Research on the behaviour of the metallic material in the draw-plate while drawing the wire

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Abstract. This research introduces the theoretical and experimental study of the plastic deformation through drawing of the copper wire, the presentation of the microstructures resulting after each drawing, certain possible flaws which occur within this plastic deformation process and the conclusions on the grains’ flip-over and elongation. During the drawing process, the metallic material undergoes some important transformations in the draw-plate. The equiaxed grains are compressed in transversal direction and elongated in the drawing direction. The wire drawn is hardened due to the elongation of the grains and due to the development of a substructure of dislocations in the deformation grains. The theoretical presentation of the topics in discussion is then followed by a calculation of the reduction and the Δ parameter which causes less unused work if it is low value, limits the cold hardening of the wire and allows the possible execution of a higher total reduction between two annealing processes. A smaller angle for the drawing favours the coating of the lubricant and lengthens the contact area. Thus, a better cooling is obtained for the wire - draw-plate interface and the lubricant film is more stable.

1. Introduction
The materials play an important role in the technical progress which is favourably influenced by the modification of the attributes of certain materials through plastic deformation or by the appearance of new materials.

A unified, fundamental and quantitative description of the structure and the behaviour of the materials undergoing various loadings is accomplished with the help of the theory of plastic deformation. This aims to produce, manufacture and rationally use the materials by acknowledging the correlation laws between the chemical composition, the atomic or molecular arrangement, the microstructure and the physico-mechanical properties of the materials as well as the possibilities to modify these properties chemically, thermically or through plastic deformation [1].

The solid bodies can be deformed by outer forces applied on them. Other factors, such as the hydrostatic pressure, humidity, temperature, magnetic fields, etc. may act upon the body together with these exterior forces. Their action modifies the entire process of plastic deformation as well as the mechanic and physical properties of the body. The plasticity theory describes the stress-deformation relation in a plastically deformed body [2] when the outer factors acting on it are known. However, the study of a deformation process by applying scientific knowledge and the scientific support given by modern engineering and the use of advanced presentation tools may change the perception of the whole process. With the help of these laboratory experiments of drawing a great variety of properties...
can be highlighted. Luksza J, Majta J, Burdek and Ruminski M studied the behaviour of the wires in plastic deformation during both single- and multi-pass-drawing [3].

An inquiry in the process of wire drawing in a steady state and the study of the effects of different variables of the process over the drawing and deformation parameters lead to more and more performant deformation processes with superior products. If we compare the drawing deformation for several materials (copper, aluminium and steel) [4], general characteristics true for the drawing process and specific to each material can be determined.

Many process variables, besides heat from deformation process, affect the quality of drawn products. U.S. Dixit and P.M. Dixit studied the effect of process variables, such as reduction ratio, semi-angle of the die, and coefficient of friction of the interface, on the quality of the drawn product [4].

In order to identify the effect of inclusions, Norasethasopon and Yoshida studied the effect of inclusions, relative latency and reduction, maximum hydrostatic stress and maximum die pressure during the copper wire drawing process [5].

The thermal effect on the drawn products has been studied by Changsun M. and Naksoo K. based on the final product dimensional predictions, based on plastic deformation theories. Thus, the practical results were twice as close to the calculated dimensions if the thermal effect was taken into account, if this effect was not taken into account [6].

2. Flaws occurring at wire drawing
We have plastically deformed through drawing, on the table by means of draw-plates with different drawing angles which are presented in table 3.1 the wire undergoing this plastic deformation operation was prepared as a number of samples, with the initial dimension d0 presented in the table 3.1 Following the first drawing, the samples had the d1 dimension.

During the drawing process, the metallic material undergoes important transformations in the draw-plate. The equiaxed grains are compressed in transversal direction and elongated in the drawing direction [7]. The wire drawn is hardened due to the elongation of the grains and due to the development of a substructure of dislocations in the deformation grains [8].

For the wire - draw-plate interface, such deformations occur not only because there is friction and lubrication in an area with temperatures rising rapidly and also due to the formation of a new lateral surface of the wire. At the wire drawing, for one passing with a 30% reduction of the transversal section surface, there is a 20% growth of the lateral surface of the wire [9]. A new lubricant film needs to be applied if the wire drawing speed is high.

When considering that the passing of the material through the wire drawing is performed so that each volume element with flat surfaces maintains these flat surfaces even after the drawing, we may state that a simplified transport occurs as it would happen if a wire would be strained through simple traction, without draw plate [10]. During such an ideal process, the deformation is considered to be homogenous or even.

In reality, the plastic deformation of the wire during the drawing through the draw-plate is not homogenous and even. When the material comes into contact with the wall of the draw-plate first, its flowing must be changed to a direction which is parallel to the wall of the draw-plate. This causes shearing within the wire. When the drawing of the wire is finished, the flow of the material must be changed again to a direction parallel to the drawing direction. This causes shearing which is opposed to the one resulting from the initial contact with the wall of the draw-plate. These two shearing results are balanced out and cannot be externally measured.

The shearing results for the deformed material fibres are higher in external regions and the deformation is uneven [11].

