characteristics of tested materials and methods

The experimental material was two wire bundles of electric conductors. Each bundle consisted of a plurality of copper wires. Copper wires in bundles were produced by drawing technology, and the manufacturer indicates that the number of dies used in their production was different. Two samples of 0.25 mm diameter were made from these conductors by removing the insulation. A schematic representation of the conductors as a whole is shown in Fig. 1.

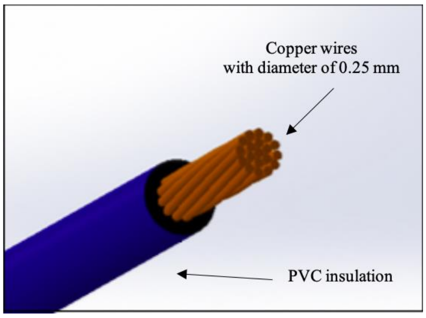

Fig. 1 *A schematic view of copper conductor wire bundle with protective insulation*

For the production of this type of conductors is used technical electrical copper, which according to STN 423001 has a purity of at least 99.98 wt.%. Verification of the chemical composition was performed by EDS method by a scanning electron microscope VEGA 3 TESCAN on the basis a polished area from the central region of the longitudinal section of etched copper wire samples. The EDS analysis confirmed that it was copper conductor with a Cu content above 99.98 wt.% (Fig. 2 and Fig. 3) and no chemical impurities were found in accordance with the analyser detection limit. Carbon which was found using EDS analysis (Fig. 2) was not considered as the element present in the wires It was deposited on the surface from the metallographic sample preparation process. In the view of this, carbon was excluded from the quantitative chemical microanalyses.

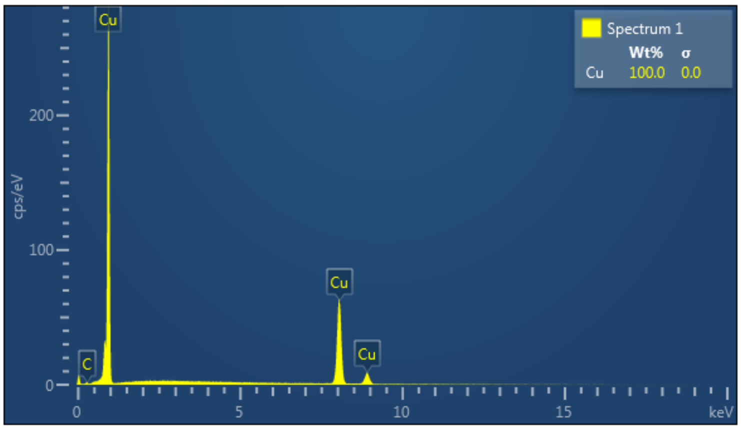

Fig. 2 *A representative spectrum of the chemical elements of a sample drawn through bigger number of dies*

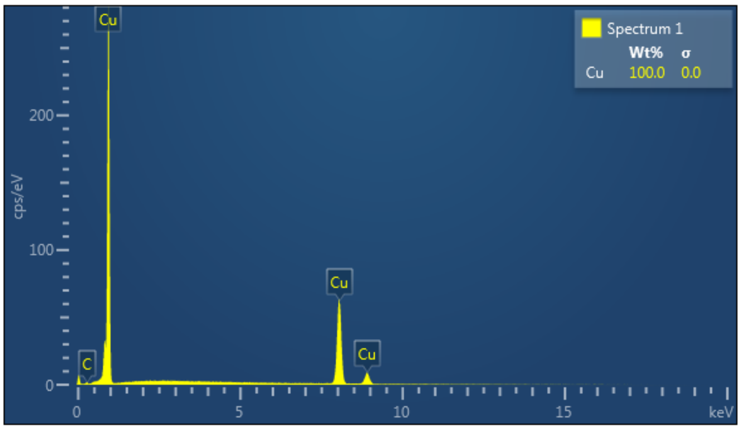

Fig. 3 *A representative spectrum of the chemical elements of a sample drawn through smaller number of dies*

Tested copper wires were made by drawing technology. Wire drawing is the process of reducing their cross-section by pulling it through the die [4]. This process makes it possible to achieve the desired wire dimensions having a constant cross-section (Fig. 4).

