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Examination of the Force Parameters in Drawing Process of CuZn39Pb3 Cast Rod using Selected Lubricants

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Abstract

The paper presents the results of research on the wire drawing process of wire brass using different deformation degree and using selected lubricants of different viscosity. The material used for the study was CuZn39Pb3 wire, which was obtained under laboratory horizontal continuous casting process using graphite crystallizer. A cast brass rod with a diameter of 9.4 mm was drawn in laboratory conditions to a diameter of 3 mm and then drawn in one operation to a diameter of 2.9 mm, 2.65 mm or 2.4 mm. Before the final deformation process, the wire surfaces were properly prepared.

Based on the results obtained, the drawing tension was used to draw conclusions. The oxide surface has been shown to increase drawing tension and decrease quality of wires, while the surface that has been etched prior to deformation has a beneficial effect both on the reduction of the strength parameters of the drawing process as well as on the improvement of its quality. In addition, it has been shown that despite the emulsion has lowest dynamic viscosity that's protect wire surface well, decrease the drawing force at high unit loads.

Keywords: Plastic working, Mechanical properties, Lubricant, Coefficient of friction, CuZn39Pb3 cast rod

1. Introduction

Wire drawing is a metalworking process based on puling wire, rod, or bar through a single die or series of drawing dies resulting in the reduction of its cross-section and increase in its length. In comparison to rolling or extrusion, drawing offers much better dimensional control, continuous processing, lower capital equipment cost, and extension to small cross section [1-4]. In many case are used lubricants in the drawing process to reduce the friction and maintaining good surface and long die life [5,6]. Friction significantly limits the process intensification, reducing the maximum amount of deformation and increasing the process temperature, so various lubricants are used to limit its negative impact [7,8]. In addition, friction also causes the occurrence inhomogeneous of deformation what causes inhomogeneous of properties on the cross-section of the product. This entails the occurrence of internal stresses, which lead to the formation of stress corrosion cracking in Cu alloys. Excessive friction causes rapid wear of the tools and deterioration of surface quality, which translates into increased roughness. It is estimated that about 30-50 % of the total drawing force is consumed to overcome friction forces.

Despite the wire drawing process is well known and widely described in many books and articles, research are still being carried out to get to know better this process. Major variables in drawing process include reduction ratio [9], die angle, friction at the interface of the wire and the die [10], drawing velocity [11]. Wire drawing process with ultrasonic vibration [12], dieless drawing method [13-15] or comparison of roller die with conventional wire drawing also were investigation [16, 17].

The selected articles concerning the drawing process and not exhaustive the problem but shows directions of current research. In this paper examination of the drawing force of Cu alloy using selected lubricants and different surface of bar.

2. Design of Experiments

The tests were carried out on CuZn39Pb3 alloy, which was obtained under laboratory horizontal continuous casting process using graphite crystallizer [18]. The composition of alloy was obtained from an optical mass spectroscopy, in which at least five spark analyses were performed and the average value was taken as the chemical composition of alloy. The actual composition of the alloy are shown in Table 1. The tested material was consistent with the requirements of the standard [19] and is designated as CuZn39Pb3 (ISO), CW614N (EN), C38500 (USA) or MO58A (PN) by various standards.

Table 1.
Chemical composition of alloy used in experiments (wt.%)

