DEFECTS ANALYSIS OF COPPER WIRES MANUFACTURED IN INDUSTRIAL CONDITIONS

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 restarting 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 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 Cu2O 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.
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 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 Cu₂O [14]. The regions of cohesion loss of the wires contain numerous craters / voids which when magnified reveal the presence of Cu₂O oxide inside the voids. Examples of the cup and cone breakage
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central internal cracks called central bursts where the
regions before and after the drawing die that may lead to
tion, i.e. such differences in the velocity of the wire re-
stages may lead to uneven deformation at the cross-sec-
ture 4. Throughout the wire drawing process the selec-
tion of appropriate lubricants or drawing emulsions is
also the quality and geometry of the drawing dies and
proper lubricants or drawing emulsions.

Factors influencing the formation of copper wire de-
fects 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 tol-
erance 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 Fig-
ure 4. Throughout the wire drawing process the selec-
tion 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 exceeded 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-se-
tion, i.e. such differences in the velocity of the wire re-
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 to-
gether create the high quality of the final product and
 assure for a failure-free process.

Copper of low quality used as a charge material (ma-
terial 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 breakage.

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.

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