Analysis of Tool Geometry and Lubrication Conditions Effect on the Forming Load During Wire Drawing Process

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ABSTRACT

Most of wire drawing processes is performed at room temperature, causing rising up the heat due to the plastic deformation and the generated friction at the work piece-tool interface. In the poor lubrication conditions, there is a likelihood that both the die and the drawn wire will be damaged. This is because the drawing load is greatly influenced by tool geometry and lubrication conditions, The research work conducted in this paper focuses on drawing of 3 mm diameter Electrolytic tough pitch (ETP) cooper wire to perform 20% reduction in cross sectional area through a conical die. Various parameters have been tested to study the effect of them on the forming load during wire drawing including die angle (4°,6°,8°), bearing distance (1.2, 1.5, 1.8) mm, and lubricant types (Lithium-based greases, soap powder, oil HP). The first phase of this paper is conducted to estimate the coefficient of friction for each lubricant type, Utilizing the experimental values of drawing force in theoretical formals. Based on the estimated values obtained, the second phase was creating numerical model to extend the work to more parameters level as well as check the results validation. The results demonstrated that the drawing force increases with increasing of bearing distance and friction coefficient.

Keywords: wire drawing; numerical simulation; drawing die; lubrication conditions; friction; lubricant type.

INTRODUCTION

The wire drawing is one of the most process which are widely used in metal forming [1]. It is a process of reducing the wire diameter by drawing it through a conical die [2]. In wire drawing process, the deformation of the wire is influenced by many parameters such as die geometry, reduction ratio, drawing velocity, lubricant, and the wire metal properties [3]. This process leads to an improvement in the properties of the produced wire. In the produced wire, the surface defects are one of the most problems in the wire drawing process, and when the wire is pulled through the die the metal surface is exposed to scratch because the friction which is generated between the wire and die [4]. To reduce these defects, various lubricants and die angles are employed. The lubrication work to separate the surface of the wire and the die in order to reduce the friction and improve

the surface quality of the wire also to reduce the required drawing force [5]. The analysis of the forces in the wire drawing process are complex owing to existence of different forces including of tension, compression, and drag [6,7].

Martínez Gustavo A.S. et al [8] proposed an experimental approach for the wire copper drawing process to find out the influence of process parameters namely die angle, types of lubricant, and the speed on the responses of the wire drawing process (coefficient of friction, the roughness of the drawn product, and temperature of the profile in the drawing zone. The authors reported that the better qualities of the drawn wire can be achieved with a smaller approach angle of die, and the drawing force can be significantly minimized at drawing speeds above 10 m/s. Also, the lubricant type D (Agip S234–60 oil at 7% concentration) which result in decreasing the coefficient of friction. Martínez Gustavo A.S. et al [9] Pointed out