Cu	Zn	Pb	Sn	Fe	Others*
58.12	38.62	2.87	0.14	0.16	0.09

* Ag, Al, As, Bi, Cd, Co, Cr, Mg, Mn, Ni, P, S, Sb, Si, Zr

The cast rod with a diameter of 9.4 mm was subsequently cold drawn on a laboratory drawing machine with a speed 0,5 m/s to wire with a diameter of 3.0 mm. The total reduction was equal to 90 %. Cold drawing process was conducted using mineral oil as lubricant and round conical dies made of cemented carbide (angle of wire die was 18°). The first step was to select the lubricants using to drawing of Cu alloys (Fig. 1), and then to determine their dynamic viscosity using a Höppler method. A viscometer with a falling ball is used to measure the viscosity of transparent Newtonian liquids, in which the viscosity is closely related to the time of falling of the ball on a given length. Due to the wide range of viscosities expected and densities of the tested oils, which was 0.97 g/cm^3 for emulsion, 0.93 g/cm^3 for oil I, 0.91 g/cm^3 for oil II and 0.88 g/cm^3 for oil III, it was decided to use three standardized balls to determine the dynamic viscosity. The density of the glass ball was 2.2 g/cm^3 and was used for emulsion; 8.15 g/cm^3 for a steel ball used for oil I and II and 7.72 g/cm^3 for a steel ball used for oil III. The measurement was carried out at ambient temperature (20 °C) at a standard pressure of 1013 hPa. The time of descent of a normalized ball, over a measuring distance of 10 cm, was measured by means of a stopwatch. After measuring and turning the cylinder by 180°, the ball returned to the initial position. The 10 measurements were taken for each oil and then the times measured were averaged.

a) b) c) d)

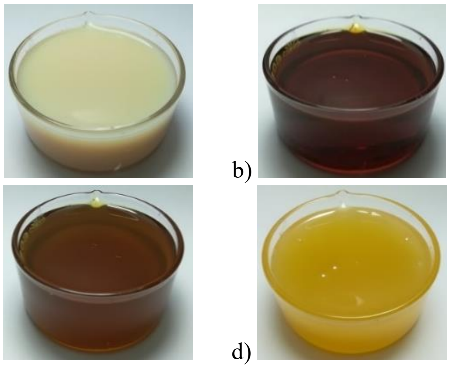

Fig. 1. View of the tested lubricants: a) 10 % oil I, b) oil I, c) oil II, d) oil III

The next step was to prepare test wires (Fig. 2). The reference material was a wire obtained under laboratory conditions (fabricated), the second sample was etching in a 20 % H_2SO_4 solution for 10 seconds (etched). The third and fourth sample was annealing at 200 °C and 600 °C for 1 hour (oxide surface).

a) b) c) d)

Fig. 2. View of the surface wires: a) fabricated, b) etched, c) annealed (200 °C/1h) and d) annealed (600 °C/1h)

The drawing force was measured on the tensile testing machine (Fig. 3) with force recording. For this purpose, four lubricating agents with different dynamic viscosities, three carbide dies with diameter of 2.9, 2.6 and 2.4 mm were used (2α = 18° angle of the dies). The test material was drawn at a speed of 100 mm/min, each time in one operation with the initial diameter to smaller final diameter. Each time the degree of deformation was increased, for which the total strain (ε) was respectively: 7, 25 and 36 %. The total strain was calculated according to the following equation:

$$\varepsilon = \frac{S_o - S_n}{S_n} \cdot 100\% \qquad (1)$$

S_o - cross-sectional area of the wire before deformation,
S_n - cross-sectional area of the wire after deformation.

a) b)

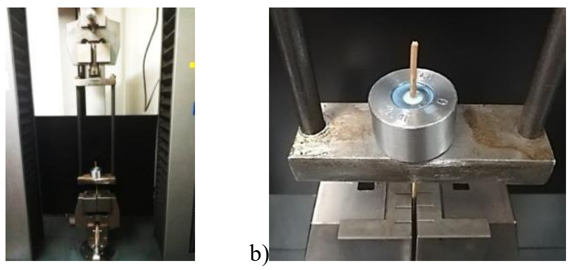

Fig. 3. View of the measuring system (a) and drawing process of CuZn39Pb3 wire

Knowing the average drawing force, the drawing tension was calculated according to the dependence 2, and then the friction coefficient was calculated using the Tarnawski formula (3) because the coefficient of friction was similar to the real value [20].

$$\sigma_c = \frac{F_c}{S_n} \quad (2)$$

$$\mu = \frac{\frac{\sigma_c}{K_{av}} - \left(\ln(\lambda) + 1{,}6 \cdot \sin(\alpha) \cdot \sqrt{\ln(\lambda) \cdot tg(\alpha)}\right)}{\frac{2 l_k}{R_k} \cdot \left(1 - \frac{\sigma_c}{K_{av}}\right) + ctg(\alpha) \cdot \ln(\lambda)} \quad (3)$$

σ_c - drawing tension,
F_c - drawing force,
S_n - cross-sectional area of deformed wire,
K_{av} - average yield stress,
α - angle of drawing,
λ - drawing ratio,
l_k - bearing length,
R_k -radius of wire.