The grains nearing the draw-plate contact area are more deformed, more sheared than those in the centre, and the grains in the central axial area are just slightly more deformed and hardened. This can lead to the occurrence of some flaws specific to the drawn wire: cone, cup (figure 2.1 and figure 2.2) or dog-leg type fractures etc.
Knowing the crystalline structure helps us to control and predict metallographic behavior relative to metal performance in different processing processes. If we understand the structure of metals we can evaluate and modify their properties. All this is necessary to make the most suitable selection for specific applications under conditions determined by demand, temperature and environmental influences [12].

![Figure 2.1. Drawn wire, cup flaw, 30 X [13]](image1)

![Figure 2.2. Drawn wire, cone flaw, 50 X [13]](image2)

The microscopic analysis of the copper wire in its initial state indicates a structure with equiaxed grains as presented in figure 2.3, a. After the first drawing, the grains in the outside wire have an elongated structure as it appears in figure 2.3, b. In the final state when the wire has hardened, the grains have a slightly elongated structure as presented in figure 2.3, c.

![Figure 2.3. Microstructure of the copper wire in initial state and after the two drawings through the draw-plate](image3)

During the cold plastic deformation of the drawn copper wire, a crushing of the crystalline grains occurred with remarkable influences over the properties of the metallic materials. Simultaneously with the crushing of the crystalline grains and the accumulation of internal residual tensions, as we have already shown, there is a reorientation and elongation of the crystalline grains in the direction of the deformation. All these determine the so-called cold-hardening state and the phenomenon itself leads to an off-balance stare. As Scott D. A 'says, there are many questions that cannot be answered simply by examining the microstructure’ [14].

The higher the degree of cold hardening, the more affected the attributes are. The increase in the yield limit and the fracture strength are accompanied by a greater diminishing of the deformation capacity (tensile elongation) caused by the cold-hardening. These may disturb the deformation, wire-drawing process to such extent that, at a certain point, it must be stopped. In order to continue the plastic deformation processing, it is necessary to first operate a full annealing to restore the cold hardened structure and to remove internal tensions.

Processing, properties and microstructure are interdependent. The microstructure depends on the composition and processing process. Microstructure is responsible for mechanical properties [1].
The size of the grains significantly influences the mechanical properties of the metals. The large size of the grain shows us strength, toughness and low ductility. A fine grain wire has better mechanical properties than a large grain [15].

3. **Expressing the reduction and the \( \Delta \) parameter for the wire drawing**

The calculated value of the reduction is used in numerical form, but in technology constructions calculations, in this case the wire drawing process with different drawing angles being characterised, it is possible to express it in percentages, as presented in the table 3.1. The deformation of the wire material during the wire drawing process has been calculated by using the formula with expresses the surface reduction of the transversal section. (figure 3.1) [1].

\[
\frac{S_0 - S_k}{S_0} = 1 - \frac{S_k}{S_0} = r \quad (3.1)
\]

\[
r = 1 - \frac{d_2}{d_0} \quad (3.2)
\]

A deeper analysis on the influence of the geometry of the active zone over the behaviour of the deformed material was possible in 1955, after Wistreich [16] laid the foundations of the understanding of the plastic deformation process. With all the apparent simplicity, numerous elements in the drawing process were not clear enough and have become the subject for detailed research [17]. The type of the material flow and the tension state are being studied for various materials. In our case, the material is cold plastically deformed electrolytic copper. We have calculated the \( \Delta \) parameter with the dimensions indicated in figure 3.1 and the formula 3.4.

\[
\Delta = \frac{d_0 + d_1}{d_0 - d_1} \cdot \sin \alpha \quad (3.3)
\]

or expressed depending on the reduction (r):

\[
\Delta = \frac{1}{r} \left(1 + \sqrt{1 - r^2}\right) \sin \alpha \quad (3.4)
\]

![Figure 3.1. Position of the wire in the draw-plate, the geometry of the active zone [1]](image)
Table 3.1. Values for the reduction r and the Δ parameter for different angles

| d₀ [mm] | d₁ [mm] | r [%] | α₁ [°] | Δ₁ [°] | α₂ [°] | Δ₂ [°] |
|---------|---------|-------|--------|--------|--------|--------|
| 2,8     | 2,6     | 14    | 5      | 2,35   | 7      | 3,29   |
| 2,8     | 2,4     | 27    | 5      | 1,13   | 7      | 1,58   |
| 2,8     | 2,1     | 44    | 5      | 0,61   | 7      | 0,85   |

Figure 3.2. Values for the reduction r and the Δ parameter at wire drawing for α₁ = 50° and α₂ = 70°

4. Conclusions
Wire drawing with a low value of Δ parameter causes less unused work, limits the cold hardening of the wire and allows the possible execution of a higher total reduction between two annealing processes.

Lower values of this parameter can be obtained for a construction of the draw-plate with small angles (α) and high reductions (r).

At wire drawing, in order to improve lubrication, it is necessary to decrease the value of the angle (α). A smaller angle favours the lubricant’s application and lengthens the contact area. In this way, a better cooling for the wire - draw-plate interface is produced and the lubricant film is more stable.

For high speed wire drawing, the recommended angle is α = (5-7)°, especially for the last drawings, when the wire begins to harden. Thus, a higher length of the wire drawing zone in the draw plate is obtained and a more intense lubrication. All these lead to improvements in the wire’s attributes and to an increase in the productivity for the plastic deformation through wire-drawing.

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