the influence of some process parameters on the drawing stress and the temperature in the wire drawing process. These parameters are drawing speed, coefficient of friction, and die geometry. The initial diameter of copper wire was 0.5 mm when the wire drawn wire drawn to a final diameter of 0.45 mm, the experiments were performed at true strain equal to 0.211 with a single block drawing with die angles 14 and 18 degrees. The study revealed that the increase in the wire drawing speed can reduce the coefficient of friction, therefore considerable drag of the lubricant from the contact zone, also the axial stresses on the outer zone of the drawn wire variations from compression to tensile because flow of the material in the direction of the central axis of the drawing die. Viktor T. et al [10] investigated the role of the different wire drawing process parameters such as drawing angle size on the wire work ability. The set of experiments was performed by $2\alpha = 11°$, and $2\alpha = 13°$ as a drawing angle size. The results showed that the lower level of the angle drawing size results in decreasing the fracture of wires and the amount of hardening, consequently we can change the angle drawing size results in a better the drawing process. Ihmood S. M. [11] investigated the performance of the wire drawing process in term of lubricant film thickness and its relation to the die angle, drawing stress, and the reduction in area. The authors used three types of lubricant namely UNOPOL CB, UNOPOL CM, and UNOPOL CBF, six levels of die angle were adopted (9°, 12°, 15°, 20°, 50° and 70°). The results showed that the optimal size of die angle in the range (20° to 30°), and the lubricant film thickness decreases whereas the drawing stress increases due to the increase in reduction of the area. The large die angle result in a higher drawing as a result of the large distortion. Kabayama Leonardo K. [12] used annealed electrolytic copper wire (ETP), with 0.5 mm original diameter, and the size of the die angle is $2\beta = 10°$ and 18° respectively. They proposed Finite Element Method to predict the distribution of the residual stress. The authors reported that the friction coefficient and wire drawing force decrease when the wire drawing velocity increases and the impact of the die geometry on the drawn wire has been clearly indicated. The results of the simulation show the generating of the compression stress in the intermediate region and tensile axial stress generated on the surface of the wire, the intense residual stress level for 2β equal to 18°. Felder E. et al [13] performed an experimental approach to evaluate the impact of sodium and calcium stearate soaps at the stainless-steel wire drawing, before drawing the wire is covered and pickled with salt, and the velocity of drawing rounded in the range 0.1–10 m/s. The results showed that the sodium stearate has better performances at the maximum velocities, whereas calcium stearate is well adjusted to minimum velocities.

The objective of this paper is to study the impact of the wire drawing process parameters namely (die angle, bearing distance, and the type of lubrication) on the characteristics of the process in term of the required drawing force.

BACKGROUND

Heterogeneous work and frictional work have adverse influences on wire features in addition to need for further energy which required for drawing process. One consequence is that the mechanical properties will not be uniform across the cross-sectional area of the produced wire [14]. figure 1 shows representation of geometrical feature of wire drawing process.

A number of approaches have been proposed for calculating forming stress based on the material properties and the die geometry:

$$\sigma_d = \bar{Y}_f \left(1 + \frac{\mu}{\tan\alpha}\right) \phi \ln \frac{A_i}{A_o} \qquad (1)$$

where: σ_d = drawing stress,
μ = coefficient of friction in die-work interface;
ϕ = redundant work factor,
α = die semi angle
A_i = wire inner area
A_o = wire outer area
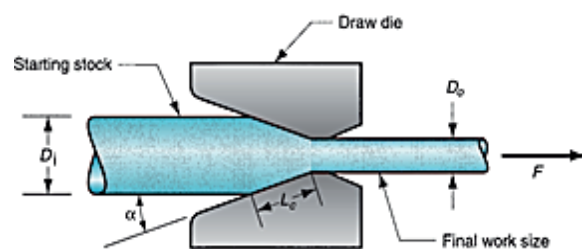$\bar{Y}_f$ = average flow stress define in equation (2)

Figure 1. Wire drawing process [15]

$$\bar{Y}_f = \frac{K\epsilon^n}{1+n} \qquad (2)$$

where: K = yield shear stress,
ϵ = true strain
n = strain hardening exponent.

The redundant work factor is highly affected by the reduction in area and die geometry and can be calculated as demonstrate in equation (3)

$$\phi = 0.88 + 0.12\frac{D}{L_c} \qquad (3)$$

where: D = average diameter of work during drawing
L_c = contact length of the work with the drawing die.

Values of D and L_c can be determined from wire inner diameter (D_i) and wire outer diameter (D_o) the following:

$$D = \frac{D_i + D_o}{2} \qquad (4)$$

$$L_c = \frac{D_i - D_o}{2\sin\alpha} \qquad (5)$$

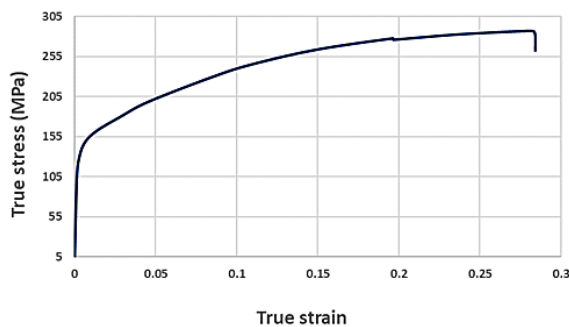The corresponding drawing load is then the cross-sectional area of the drawn wire multiplied by the equation (1)

