P. STRZĘPEK, A. MAMALA, M. ZASADZIŃSKA, A. NOWAK

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EXTENSIVE ANALYSIS OF THE ETP GRADE COPPER WIRE DRAWING FORCE PARAMETERS IN CORRELATION WITH THE LENGTH OF THE ELASTIC DEFORMATION REGION

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Wire drawing process is generally known as the most recognized metal forming process, however, elastic deformations present during the process before entering the drawing die are mostly omitted. That is why the extensive experimental study of the process have been conducted using drawing dies of various geometry. It allowed to define the length of elastic deformation region and its influence on the recorded drawing force parameters which are closely related to drawing stresses and thus the safety factor of the process.

Keywords: Cu-ETP, wire drawing, force elastic deformation, plastic deformation

INTRODUCTION

Drawing process, and especially axi-symmetric wire drawing process is commonly known metal forming processes both theoretically and technologically. Many well-known formulae made it possible to quite accurately calculate the drawing forces, the coefficient of friction, residual stresses, unit pressure values, back tension, etc. [1 - 3]. The process itself may be easily described due to its stationarity which macroscopically may be defined by constant drawing forces present during the process [4]. Throughout the years there have been many attempts of lowering these forces by for instance using various die bearing geometries [5 - 6], electro pulsing assisted wire drawing [7 - 8], accumulated angular drawing (AAD), which tests the influence of the linearity of dies throughout the process, drawing with the use of ultrasound or drawing with an elevated temperature of the die [9]. All these research works have one thing in common, the attempt to lower the occurring drawing forces and thus the drawing stresses during the process as the stresses are, among others, responsible for the breakages during the industrial processes The classical model of Avitzur's central burst defect formation is based on a rigid-plastic body model, while in fact in the observed area where the fractures are being formed, the material is probably in an elastic state. [10]. Even though there are many research works concerning the drawing force itself, there are only a few which connect these forces with not only the plastic deformation but also elastic deformation region [11], especially before entering the drawing die which may be of much importance for the continuity of the wire drawing process.

P. Strzępek (e-mail: strzepek@agh.edu.pl), A. Mamala, M. Zasadzińska, A. Nowak, AGH University of Science and Technology, Faculty of Non-Ferrous Metals, Cracow, Poland

EXPERIMENTAL PROCEDURE

The stated hypothesis is that the wire drawing process is stationary and the macroscopic result of such stationarity is a constant drawing force needed for the process. However, the authors believe that the elastic deformation region is being generated before the material enters the die reduction angle which should result in increasing of the measured drawing force values. To test that theory an extensive analysis of the drawing forces with low drawing velocity was conducted using 4 drawing dies which geometry is presented in Table 1. Each of the drawing processes was conducted using pre-hardened ETP grade copper rod with a diameter of 11,55 mm and 10,5 mm giving deformation coefficients λ = 1,33 and λ = 1,1 respectively. Measured drawing velocity after exiting the drawing die was approximately 0,1 mm/s. The value was set on such a low level in order to eliminate the temperature influence on the process, thus making it as clean as possible in laboratory conditions.

Table 1 **The geometry of the drawing dies used during experimental studies**

Drawing die number	1	2	3	4
Diameter / mm	10	10	10	10
2α die angle / °	16	20	20	24
Bearing length / mm	1	1	3	1

RESULTS AND DISCUSSION

In order to determine the influence of the drawing die geometry on the drawing forces and thus the elastic deformation region 4 dies of various die angle and bearing lengths were used. All 4 studied cases were presented at Figures 1 – 4 and in each of the analysed cases, regardless of the applied deformation coefficient (high or low diameter reduction) the increase of the force value at the end of the process is present. The beginning, the end of the observed increases and the constant values were marked with straight lines forming triangles of various shape. It may be stated in a vast simplification that the bigger the triangle the longer the elastic deformation region, however, using formulae 1 – 4 [12] a closer estimation has been proposed.

$$L_{el} = (\Delta_t - t_b - t_r) * V_b \quad (1)$$

Where:
L_{el} – The length of the elastic deformation region
Δ_t – The time of the registered force increase
t_b – The time the material was at the bearing length
t_r – The time the material was at the die reduction angle
V_b – The material velocity before entering the drawing die

$$\Delta_t = t_s - t_e \quad (2)$$

Where:
t_s – The start of the force increase
t_e – The end of the force increase

$$t_b = \frac{L_b}{V_f} \quad (3)$$

Where:
L_b – The length of the bearing length
V_f – The material velocity after exiting the drawing die

$$t_r = \frac{L_r}{V_r} \quad (4)$$

Where:
L_r – The length of the die reduction angle
V_r – The material velocity at the die reduction angle

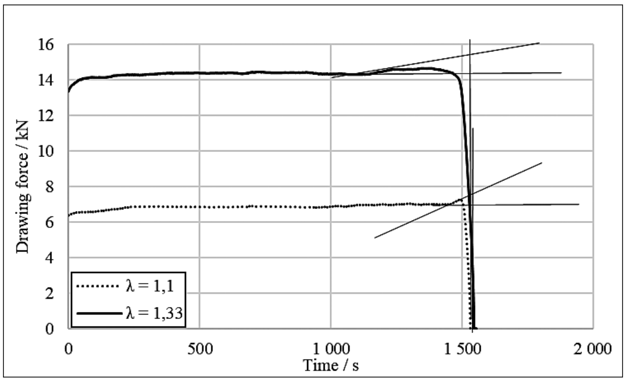

Figure 1 Registered drawing forces for drawing die number 1 with increases of value marked at the end

