STUDIA UBB PHYSICA, Vol. 60 (LX), 2, 2015, pp. 77-88
(RECOMMENDED CITATION)

EXPERIMENTAL AND FINITE ELEMENT ANALYSIS REGARDING THE INFLUENCE OF FRICTION CONDITIONS ON MATERIAL FLOW IN METAL FORMING PROCESSES

M. POP[1*], D. FRUNZA[1]

ABSTRACT. When friction occurs between tool and workpiece, surface expansion and high normal pressure between work piece and die, leads to adhesions(cold-weld), abrasion of die and work material. To reduce the friction, it requires a suitable lubricant. In the present work different lubricated condition were tested in the extrusion process of lead. The influence of lubricated conditions on the material flow and process parameters were determined. Experimental values were compared with simulation.

Keywords: *friction, plastic deformation, simulations.*

INTRODUCTION

One of the most important considerations in optimizing metal forming processes is the friction between the workpiece and forming tools. Material flow is directly linked to the frictional conditions, and this in turn influences the required forming load and the mechanical properties of the final product. Other aspects of product quality, such as surface finish and dimensional accuracy are also affected by the friction condition. In addition, tool design, tool life, and productivity depend on the ability to determine and control friction.

In forging, the flow of metal is caused by the pressure transmitted from the dies to the deforming workpiece. Therefore, the frictional conditions at the die/workpiece interface greatly influence metal flow, formation of surface and internal defects, stresses acting on the dies, and load and energy requirements [1]. Also in metal forming, friction is a crucial factor that determines whether an

---

[1] *Technical University of Cluj-Napoca, 103-105 Muncii Avenue, 400641 Cluj-Napoca, Romania.*
[*] *Corresponding author e-mail: mariana.pop@ipm.utcluj.ro*

industrial process can be run with acceptable, economic result. In many forming applications, the actual friction conditions are not sufficiently known. The friction phenomenon in metal forming is of great importance. Various reasons for this are: forming loads and stresses transferred to the dies depend on friction and can be reduced by use of appropriate lubricants; the surface quality of the formed workpiece depends on the lubricant used; wear of the dies can be reduced if lubricant films are applied, which provide reduced friction, or even full or partial separation, between the die and the workpiece during forming. Major factors affecting friction include the normal stress along the die–material interface, the lubrication condition, the relative velocity, the temperature, the roughness, and the mechanical properties of the material and/or the die. A detailed investigation of these factors is not easy because the die–material interface in metal forming is under high pressure and temperature [2].

THEORETICAL DETAILES

No surface is geometrically perfect. Surfaces contain irregularities that form peaks and valleys. Thus, contact between the die and the workpiece is maintained over limited portions of the apparent interface. The apparent area of contact is the total area, but the actual area of contact is limited to that between the peaks of the opposing asperities (Fig. 1).

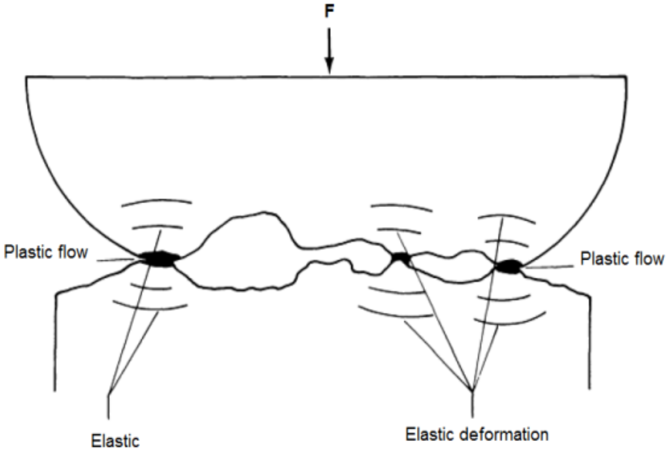


Fig.1. Representation of surface irregularities [3].

Figure 2 illustrates this fundamental phenomenon as it applies to the upsetting of a cylindrical workpiece. As figure shows, under frictionless conditions, the workpiece deforms uniformly and the resulting normal stress, σ_n, is constant across the diameter.

