INFLUENCE OF FRICTION COEFFICIENT ON MECHANICAL PROPERTIES IN PROCESS OF COLD BULK FORMING

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Abstract. *Bulk forming is one of the most effective and efficient manufacturing processes. Mass production of many of the items without any defects has been possible because of the advancements in cold bulk forming. The characteristic of a lubricant, especially coefficient of friction influences the interfacial friction during the forming process. This friction causes defects and many difficulties and has to be kept within limits so the proper choice of lubrication is very important for the quality of the formed product. The influence of lubricant's coefficient of friction on different mechanical and electrical properties of cold extruded material has been investigated and described in this paper by performing many different tests and measurements for mechanical properties and electrical conductivity of the formed material. Coefficients of friction for four different lubricants were first obtained by ring test, and then these lubricants were used in cold extrusion process. The obtained experimental results describing the effect of lubrication on material properties were presented in a form of diagrams and have shown that choice of lubrication could influence some material properties.*

***Keywords**: BULK FORMING, FORWARD EXTRUSION, LUBRICANTS, FRICTION COEFFICIENT, RING TEST, MECHANICAL PROPERTIES*

1. Introduction

Mass production of many of the products without any defects, in different fields has been possible because of the advancements in cold bulk forming, extrusion for example. During extrusion process, there is a relative movement between the tool and die setup, and the billet formed; Due to this friction arises in the interface between them. [1]

This friction causes defects and difficulties like inadequate filling up of metal in the cavity, cracks and porous surfaces, subsurface defects in the formed part, premature wear and tear of the tool and die setup, increased energy requirements [1]. Therefor the interfacial friction has to be kept within limits, though cannot be eradicated. The lubrication problems are one of the most delicate problems in cold forming. The influence of lubrication on wear, friction, forming force, temperature, material and geometrical properties and finally costs are very important [2]

In a bulk metal forming, the characteristic of a lubricant (especially coefficient of friction) influences the interfacial friction during the process. It is generally expressed in two terms, co-efficient of friction, μ and shear friction factor, *m*. In metal forming analysis, two friction models namely Coulomb friction model and Tresca friction model are used to describe friction. In Coulomb's theory, frictional shear stress, τ is expressed as follows [1]:

$$\tau = \mu \, \sigma_n, \tag{1}$$

where σ_n is the normal stress or pressure that acts perpendicular to the surface and μ is the coefficient of friction.

Tresca's friction model relates the shear stress to a constant shear friction factor, *m* as given below [1]:

$$\tau = m \, \sigma_f / \sqrt{3} \tag{2}$$

where σ_f is the flow stress of the material.

The flow stress, a property of the material, in turn depends upon the strain, strain rate and temperature of the billet. The value of shear friction factor varies from 0 to 1, where $m = 0$ represents frictionless interface and $m = 1$ represents sticking friction.

In the majority of metalworking processes the material is deformed by means of a contacting die. The pressure required for deformation generates a normal stress to the die surface, and movement of the specimen relative to the die surface generate a shear stress at the interface [3, 4]. Thus a classical tribology situation arises, with friction at the die-specimen interface, and with potential for wear of both die and specimen materials. The first step in controlling this friction is to quantify it, and then properly apply a suitable lubricant for the extrusion process [5, 6].

The success or failure of such lubrication has important consequences on the quality of the issuing product, and also on pressures, forces and on the mechanical properties as well as some other properties of the product. The choice of the right lubricant and its proper application is very important. There are some articles describing new lubrication technologies [6, 7, 8] with new lubricants and also optimization of application of known and widely used lubricants [9, 10]. Authors in [11] describe numerical analysis of lubrication while in papers [12] decreasing of friction during cold forming by using a nano-molecular layer or adding a nano particles [13] was investigated. Despite the extremely wide range of conditions under lubricants must function, some systematic approach to selection can be made.

Final selection is almost always a matter of compromise, but there exists some fairly general, desirable attributes which must be taken into account when choosing the optimal lubricants for bulk forming processes [14]:

- separation of die and specimen surfaces,
- prevention of cold welding (pressure welding),
- controlled friction,
- control of surface temperature,
- easy handling, safety,
- low costs, ecological friendly.

2. Experimental work

In the frame of the experimental work the process of cold forward extrusion of a cylinder from the copper alloy CuCrZr was analysed. This is a copper-chrome-zirconium alloy with high electrical and thermal conductivity and excellent mechanical and physical properties also at elevated temperatures. It is used as electrode material in spot, seam and butt resistance welding of low carbon steel sheets. Further it is used for manufacture of various components for resistance welding equipment.