The tensile tests were conducted following the ISO standard [21] using Zwick Z020 testing machine equipped with testXpert Testing Software and a 20 kN load cell. All the tests were performed at ambient temperature (~ 20 °C). The gauge length of the extensometer was 50 mm and the ramp rate for extension was 50 mm/min. From these measurements the ultimate tensile strength (UTS), yield strength (YS) and percentage elongation after fracture (E) were determined.
The quality surface of the wires was determined using Hommel-Etamic T1000 testing machine. This mobile device was equipped in skid probes for picking up the roughness, waviness and profile parameters. Five roughness measurements were made on each sample along the axis of symmetry of the wire and then the arithmetic mean was calculated. Moreover, the standard deviation was also calculated, which didn't exceed 10 % of the measured value.
The Ra parameter was selected to evaluate the surface roughness. Roughness average (Ra) is the arithmetic average of the absolute values of the profile heights over the evaluation length [22].

3. Results and Discussion

The CuZn39Pb3 brass is classed as a stamping brass with excellent hot forming properties, high machinability rating and good corrosion resistant, so it used to automotive components, valve parts, architectural hardware. Lead is often added in concentration of around 2 % to enhance the machinability of brass. The consistency of the lubricants used for the research was from water to dense honey and the dynamic viscosity of the lubricants using to drawing of Cu alloy was as follows: 1.4±0.1, 113±0.2, 160±0.3 and 10223±0.6 mPa·s respectively for 10 % oil I, oil I, oil II and oil III. Based on annealing curves (Fig. 4) decided to choose four wires to laboratory wire drawing process. The reference material and etched material was wire with a diameter of 3.0 mm (20 °C) in hardening temper, while others wire was annealing at 200 and 600 °C during 1 hour (Fig. 5).

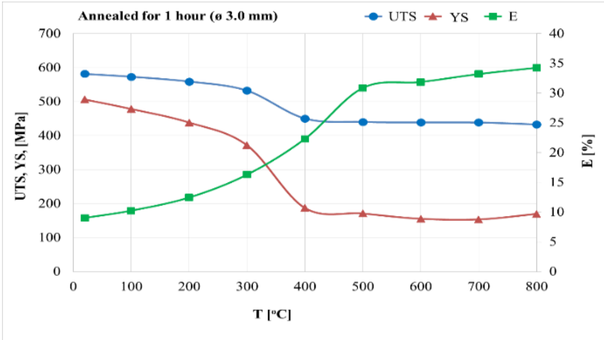

Fig. 4. Annealing curves for wires with a diameter of 3.0 mm annealed for 1 hour at different temperatures

Figure 4 shows typical softening curves. The wire as fabricated temper has high strength properties and lower plasticity properties. This strengthening occurs because of dislocation movements and dislocation generation within the crystal structure of the material. Growth the temperature causes increase elongation as a parameter of plasticity and decrease ultimate tensile strength and yield strength as a parameter of strengthening. We observed static recrystallization process at from 300 to 500 °C. Recrystallization is a process by which deformed grains are replaced by a new defect-free grains. Choose two wires annealed at 200 and 600 °C for 1 hour because in the first case at this temperature is stress relief annealing, and in the second case material is softening.

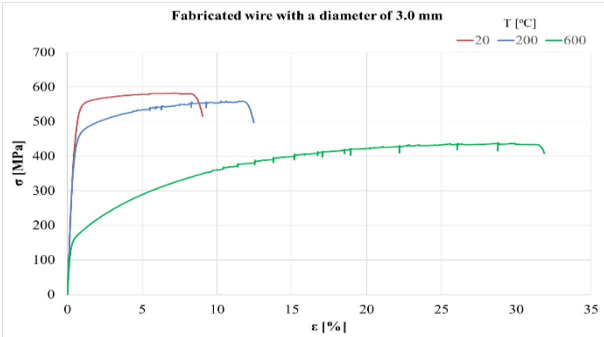

Fig. 5. Stress-strain curves for wires with a diameter of 3.0 mm not annealed (20 °C), annealed at 200 and 600 °C for 1 hour