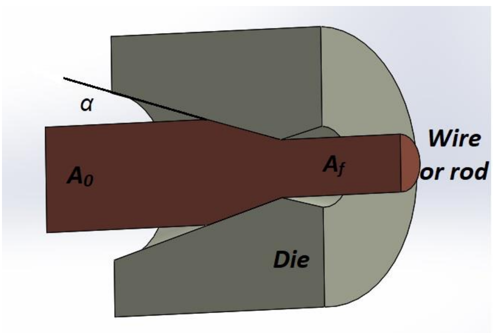

Fig. 4 *A schematic image of the cold-drawing process*

Based on the diameter of the wires, we assume that their production utilized the medium cold drawing technology. The feed stock in the form of a wire with a diameter from 1.8 mm to 3.6 mm could pass up to 28 dies in the technological method of drawing (Table 1) [5].

Table 1 *Parameters of the medium cold drawing technology*

Parameter	Medium drawing
Input wire (Ø mm)	1.8 – 3.6
Final wire (Ø mm)	0.1 – 1.6
Amount of dies	1 – 28

Several experimental methods can be applied for the analysis of selected material properties. Due to the small geometrical dimensions of the samples, the method of scanning electron microscopy was used. This method, in combination with EDS, provides information on the microstructure and micro-purity of the material. The depth of the reinforced area was also measured by SEM for both samples. Since both specimens have structural changes on the surface that cause a change in mechanical properties, the Vickers hardness method according to STN EN ISO 6507-1 was applied. These changes in mechanical properties on the surface are related to the different number of dies used in the intermediate drawing technology [6]. The tensile test method according to STN EN ISO 527-1 was chosen to detect changes in some stress-strain characteristics across the sample cross-section. To enhance the microstructure, metallographically prepared samples were polished and etched using MS $\alpha+\beta$ (potassium dichromate). From the etched microstructure observation, a very fine-grained structure with an average grain size up to 5 μm was found.

3 Results and discussion

The resulting depth of the reinforced area is shown by the yellow line in Fig. 5 for a sample drawn through a bigger number of dies, and Fig. 6 for a sample drawn through a smaller number of dies. From the comparison of Fig. 5 and Fig. 6 results that a sample drawn through bigger number of dies has a visibly greater depth of the reinforced area.