The analysis of the registered drawing forces based on the proposed formulae (1 – 4) made it possible to estimate quite accurately the values of the length of the elastic deformation region and the calculated values were presented in Table 2 along with the average drawing forces registered. When considering the registered forces it is clearly visible that the average value decreases as the die angle increases. In the case of the drawing dies 2 and 3 which differed only in the size of the bearing length it may be stated that the values are much

lower in the case of 3 mm bearing length (drawing die number 3). However, as presented in Table 2 judging the process just by the force parameters registered during the process is not necessarily correct. The estimated length of the elastic deformation region is the highest in the case of the number 1 drawing die which also had the highest values of the drawing force, however, the drawing die number 4 which force parameters

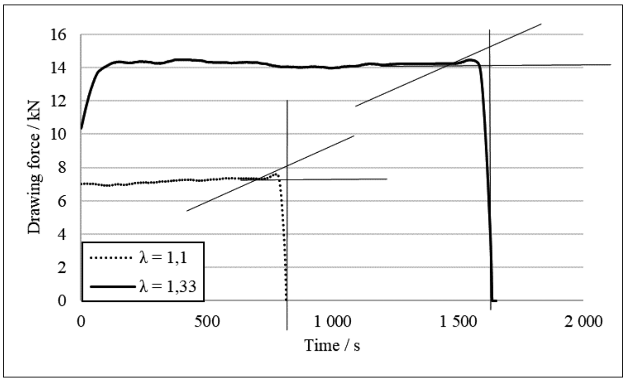

Figure 2 Registered drawing forces for drawing die number 2 with increases of value marked at the end

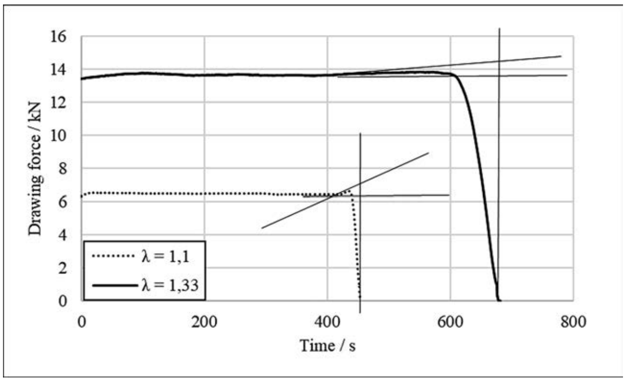

Figure 3 Registered drawing forces for drawing die number 3 with increases of value marked at the end

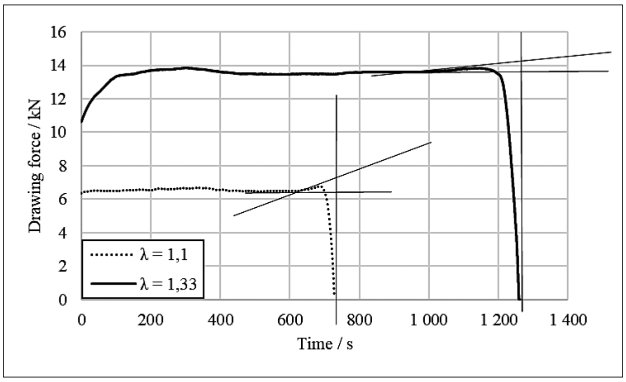

Figure 4 Registered drawing forces for drawing die number 4 with increases of value marked at the end

Table 2 **Collective data of the estimated based on the experimental processes lengths of the elastic deformation regions**

Drawing die number	1		2		3		4	
λ	1,103	1,334	1,103	1,334	1,103	1,334	1,103	1,334
Average drawing force / kN	6,95	14,39	7,2	14,2	6,49	13,71	6,47	13,62
Estimated length of the elastic deformation region / mm	18,7	24,1	6,1	7,1	1,8	13,3	8,0	13,5

were the lowest have longer elastic deformation regions than the drawing dies with 20 ° die angle (number 2 and 3). This may suggest that the values which were closer to the optimal die angle (between 18° and 20° for copper regarding on its state) not necessarily provide the lowest values of the drawing force parameters, but the elastic deformation regions are certainly the shortest. The discussed region may influence the axis of the drawn material and transform into cracks which depend not only on the kinematic incompatibility of the velocity field of the material particles, but also on the stress state. Realizing that such phenomenon exists creates possibilities of development of new mechanism for the emergence of central burst defects, and as such, the development of new technological recommendations which might prospectively eliminate the wire drawing defects discussed in other research works [4, 10].

CONCLUSIONS

On the basis of the conducted research it may be stated that:

The increase of the drawing force at the end of the process was directly related to the elastic deformation region before the drawing die.

The calculated values of the average drawing force do not necessarily reflect the calculated lengths of the elastic deformation region as the drawing die with the highest drawing force had the longest elastic deformation region, however, the drawing die with the lowest drawing force did not have the shortest elastic deformation region.

The optimal die angle did not reflect the lowest drawing force values, however, the closer the die angle was to the optimal die angle the lower were the values of the estimated elastic deformation regions.

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