M. ZASADZIŃSKA, B. SMYRAK, T. KNYCH, P. STRZĘPEK

ISSN 0543-5846
METABK 61(3-4) 774-776 (2022)
UDC – UDK 669.3.621-426:539.417.004.64:539.375:539.26=111

DEFECTS ANALYSIS OF COPPER WIRES MANUFACTURED IN INDUSTRIAL CONDITIONS

Received – Primljeno: 2021-10-25
Accepted – Prihvaćeno: 2022-02-28
Preliminary Note – Prethodno priopćenje

Many factors are responsible for the formation of surface and internal defects during copper wire drawing process. Generally they may be divided into defects of material or processing origin. Even input material of the highest quality with little to none defects cannot ensure the absence of breakages during the process due to inadequate process parameters. Optimally selected process parameters may reduce the risk of cracks forming during the metal forming process. The paper presents examples of wire defects and cracks occurring throughout the wire drawing process of copper in industrial conditions and a wide analysis of their source.

Keywords: copper wires, drawing process, wire defects, fracture, scanning electron microscopy (SEM)

INTRODUCTION

Copper wires are mostly responsible for failure-free transmission of electrical energy and thus the presence of material defects is particularly dangerous. Wire defects generate not only the risk of the material breakage during metal working process but also lowers the quality of the final wires and microwires. The interruption of the wire drawing process also generates high costs related to re-starting of the process and machines. There are many types of defects both surface and internal. The former include slivers, weld fracture and die loading fracture. The latter are mostly related to voids inside the material and the literature names them central bursts or chevron (the name comes from the characteristic V-shaped shape) [1-3]. Internal defects such as central bursts not necessarily have to appear in the initial stage of the metal working process (these types of defects are common not only in the wire drawing process but also in the extrusion process). The compressive state of stress inside the drawing die in the radial direction prevents the defects and material breakage in the initial state of the process from manifestation, however, the defects may be located inside of the material and present in later stages of metal working process. This is especially dangerous throughout the cold drawing process and requires inter-operational annealing with appropriate time and temperature which restores the full deformability of the drawn material. Proper selection of process parameters also prevents the formation of internal defects. As one of the examples the optimization of the drawing die angle may be applied (for copper the optimal drawing die angle is $2\alpha = 18\ °$) [4]. Increasing the value of the drawing die angle may result in the formation of dead zones and thus lowering the elongation of wires due to the internally present chevrons [5]. Many valuable research works are devoted to the conditions and process parameters which favour the formation of these defects and at the same how to prevent them [6-8]. A significant cause of internal defects formation and often their origin in the initial state are inclusions. In the case of copper they may be divided into primary inclusions in the form of Cu_2O oxide [9] bound to copper processing into wires and microwires at all stages [10] and those of external origin e.g. acquired from the lining of the melting and casting furnace during previous processing stage [11,12]. Therefore, it is extremely important to control material defects at every stage of processing as it allows for constant maintaining of high quality wires and microwires, minimizing the wear of the drawing dies and what is more reducing costly breakages.

EXPERIMENTAL PROCEDURE

The article discusses the examples of defects and cracks occurring in copper wires during the industrial wire drawing process. The analysis was conducted in various magnifications of the surface and fractures using scanning electron microscope (SEM) Hitachi S-3500N.

RESULTS AND DISCUSSION

The conducted study distinguishes two main groups of defects origins during copper wire drawing process. The first is related to the quality of the charge material (poor quality starting from the cathode all the way to the wire rod) and the second is related to the process parameters which also influence and accelerate the formation of the defects and breakages.