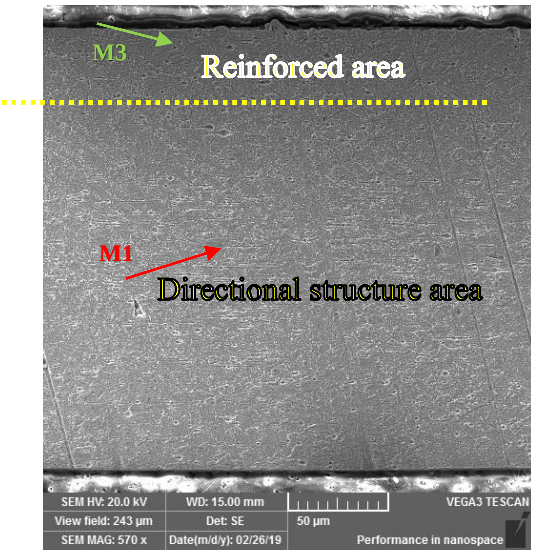

Fig. 5 *The sample drawn through a bigger number of dies*

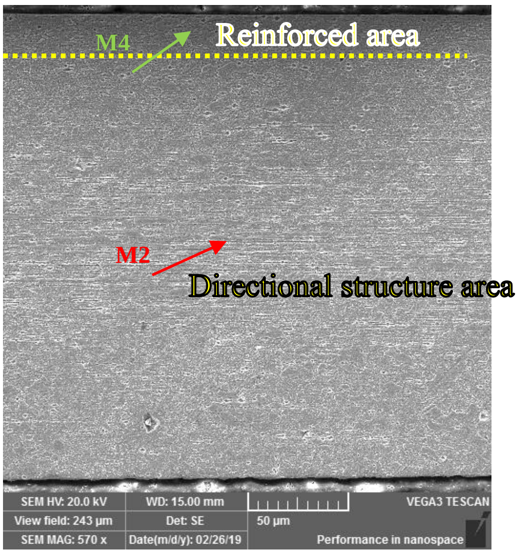

Fig. 6 *The sample drawn through a smaller number of dies*

Given the observed fine-grained structure, an assessment of the structural changes in a more detailed view was necessary. In both samples was found that a fine-grained structure in the central region was parallel with the direction of cold forming (Fig. 7 and Fig. 8). This guided structure is characterized by the longitudinal shape of the grains in the direction of the pulling axis and is generated by the tensile force that ensures the passage of the wire through the individual dies. More detailed views of the directed structure of both samples are from the locations M1 and M2, which are visible in Fig. 5 and Fig. 6.

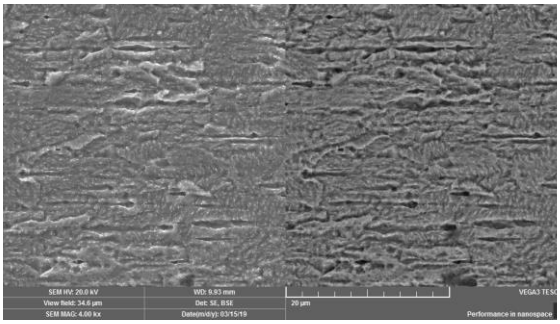

Fig. 7 *Directional structure in the center of the sample drawn through a bigger number of dies – place M1*

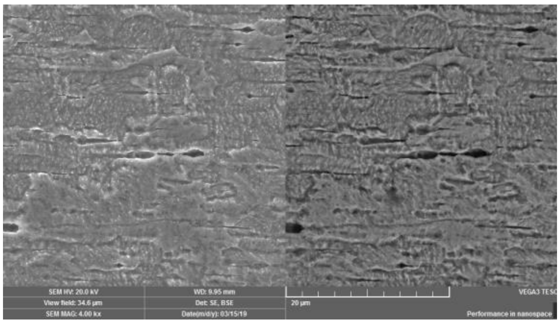

Fig. 8 *Directional structure in the center of the sample drawn through a smaller number of dies – place M2*

Strengthening of the material can be seen in the marginal parts of both samples. Polyedric grains are observed in this region, and this reinforcement was due to the compressive forces of the marginal portions of the die which cause a reduction in the wire diameter (Fig. 9 and Fig. 10). More detailed views of the directed structure of both samples are from the locations M3 and M4, which are visible in Fig. 5 and Fig. 6.

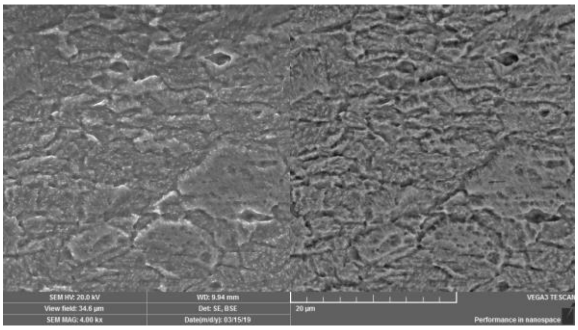

Fig. 9 *Reinforced edge etched structure of the sample drawn through a bigger number of dies – place M3*