Figure 2. Stress–strain curves of copper wire

$$F_d = A_o\sigma_d = A_o\bar{Y}_f\left(1 + \frac{\mu}{\tan\alpha}\right)\phi\ln\frac{A_i}{A_o} \qquad (6)$$

MATERIALS AND METHODS

Mechanical properties

Electrolytic tough pitch (ETP) copper (C11000) has been used as a material for wire with initial diameter 3 mm. In order to apply equation 6, the mechanical properties of wire material to be calculated by carried out tensile test at speed (1 mm/min) on universal testing machine INSTRON 1195 and according to ASTM A931 standard. The purpose of the tensile test is to determine the hardening parameters are the strength coefficient (K) and the hardening exponent (n), and the flow stress. Determining these parameters is necessary to construct the true stress strain curve as can be seen in figure 2. And the mechanical properties that obtained from tensile test presented in table 1.

Lubricants

The wire surface layers will not only be subjected to a change in the cross section area, but they have also deformation in shear friction at the die wire interface. Using of an appropriate lubricant can contribute in reducing frictional work, and consequently tends to reduce the redundant work. Any improvement in the lubrication condition will be reflected in decreasing the energy needed for the drawing, thereby the forming load. Three lubricants have used in the experimental work denoted as (A, B and C)

- Type A: Lithium-based greases.
- Type B: Dry Soap 70% Fatty Acid and 30% Additive.
- Type C: Oil HP140 with 5% graphite weight ratio.

Table 1. Mechanical Properties of (C11000)

Property	Young's Modulus (GPa)	Poisson's ratio	Flow stress (MPa)	Yield shear stress (MPa)	Strain hardening exponent
Value	120	0.34	138	342	0.48

Wire drawing tools

Selection of the proper die geometry is crucial for the success of any wire drawing process. Based on the fact that the work of friction rises with decreasing of die semi angle and redundant work rises with increasing of die semi angle. So, the forming of wire is highly influenced by the tool geometry (die angle and bearing distance) as well as the friction conditions. Figure 3 shows the general design concepts of wire drawing tool. As it is clear evident from figure 3 the space of lubricant is closely associated with the die angle and the bearing distance, based on the good lubrication conditions could be only attained by selecting the best geometrical feature that matches a certain lubricant. Table 2 presents the dimensions of the die which is used in this study. Wire drawing dies and die casing presented in figure 4.

Experimental tests

A multiple drawing dies are used for this purpose to carry out practical tests involving lubrication conditions. A computerized universal testing machine WDW-200E is used to achieve the drawing tests as presented in figure 5. Drawing process has performed at 50 mm/min velocity using three types of lubricant, three drawing

angle-levels as shown in Table (3). The drawing force has been measured and recorded by a testing machine in synchrony with the progress of drawing process. For each experiment, the maximum magnitude of drawing force has determined using equation 6 in order to estimate the coefficient of friction which corresponds to the lubricant type. The obtained coefficient of friction is to be used to build a numerical model as will be explained in the next section.

NUMERICAL SIMULATION

Two main purposes of numerical simulation in this study, the firstly is to extend the work to study the bearing distance numerically, the secondly is to check the validity the results that obtain using theoretical consideration and experimental tests. The numerical model has created by utilizing the commercially available ANSYS software package. The numerical model also used to extend the research work for further study of more geometrical tool features and lubrication conditions.

Based on symmetrical conditions of shape geometry and the applied load a 2D axisymmetric model has created in ANSYS spaceclaim. The geometrical model consists of die and wire. In the transient structure module, the pat meshing has performed as demonstrated in Figure 6.