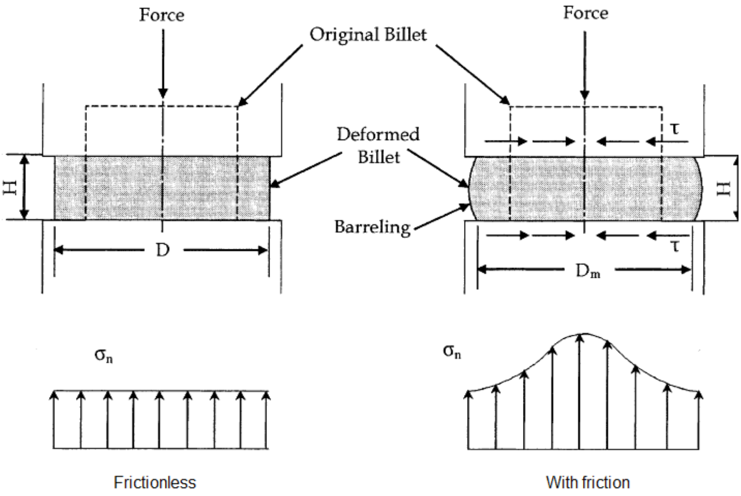


Fig.2. Upsetting of cylindrical workpiece [1].

Where some level of frictional stress is present, the deformation of the workpiece is not uniform (i.e., barreling).

As a result, the normal stress, σ_n, increases from the outer diameter to the center of the workpiece and the total upsetting force is greater than for the frictionless conditions [1].

Excessive friction leads to heat generation, wear, pick-up and galling of the tool surface, which contribute to the premature failure of the tools. Friction can increase the inhomogeneity of deformation, leading to defects in the finished products. In order to reduce the detrimental effects of friction, lubricants are used extensively. Nevertheless, it should be noted that it is not always the practice to reduce the interfacial friction to a minimum value.

In order to evaluate the performances of various lubricants under various material and process conditions and to be able to predict forming pressures, it is necessary to express the interface friction quantitatively. There are two laws that can be utilized for this purpose: Coulomb and Tresca. The Coulomb friction law uses a coefficient of friction, μ, to quantify the interface friction. Equation 1 shows that μ is simply the ratio of the frictional shear stress, τ, and the normal stress (pressure), σ_n.

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

At high contact pressures instead of the Coulomb friction model, it is recommended to use the Tresca model .Tresca proposed a different friction model, which is able to describe the physics of the friction at an interface at high contact pressures. *Tresca's friction model* is commonly expressed as:

$$\tau = f\overline{\sigma} = \frac{m}{\sqrt{3}}\overline{\sigma} = mk \tag{2}$$

The interface shear friction law uses a friction factor, f, or a shear factor, m, to quantify the interface friction. Equation 2 shows that the frictional shear stress, τ, is dependent on the flow stress of the deforming material, $\bar{\sigma}$, and the friction factor, f, or the shear factor, m.

The parameter m is called the friction factor, and can vary in the range $0 < m < 1$. In the case of sticking between workpiece material and the die, this factor equals 1, and the friction shear stress transferred through the interface equals the shear flow stress of the softer contact body, so that the situation agrees with the physics of the interface. In metal forming simulations, friction has traditionally been assumed to follow the Coulomb friction and the constant shear friction [2,4,5,6,7].

The finite element analysis (FEA) based simulation of metal forming processes has been widely used to predict metal flow and to optimize the manufacturing operations.

Friction during extrusion can lead to the development of tensile stresses at the surface of heterogeneous alloys. Thus, lubrication is often required, although in some cases, hot extrusion is done without lubrication (especially for aluminum alloys). Of all bulk deformation processes, extrusion is perhaps the most sensitive to lubrication, partly because the non-steady-state conditions at the beginning and end of extrusion are conducive to instabilities, and partly because any unwanted change in lubrication leads to defects that affect not only the appearance but also the properties and integrity of the product [8]. In forward extrusion, the material is pushed through the container and the die by means of the ram (Fig.3).