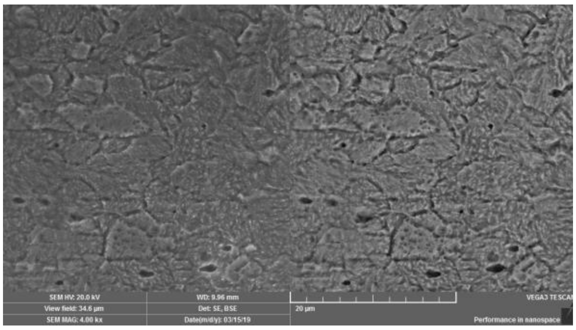

Fig. 10 *Reinforced edge etched structure of the sample drawn through a smaller number of dies – place M4*

This force action causes a change in the basic mechanical properties, especially in the change of surface hardness. Vickers hardness measurements according to STN EN ISO 6507-1 showed a dependence of the number of dies (through which the copper wire was drawn) on the microhardness value. The sample drawn through over bigger number of dies having a larger edge reinforcement region also had higher hardness values in the edge region. The results of the hardness measurements of the individual regions of both samples are shown graphically in Fig. 11.

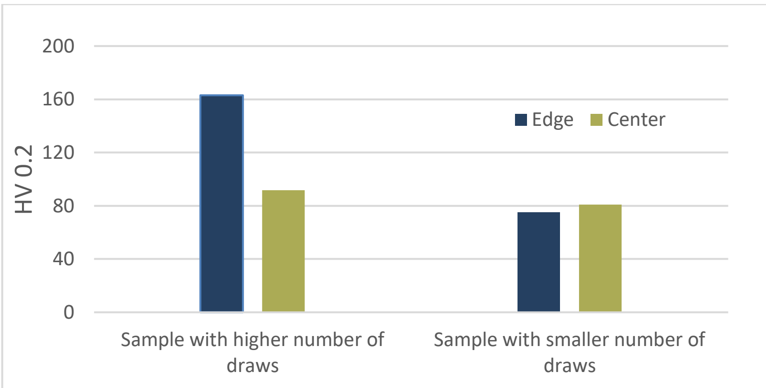

Fig. 11 *Graphical representation of measured hardness values HV0,2*

A comparison of mechanical properties between surface and core revealed the change across the wire cross-section. The tensile test showed that there were visible changes in strength, ductility and contraction. Due to the more pronounced edge reinforcement observed on the sample drawn through bigger number of dies, this sample had greater tensile strength, less ductility and less contraction than the sample drawn through a smaller number of dies according to STN EN ISO 527-1. The values determined from the tensile test are shown graphically in Fig. 12.