Contact interface between the work piece (the wire) and the die is treated as a frictional contact. Pure penalty formulation has been used to define the frictional behavior. For lubricant types, A, B and C the coefficient of friction (u) was 0.082,0.11 and,0.075 respectively.

Fixed support has subjected to die, while a distance is applied on lower edge of wire. The

Table 2. Dimension of drawing dies

Die No. Geometry	Die 1	Die 2	Die 3
Hight (mm)	12	12	12
Angle (degree)	4	6	8
Bearing distance (mm)	1.2	1.5	1.8
Exit distance (mm)	2.4	2.4	2.4

Figure 3. Section view of wire drawing die with general concept

Figure 4. Wire drawing dies and die casing

velocity is distance into tubular time step to simulate the velocity that used in experimental tests.

RESULTS

Effect of the die angle on the drawing force

The die angle is significantly associated with contact length and lubrication approach. Since the contact length decreases and the lubricant can flow effortlessly in the die wire interface as the die angle increase, as illustrated in the Figure 7a. For the same lubricant type and the bearing distance the drawing force is significantly decreases with increasing of die angle. When the type B lubricant has used, and with increasing of die angle, it has been noted there is a significant increase in the drawing force. However, the drawing force is slightly changed in the case of using type A or C from lubricants. As mentioned earlier, this is attributed to the contact length and lubrication properties. Numerical simulation results in Figure 7b showed the same trend of experimental results but there are the variations in the values. The maximum deviation was around 11% between numerical and experimental. Sequence of drawing process in simulation presented in Figure 8

Table 3. Parameter's level of Experimental and numerical work.

Process parameters	Die angle (degree)	Bearing distance (mm)	Lubricant (type)
Parameter levels	4	1.2	A
	6	1.5	B
	8	1.8	C

Figure 5. A computerized universal testing machine WDW-200E.

Effect of the bearing distance on the drawing force

In bearing distance region of drawing die, the change from circumferential (compression) stress to drawing (tension) stress is responsible
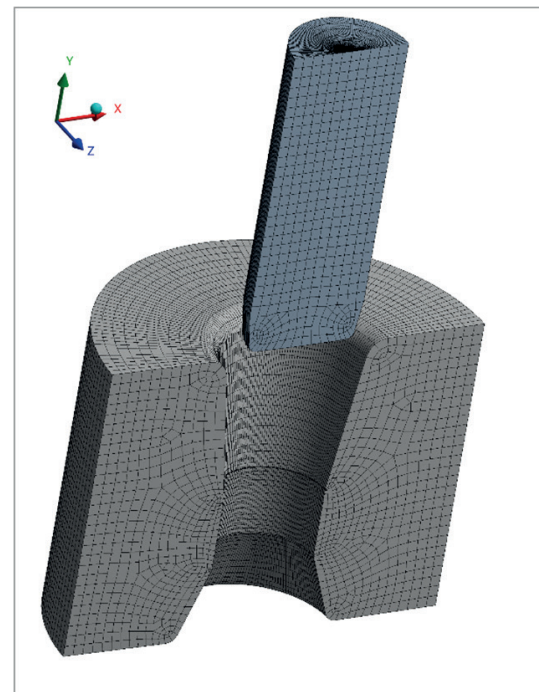