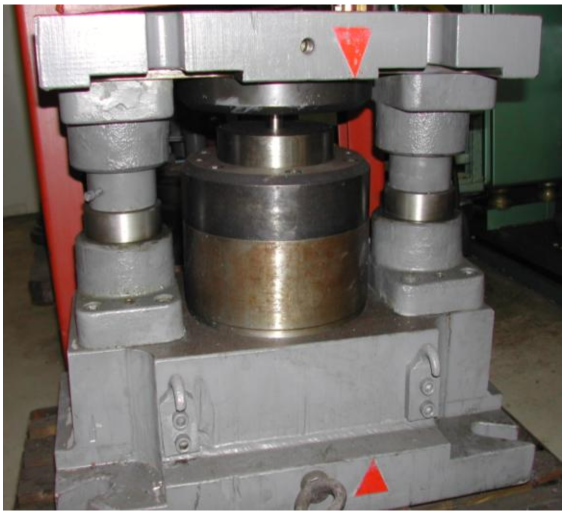

Fig. 1. *Experimental tool for cold forward extrusion*

The cylinders of dimension Φ22 mm x 32 mm were extruded in a special tool for forward extrusion (Fig.1) at 20°C temperature and four different lubricants coefficients of friction (μ = 0,05, 0,07, 0,11 and 0,16). The effective strain was in all cases ε_e = 1, 29. The measurements of coefficient of friction for each of the four different lubricants were carried out by using the ring-compression test. It is a very simple test. There is no need for load measurement or knowledge of material yield stress. This test is most suitable for processes with low effective strains. A ring-shaped billet is compressed by two plates in several increments. Deformation of diameter and height is measured after each increment [15]. Friction is evaluated by comparing obtained results (curve) with friction calibration curves given in literature [16, 17, 18, 19]. Increasing friction presents increasing resistance to free expansion of the ring, resulting in a decrease of the ring internal diameter (Fig. 2).

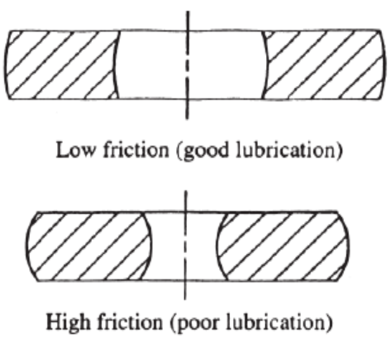

Fig. 2: *Effect of friction on metal flow during the ring compression test [17]*

Thus lubricants can be ranked simply by measuring the change in internal diameter and height of the ring. For each lubricant three ring tests were performed and then average values of coefficients of friction were calculated. The results of the ring-compression test for all four lubricants gave us these average values:

- Lubricant No. 1 (oil) μ = 0, 05
- Lubricant No. 2 (oil) μ = 0, 07
- Lubricant No .3 (oil) μ = 0, 11
- Lubricant No. 4 (grease) μ = 0, 16

To determine the influence of the coefficient of friction on mechanical and electrical properties of cold forward extruded specimens, tensile tests, Brinell hardness measurements and electrical conductivity measurements were carried out.

Tensile strength, yield stress, reduction of area and elongation were determined with the tensile tests. Brinell hardness was measured by using the measuring instrument WPM, electrical conductivity of extruded specimens was measured by the Sigmatest instrument. Many experiments were done to provide reliable results.

3. Results and discussion

The diagrams on the Fig. 3 and Fig. 4 present the change of tensile strength R_m, yield stress $R_{p0,2}$, reduction of area Z and elongation A_5 as a function of lubrication friction factor μ at the constant tool speed v_{tool} = 12 mm/s. The results at different coefficients of friction are very similar but the difference between them range from 2% to 7%.

Although this difference in mechanical properties could be of importance in some specific cases, in general it is possible to say that the value of lubricant's coefficient of friction does not affects significantly the measured mechanical properties of the cold extruded alloy. Of course this conclusion can be made only for lubricant friction factor interval from μ= 0, 05 to 0, 16.