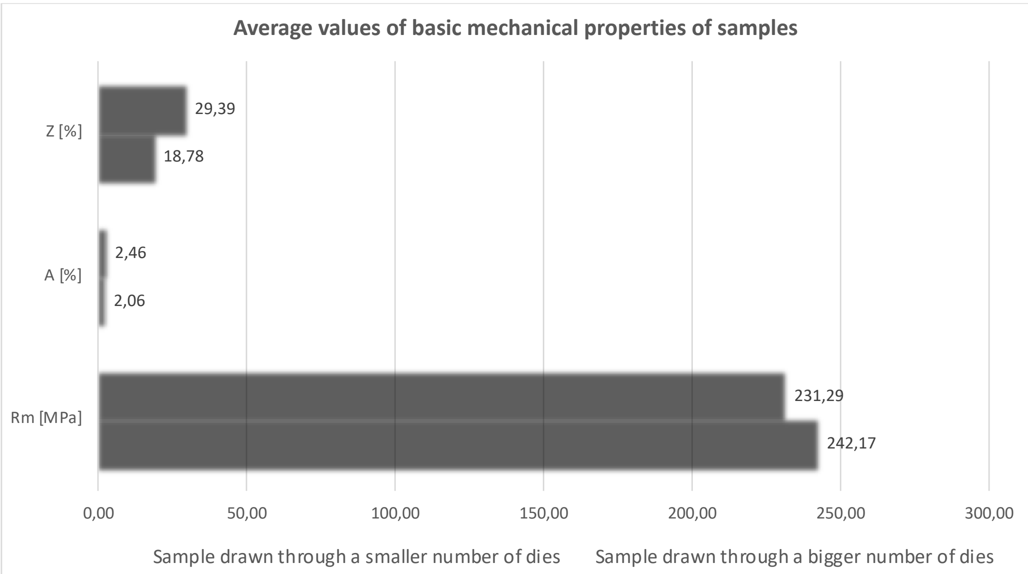

Fig. 12 *Graphical representation of basic mechanical properties of samples*

From the character of fracture surfaces created after the tensile test, it is obvious that this is a ductile fracture. On the edge of the fracture surface it is possible to observe the cup-and-cone shaped failure surface. (Fig. 13 and Fig. 14), detailed images of the fracture surface are visible in Figs. 15 and 16 and represent the failure mechanism of wires.

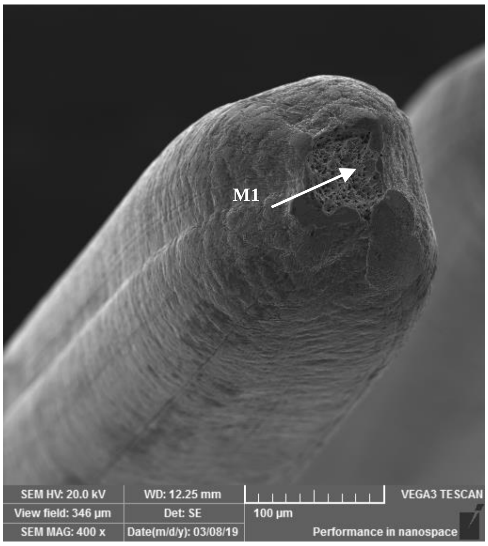

Fig. 13 *Fracture area of the sample drawn through a bigger number of dies*

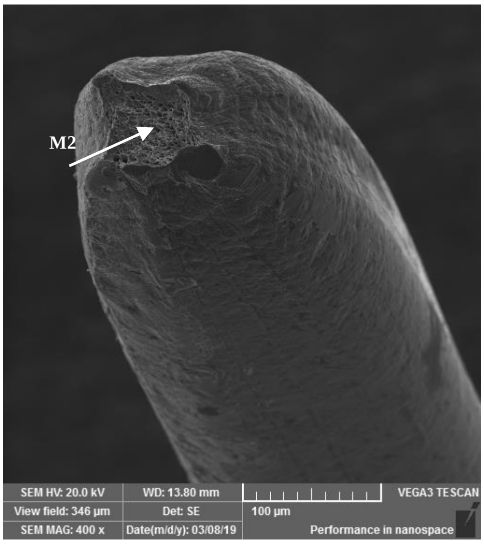

Fig. 14 *Fracture area of the sample drawn through a smaller number of dies*

In the detailed images, the large depth of the dimples is visible and characterizes ductile materials (Figs. 15 and Fig. 16). Dimples seen in these figures are without any others particles what corresponds to the material with high purity. In the region of the neck of the broken sample (Fig. 17), no strengthening of the edge layers is observed due to the large plastic deformation and tensile stress during the test.