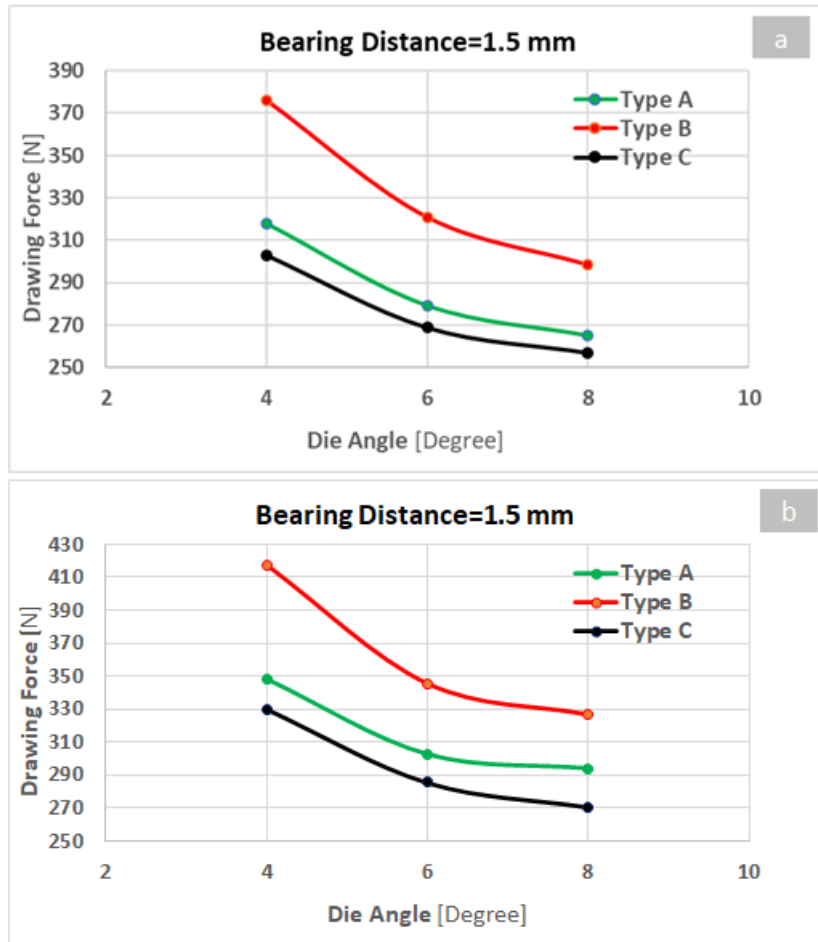
Figure 6. Part Meshing of numerical model

Figure 7. Effects of die angle on drawing force: (a) experimental results, (b) FEA

about increasing the distance of this region which leads to increase the magnitude of the drawing force. In order to discuss the effect of bearing distance on the drawing force three values of bearing distance (1.2, 1.5 and1.8) mm with constant die angle for each case as demonstrated in Figure 9. The drawing force increases with any increase in the bearing distance as a result of increasing of contact length and existence of the residual stress. The obtained results have shown that bearing distance is an important parameter that affects die region to perform the required reduction in cross section area as well as eliminating any elastic recovery.

Effect of the bearing distance on the drawing force

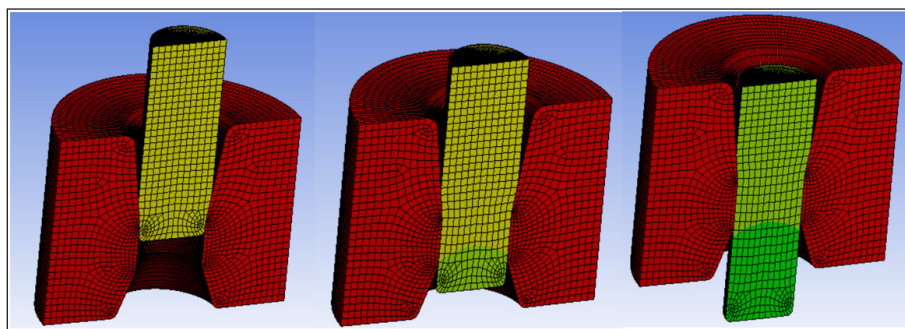Coefficient of friction or lubrication conditions consider as the dominating parameters in