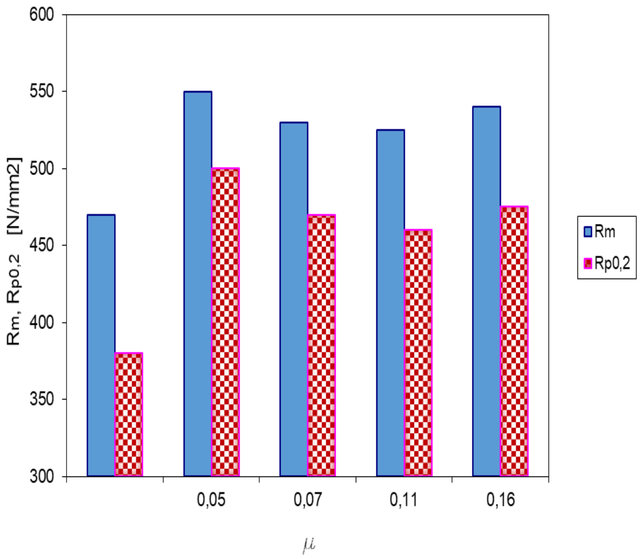

Fig. 3. *Influence of lubricant's friction coefficient μ on tensile strength (R_m) and yield stress ($R_{p0,2}$)*

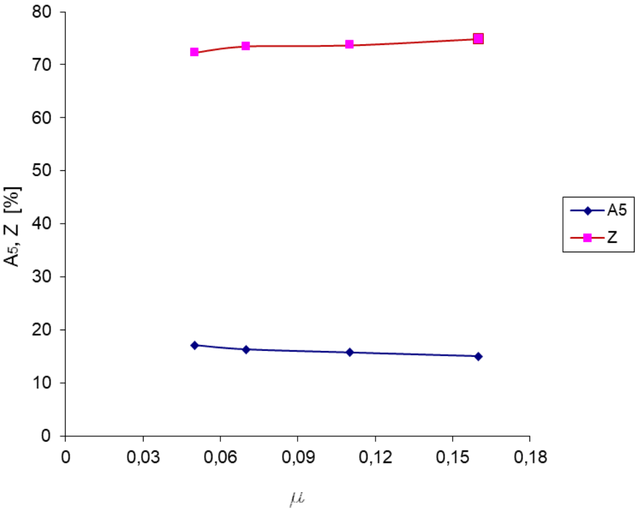

Fig. 4. *Influence of coefficient of friction μ on reduction of area (Z) and elongation A_5*

If we compare the results for tensile stress R_m and yield stress $R_{p0,2}$ measured at different values of coefficient of friction very interesting thing can be observed. By using lubricator with the lowest coefficient of friction (μ = for lubricator Nr.1) the highest tensile strengths and yield stresses were measured. With increasing coefficient of friction (μ= 0, 07 and) both, tensile and yield stress decreases, although insignificantly. The biggest difference in yield stress measurement was obtained when we compared results for lubricant's coefficient of friction μ= 0, 05 and μ= 0, 11. The yield stress measured at μ= 0, 11 was 7% lower compared to yield stress at μ= 0, 05. We could expect a further decrease of both stresses when using lubricant with the highest value of coefficient of friction (μ= 0, 16). But tensile strength and yield stress increase for about 2% to 4% compared with stress values when lower coefficient of friction was used.

The same phenomenon can be observed with elongation A_5 and reduction of area Z on Fig. 4. But the change of values for elongation and reduction of area measured at different coefficients of friction is even smaller (less than 4%) than the change of tensile strength and yield stress.

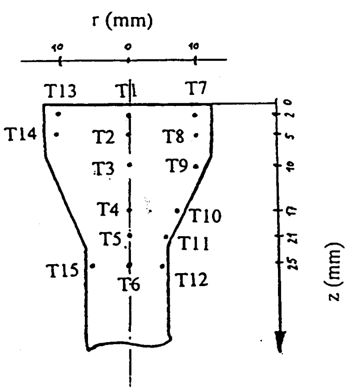

Fig. 5. *Measuring points for Brinell hardness*

By means of Brinell hardness measurements in several measuring points of the cold extruded part (Fig. 5), it was possible to determine the influence of the strain and lubricants coefficient of friction factor on the hardness. Fig. 5 presents the measuring points on the extruded alloy CuCrZr.

Fig. 6 shows the influence of lubricant friction factor to Brinell hardness of the extruded alloy, measured at points according to Fig. 5.

According to diagram on Fig. 6 the influence of lubricant friction factor on Brinell hardness has no big importance but it is obvious that with increasing coefficient of friction there is an increase of hardness (especially in measuring points T1, T3 and T5, which are all in the middle axis of the specimen) although this increase is relatively small.