M. Zasadzińska (e-mail: malgozas@agh.edu.pl), B. Smyrak, T. Knych, P. Strzępek AGH University of Science and Technology, Faculty of Non-Ferrous Metals, Cracow, Poland

Defects related to the quality of the charge material

Surface

Copper wire rod is usually covered at the surface with a layer of CuO (II) oxide which thickness may reach even up to a few micrometres. If the layer on the surface of the drawn material in industrial conditions is too large it may cause the so-called excessive copper dusting which may directly cause the unfavourable increase of the drawing force and generate surface defects of the wires. The poor surface quality causes, among others, cracks, slivers or surface defects lowering its final properties. The example of surface defects of copper wire was presented at Figure 1. In order to eliminate the above-mentioned wire defects during industrial manufacturing processes of wire rods surface copper oxide are removed by reduction with isopropyl alcohol or by etching.

Internal

The charge material may have several types of internal defects. Starting with the voids or porosity caused by the presence of gases, especially hydrogen during the manufacturing process of wire rod in the liquid copper and ending with a large amount of defects connected with the large concentration of impurities and inclusions which are responsible for most of the breakages of the continuity of the industrial multistage wire drawing process [13]. The most common impurities being sulphur, lead, iron and copper oxide and these impurities may be usually divided into those of metallic and non-metallic origin. Non-metallic inclusions include iron oxides, calcium oxides, sodium oxides and aluminium