The engineering stress in function of engineering strain curves (Fig. 5) shows the Portevin-Le Chatelier effect [23, 24]. The PLC effect describes a serrated stress-strain curve which some materials exhibit as they undergo plastic deformation. In this case the recrystallization process intensifies PLC effect.
Next step was measuring of the drawing force at the tensile test machine. Having registered drawing force in function of time calculated drawing tension according to equation 2. Conducted three draws with an initial diameter of 3.0 to 2.9, 2.65 and 2.4 mm which corresponds to total deformation 7, 22 and 36 % (reduction cross-section of wires). Three repetitions were carried out for each sequence variant and the standard deviation didn't exceed 5 % of the measured value.

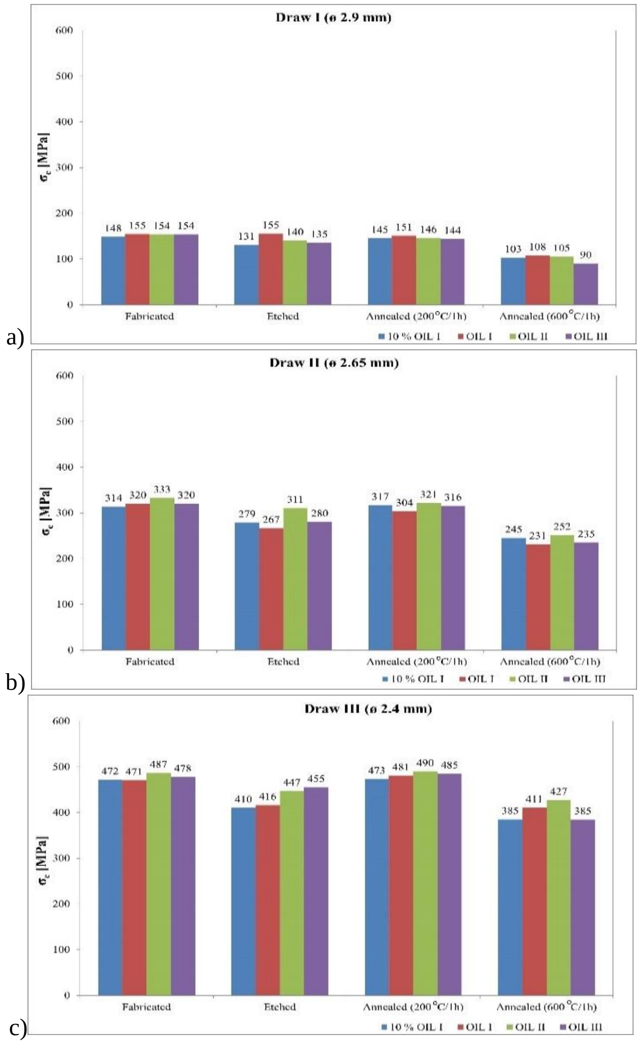

Fig. 6. The calculated drawing tension for drawn wires with a diameter of 2.9 mm (a), 2.65 mm (b) and 2.4 mm (c) using different lubricants

Figure 6 shows drawing tension for fabricated, etched and annealed drawn wires using four different mineral oils: emulsion (10 % of oil I), oil I, oil II and oil III. The greater degree of deformation causes increase drawing tension because rise the strain (Fig. 6a,b,c). In all cases the lowest drawing tension had wire which was annealed at 600 °C for 1 hour because its strengthening is low. In the case of the first draw doesn't matter the lubricant which is used (Fig. 6a). It was notice higher difference in drawing tension in second and third draw (Fig. 6b,c) especially for etched wire, which observed lower drawing tension for emulsion. Most likely low dynamic viscosity causes better flow emulsion to shaped hole through which wire is drawn to reduce its diameter and better isolation wire and die surface (semi-fluid friction). That lubricant which had higher dynamic viscosity is better to drawing soft wire because it was observed lower drawing tension for all draws. There was no significant differ in drawing tension between wires which was fabricated and annealed at 200 °C for 1 hour in all draws.