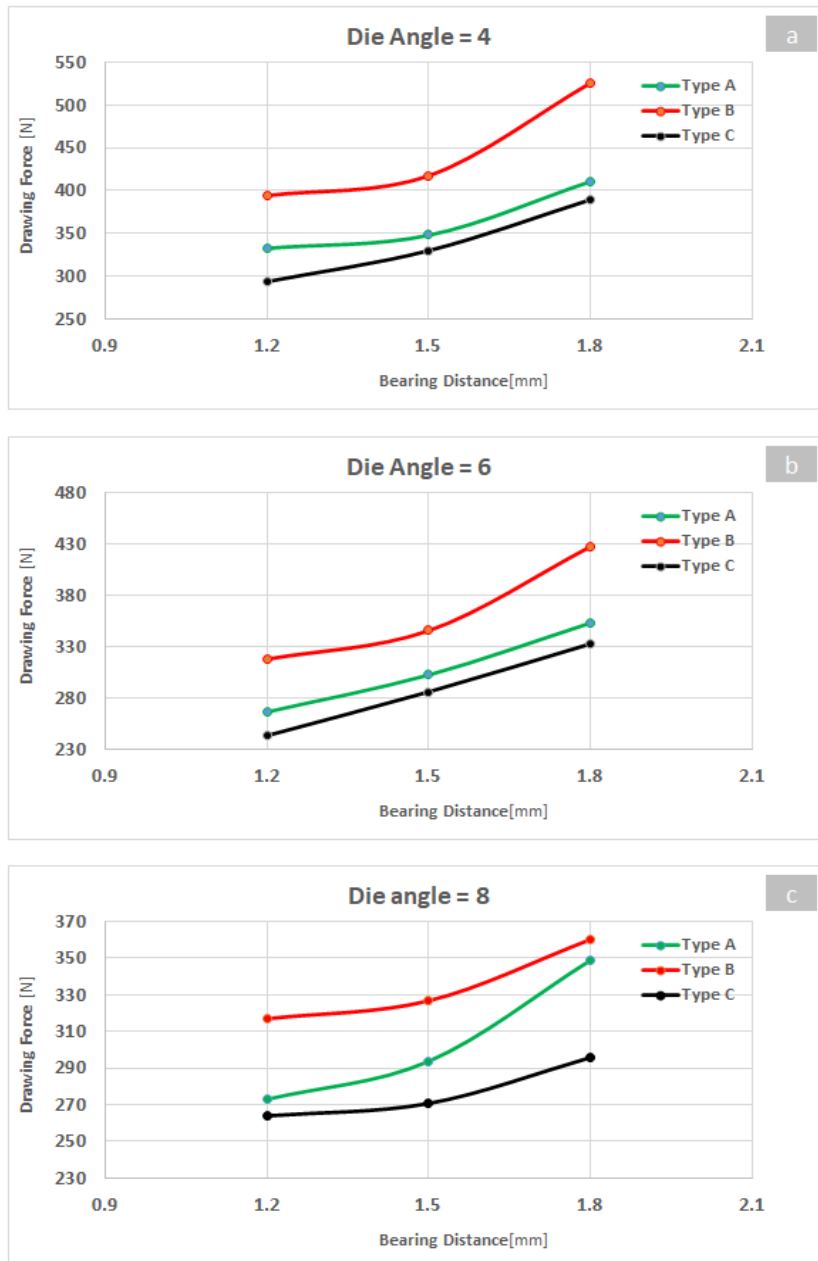**Figure 8.** Sequence of drawing process through numerical modeling

Figure 9. Effects of bearing distance on drawing force

the wire drawing process. Moreover, success cannot be assured in drawing of wire without appropriate controlling of lubrication conditions and geometrical features of the drawing die. As clear from Figures 7 and 9 the drawing force greatly influenced by the lubricant type. In general, the drawing force decreases when the coefficient of friction decreases. For relatively small drawing angle value the use of dry lubricant type was not appropriate. Therefore, with using of type B lubricant, the values of drawing force rise.

CONCLUSIONS

The following conclusions have been reached through the present study:
1. Adopting numerical modelling, allows to extend the study to more parameters level as well as validating experimental results.
2. The drawing force appears to be dependent on the bearing distance and the coefficient of friction.
3. The die angle has a significant role on the drawing force, when the die angle increases (at different bearing distance or lubrication condition) the drawing force decrease.

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