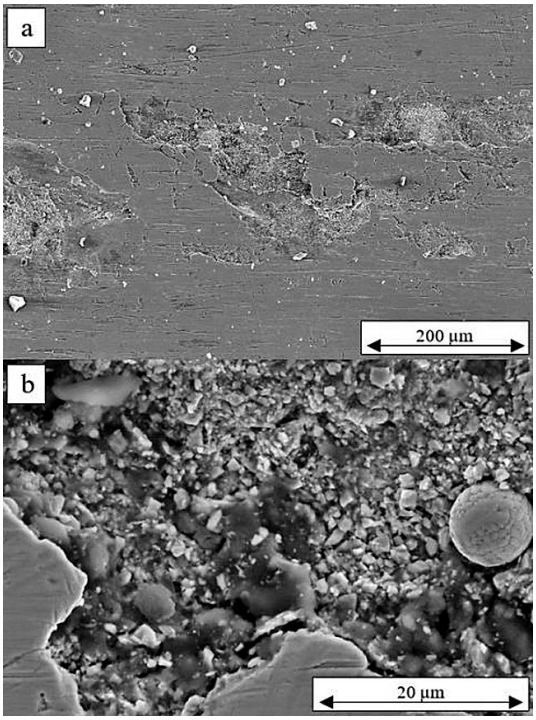

Figure 1 Surface of Cu-ETP wire, SEM, magnification a) x 200, b) x 2 500

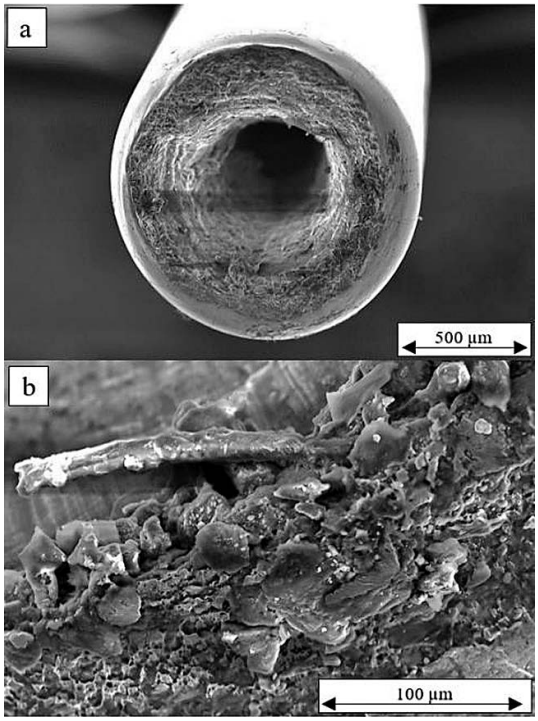

Figure 2 Fracture of Cu-ETP wire, SEM, magnification a) x 60, b) x 500

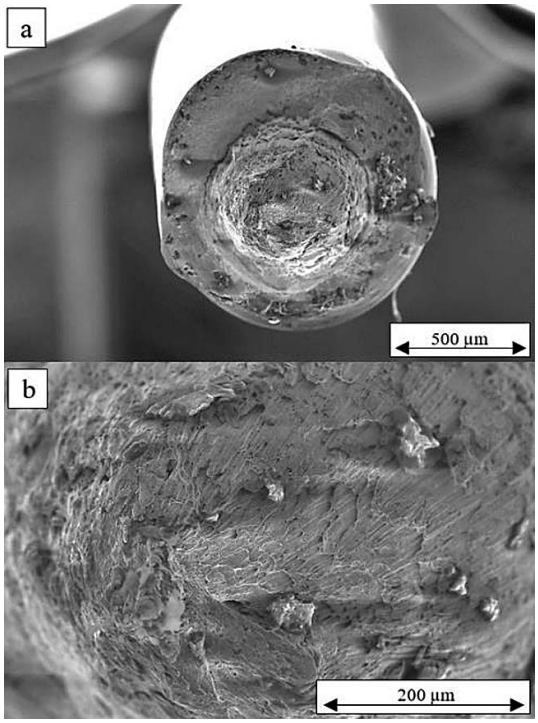

Figure 3 Fracture of Cu-ETP wire, SEM, magnification a) x 60, b) x 250

oxides (corundum) which usually come from the furnace lining or crucible contact. Typical metallic inclusions on the other hand are iron and iron alloys (steel), nickel, chromium, etc. The main source of limiting the ductility of copper is very often the excessive amount of copper (I) oxide Cu_2O [14]. The regions of cohesion loss of the wires contain numerous craters / voids which when magnified reveal the presence of Cu_2O oxide inside the voids. Examples of the cup and cone breakage

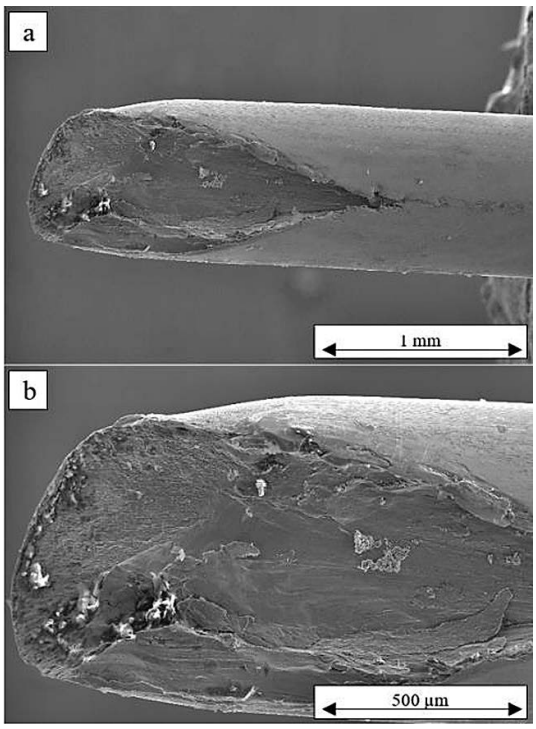

Figure 4 Fracture of Cu-ETP wire, SEM, magnification, a) x 50, b) x 100

type, which name comes from the shapes formed at the point where ETP grade copper wire breaks during the wire drawing process are presented at Figures 2 and 3.

Defects related to the process parameters

Factors influencing the formation of copper wire defects manufactured in industrial drawing process may include among others wrong selection of die geometry. The basic tool of the wire drawing process determining the quality of the final product and its dimensional tolerance and wear is a drawing die (insert to be specific) which may have various design (geometry) and may be manufactured with various materials. The example of the wire breakage due to the wrongfully selected of the insert geometry of the drawing die was presented at Figure 4. Throughout the wire drawing process the selection of appropriate lubricants or drawing emulsions is also an important factor as not enough or uneven amount of the lubricating layer increases the friction and might, when excessed lead to uneven deformation or even breakage of the copper wire. Whereas wrong selection of too little deformation coefficients in each drawing stages may lead to uneven deformation at the cross-section, i.e. such differences in the velocity of the wire regions before and after the drawing die that may lead to central internal cracks called central bursts where the velocity discontinuity occurs.