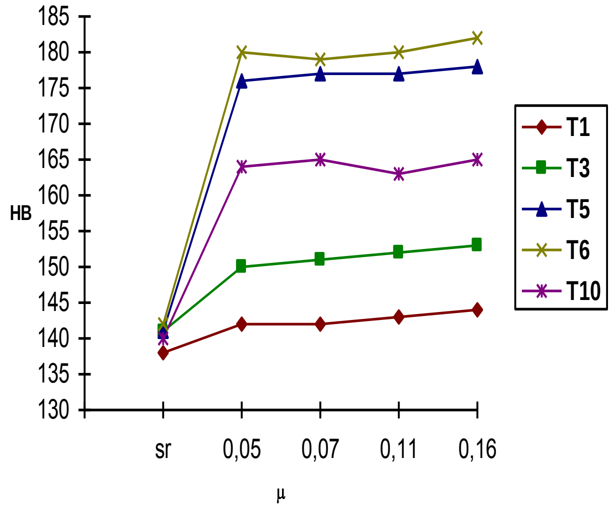

Fig. 6. *Brinell hardness HB measured in different points T as a function of lubricant's coefficient of friction μ (sr. = unformed alloy)*

The differences between values of Brinell hardness in the same measuring point of the extruded alloy but at different lubricant coefficients of friction μ are less than 4%. Of course, this conclusion can be made only for lubricant's coefficients friction interval from μ = 0,05 to 0,16.

Measurement of the electric conductivity was performed on the cylinders taken from the root of the cold extruded alloy. Dimension of these cylinders was Φ 11mm x 16mm and the conductivity was measured by special Sigmatest instrument with measuring frequency of 120 kHz. Many measurements were done to provide reliable measuring results of electric conductivity. The influence of coefficient of friction on the electrical conductivity of the cold extruded material is presented in Fig. 7.

Electrical conductivity is decreasing with higher strain. When measured on the specimen which was extruded with lubricant's coefficient of friction μ = 0,05, the electrical conductivity is about 20% lower than the electrical conductivity of unformed material (0 on x-axis in the Fig. 7). It is obvious that the electrical conductivity increases with increased lubricant's coefficient of friction, the difference between electrical conductivity values when using smallest (μ = 0,05) and highest (μ = 0,16) coefficient of friction is less than 6 %.

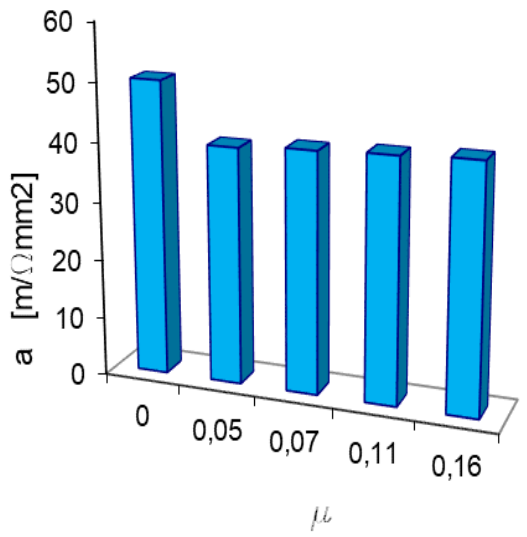

Fig. 7. *Effect of coefficients of friction on electrical conductivity a of the extruded specimens (No. 0 on x-axis represents the value of unformed alloy)*

4. Conclusion

Friction is a very important parameter in all metal forming processes. It affects in unfavourable way all main process parameters and product quality. The magnitude of friction needs to be known for several reasons. Pressures, forces and energy requirements can be calculated only if interface conditions can be described by shear strength or friction factor. For this, a numerical value must be established. In most cases reduction of friction by lubrication has a beneficial effect by lowering the forces required for a given operation. This reduces the stresses imposed on tooling and may allow the use of smaller and less costly equipment. Effective lubrication can also improve product quality by eliminating surface defects such as scoring or cracking through the reduction of metal-to-metal contact and avoiding harmful residual stresses and internal defects through promoting more homogeneous deformation conditions.

The values of lubricant's coefficient of friction can also have effects on the material properties during and after forming process. Although this influence is in general not very significant, it could be of importance when very precise information of mechanical and other properties of the extruded specimen is necessary.

One of the reasons for small difference in measured mechanical properties when using different lubricators with different coefficients of friction could be the fact that we have done our experiments with lubricants with rather low coefficients of friction. By using lubricants with higher coefficients of friction, the influence on the mechanical and electrical properties of the formed material could be more significant.

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