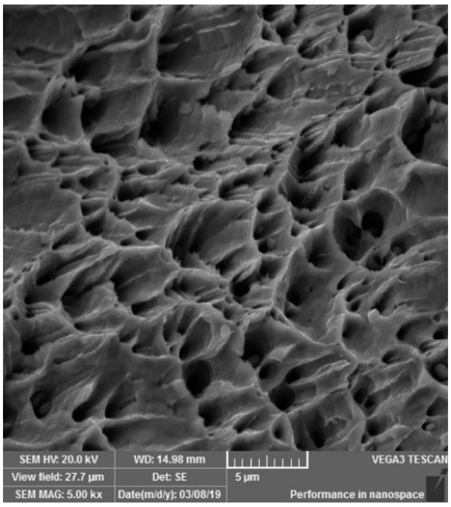

Fig. 15 *Detailed image of fracture area M1 Sample drawn through a bigger number of dies*

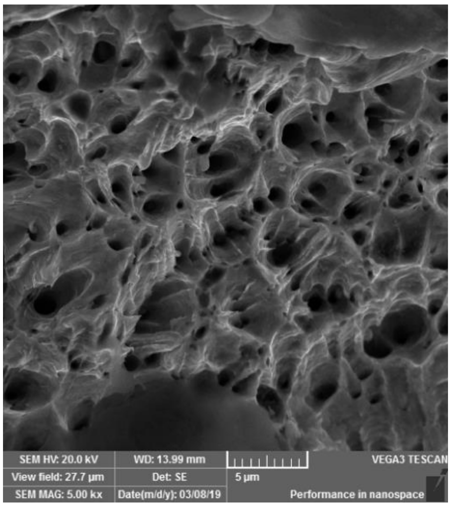

Fig. 16 *Detailed image of fracture area M2 Sample drawn through a smaller number of dies*

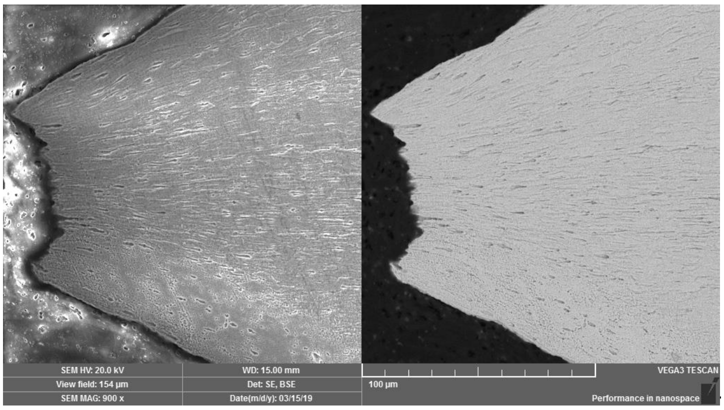

Fig. 17 *Fracture surface in the longitudinal section of the copper conductor wire - sample drawn through a bigger number of dies*

4 Conclusion

Considering the results of individual analyses of the mechanical properties and measured values by scanning electron microscopy, the following conclusion can be obtained:

(i) Good chemical homogeneity of the material was confirmed by both longitudinal and cross-sectional chemical analyses in both samples, and it was confirmed high purity of copper, i. e. 99.8 wt.%.

(ii) The copper wire sample, drawn through a bigger number of dies, showed a higher hardness, confirming the fundamental effect of drawing on the enhancement of some mechanical properties. During plastic deformation, the crystals gets the elongated shape and stretch in the direction of the main deformation. The slip planes rotate and orient in the direction of the main deformation while the final structure has a significant anisotropy. The strength and plasticity of the metals in the direction of the main deformation increase, while in the cross-section they decrease [7].
Thus, the number of calibres in copper wire drawing technology affects the final surface hardness of the wire and also affects the final strength. The inclusion of a bigger number of dies in the copper wire drawing process increases the strength and surface hardness to a greater extent than when using a smaller number of dies.

(iii) In this forming process, a compressive stress is applied to the surface of the wires, reducing the effect of tensile stress, which is more dangerous due to the occurrence of residual stresses in the material during the manufacturing process and the possible occurrence of notch effects that reduce the life of the material. It was confirmed that cold drawing causes anisotropic crystallography and grain elongation along the wire drawing axis [8]. We also noted an increase in hardness and mechanical resistance of the drawn wire with an increase in the level of strain caused by pulling.

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