CONCLUSIONS

In order to avoid the formation of defects throughout the industrial wire drawing process it is important to carefully select a number of factors which when put together create the high quality of the final product and assure for a failure-free process.

Copper of low quality used as a charge material (material with high content of impurities atoms) creates a high risk of defects formation and as a result breakage of the wires. The nucleated at the inclusions and copper matrix voids are especially dangerous as ultimately they lead to material brakeage.

In order to minimize the risk of defects formation caused by poorly selected wire drawing parameters or drawing tools it is necessary to bear in mind not only the appropriately selected deformation coefficients but also the quality and geometry of the drawing dies and proper lubricants or drawing emulsions.

REFERENCES

[1] S. Norasethasopon, K. Yoshida, Prediction of chevron crack initiation in inclusion copper shaped-wire drawing, Engineering Failure Analysis 15 (2008) 378–393.

[2] V. V. Bitkov, Minimization of Breaks during Drawing Thin Wire of Nonferrous Metals, Russian Journal of Non-Ferrous Metals 51 (2010) 2, 134–139.

[3] B. Moharana, B. Kumar Kushwaha, Breakage Analysis of Aluminum wire rod in Drawing Operation, International Research Journal of Engineering and Technology 4 (2017) 971-981.

[4] P. Strzępek, A. Mamala, M. Zasadzińska, G. Kiesiewicz, T. Knych, Shape analysis of the elastic deformation region throughout the axi-symmetric wire drawing process of ETP grade copper, Materials 14 (2021) 16, 4713.

[5] K. Kazutake, Effect of ductile fracture criteria on chevron crack formation and evolution in drawing, International Journal of Mechanical Sciences 45 (2003) 141–160.

[6] B. Avitzur, Analysis of Central Bursting Defects in Extrusion and Wire Drawing, Trans. ASME Ser. B 90 (1968) 79–91.

[7] J. Kuricová, M. Kianicová, A. Dubec, D. Kottfer, P. Kováčiková, Basic mechanical properties influenced by drawing Technology of copper wires, University Review 13 (2019) 3, 23-29.

[8] D. Souvik, M. Jitendra, B. Sandip, Metallurgical Investigation of different causes of center bursting led to wire breakage during production, Case Studies in Engineering Failure Analysis, (2013), 32-36.

[9] I Kinas, E, Tan, H. Can, The Effect of Oxygen Content on Mechanical and Conductivity Properties of Copper Rods Produced by Contirod and Up-Cast Continuous Casting Methods, International Journal of Scientific and Technological Research 4 (2018) 10, 384-391.

[10] E. H. Chia, G. R Patel, Characterization of rod and wire defects produced during the manufacturing of copper, Wire Journal International 6 (1996) 50-59.

[11] S. Norasethasopon, Chevron Crack Initiation in Multi-Pass Drawing of Inclusion Copper Shaped-Wire, Journal of Metals, Materials and Minerals 21 (2011) 1, 1-8.

[12] A. Haddi, A. Imad, G. Vega, The influence of the drawing parameters and temperature rise on the prediction of chevron crack formation in wire drawing, International Journal of Fracture 176 (2012) 171–180.

[13] C. Raskin, J. Jansen, Copper wire breaks-another view, Proceedings of the Wire Journal International (1998) 80–86.

[14] M. Zasadzińska, T. Knych, The morphology of eutectic copper oxides Cu_2O in the processing of wire rod and wires made from ETP grade copper, Archives of Metallurgy and Materials 64 (2019) 4, 1611–1616.

Note: The translator responsible for English language: Grzegorz Kiesiewicz, AGH University of Science and Technology, Cracow, Poland