Knowing the basic parameters of wire drawing process calculated the coefficient of friction using Tarnawski formula (3). They were tried to use Sachs'a or Hill'a and Tupper'a method, bad receive of values were unreal. Also the Tarnawski method it is not precise enough. Should be expected that draws from I to IIII causes increase strain (Fig. 7a,b,c) and more pressure in shape hole consequently separate the lubrication film causing rise in the coefficient of friction (dry friction). The lowest coefficient of friction is for wires which surface was etched and the highest is for wires which surface was annealed at 600 °C for 1 hour (Fig. 7c). Etched surface of wires is porous so emulsion fills of pores and lubricates the wire die and wire during plastic deformation. On the other hand the oxide broke away from the wire causes increase of coefficient of friction (Fig. 7a,b,c).

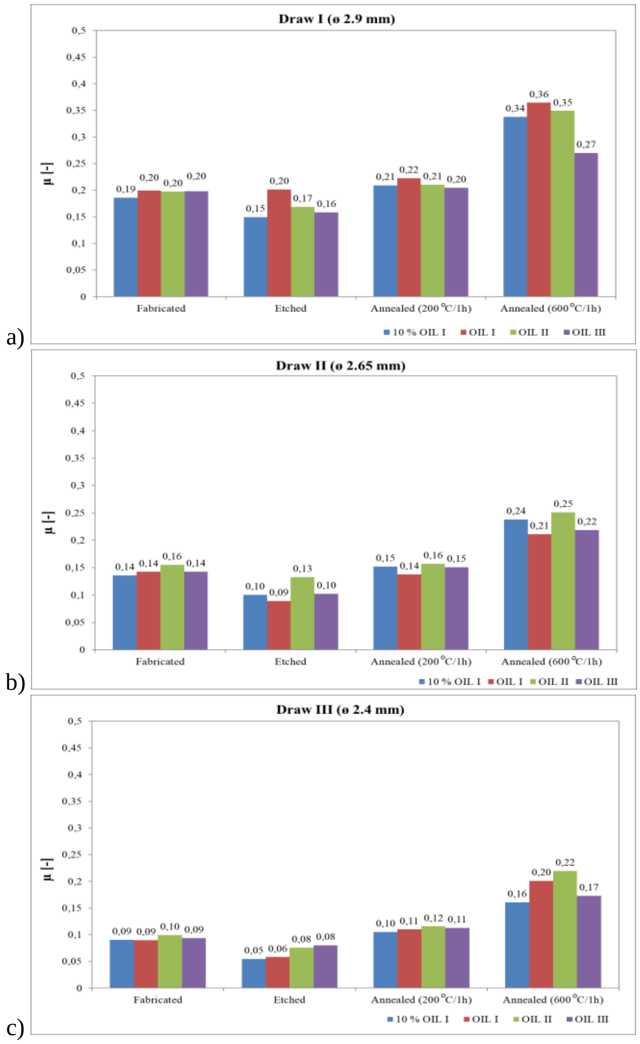

Fig. 7. The calculated coefficient of friction based on Tarnawski formula for drawn wires with a diameter of 2.9 (a), 2.65 (b) and 2.4 (c) using different lubricants

An important factor when selecting a lubricant is the surface quality of the wires. The Ra parameter was used to assess the quality of the wires surface after the drawing process. Figure 8 shows roughness average for fabricated, etched and annealed drawn wires using different lubricants.

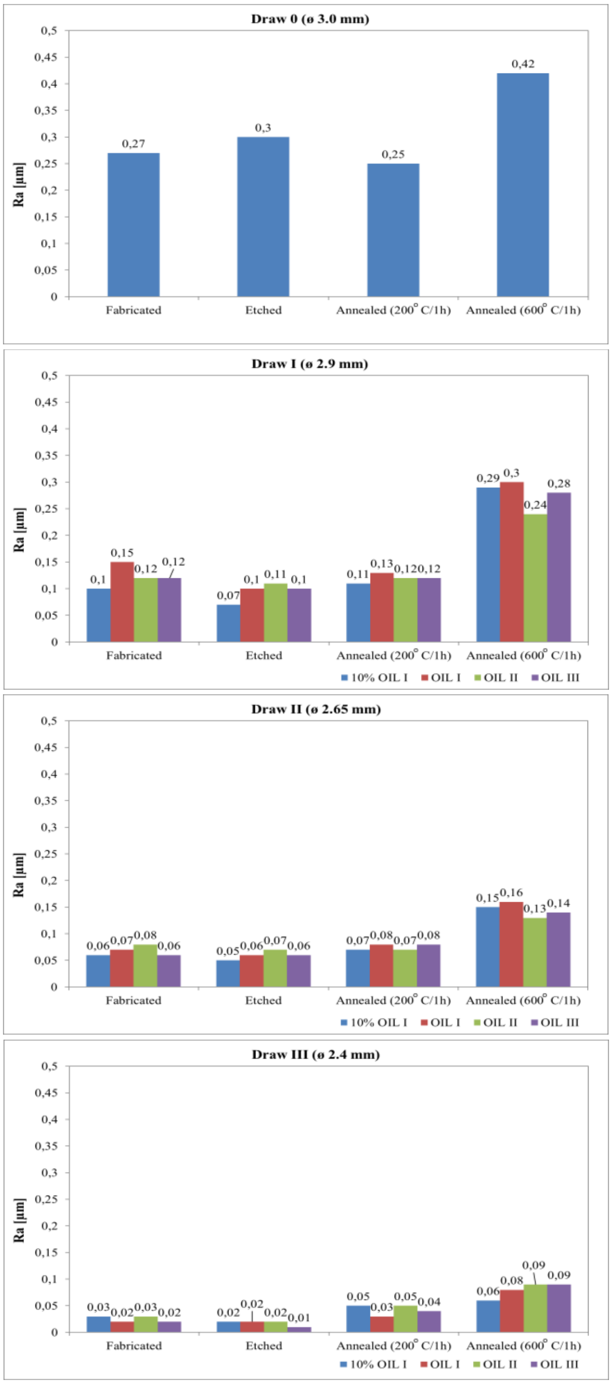

Fig. 8. Roughness average (Ra) for fabricated, etched and annealed wires before (a) and after deformation (b, c and d) using different lubricants

Analysing the surface quality expressed by the parameter Ra, we note that the etching and annealing at 600 ^{o}C during 1 hour deteriorated the quality of the wire surface before the deformation (Fig. 8a). After wire drawing process, we note that in each case decrease in surface roughness i.e. increase in surface quality which was directly related to the quality of the wire die (Figure 8b,c). In the case of emulsion (10 % oil I) and oil I after deformation (Fig. 8b,c), the etched surface was of the best quality. Most likely, thin oil was able to flow into the working zone of the wire die and provide good isolation of the contacting surfaces during deformation. In the case of thick oil II and oil III, the lowest roughness was observed for the etched, fabricated and annealed (200 ^{o}C/1h) surface. In turn, increasing unit strain during wire drawing process decrease in roughness for all tested lubricants (Fig. 8c). It was noted that in the case of a very thin lubricant, which was undoubtedly an emulsion, no decrease in the quality of the wire surface was noticed, which was smooth and shiny. It would seem that high unit pressures and low dynamic viscosity of the emulsion should result in surface deterioration, but this effect was not noticed. In turn, increasing the density of the oils deteriorated the surface quality of the wires after deformation, which had previously been annealed. Most likely, the gravitational supply of lubricant to the wire die turned out to be insufficient, which resulted in oxides entering the working zone of the wire die and scratching the surface of the wire.

4. Conclusions

The aim of this work was examination of the force parameters in drawing process of brass using selected drawing compounds. On the basis of the conducted research it may be stated that:

- Laboratory wire drawing process causes work hardening wires brass on account of rise dislocation, vacancy and fragmentation of structure (reducing the grain size and increase the grain boundaries) resulting in increased ultimate tensile strength, yield strength and decrease elongation at fracture,
- Brass in chemical composition of CuZn39Pb3 has a temperature of recrystallization in the range from 300 to 500 ^{o}C resulting is an increase elongation and decrease ultimate tensile strength and yield strength,
- Despite the emulsion has lowest dynamic viscosity that's protect wire surface well and decrease the drawing force, therefore it is recommended to use it for economic reasons,
- It's recommended etched surface wire before drawing process because decrease the drawing tension and enhancement of quality of the drawn wire. In the case of oxidation surface of wire increase the coefficient of friction. Such an oxide surface is noticeable especially after the hot extrusion process in the production of brass.

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