The aim of this paper is to present by using numerical simulation the influence of friction condition on deformation parameters in direct extrusion.

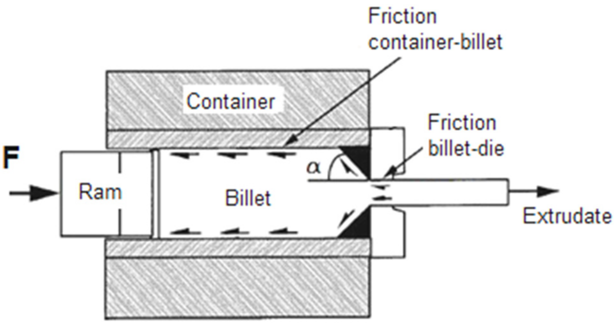


Fig.3. Principle of direct extrusion.

RESULTS AND DISCUSSION

The lead (Pb99,5) samples were used to study the influence of lubrication conditions of the process on the extrusion force and material flow pattern. The cast lead alloys of dimensions 60mm in diameter produced were machined into smaller lead alloy specimens of dimensions 30 mm in diameter and 20 mm in height. The billets were subjected to upsetting tests on Heckert type hydraulic press with maximum force of 200KN. The ram speed during the tests were 0,5mm/s. The assembly ram-billet-die is presented in figure 4.

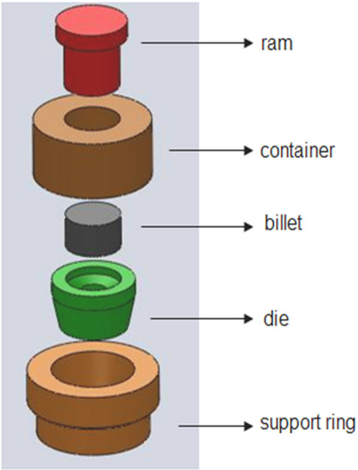
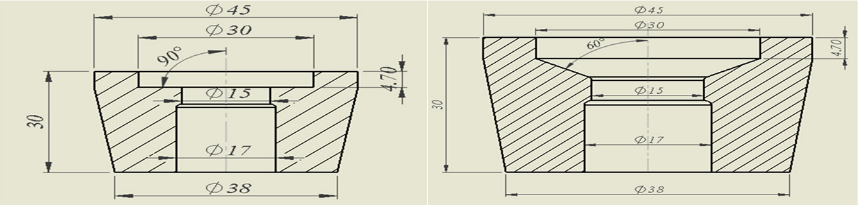


Fig.4. Assembly ram-billet-die.

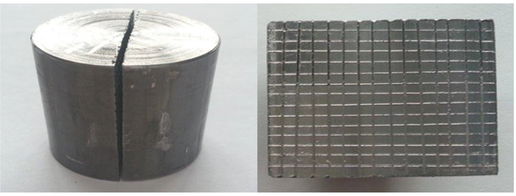
The geometry of the dies generated in SolidWorks are presented in figure 5.



a. die angle 90^0 b. die angle 60^0

Fig.5. Geometry of the dies.

Figures 6 and 7 presents the shape of the flow lines in the extruded material function of die angle and lubrication conditions.



Initial sample

a. Dead zone b. Shape of flow lines

Fig. 6. Extruded samples on die with 90^0 angle
a. unlubricated; b. lubricated with mineral oil.

a. Shape of flow lines b. Shape of flow lines

Fig. 7. Extruded samples on die with 60^0 angle
a. unlubricated; b. lubricated with mineral oil.

The extrusion load, *F*, using a modified upper bound equation is given by the following expression [9].

$$F_d = 2k\left[4\mu\left(\frac{H}{D}+\frac{h}{d}\right)+\left(\frac{\mu}{\sin\alpha}+1\right)\ln\frac{D^2}{d^2}\right]\frac{\pi D^2}{4} \tag{3}$$

where μ is the coefficient of friction at die/billet interface, *D* the billet diameter (mm); *d* the die land diameter (mm), *h* the die land height (mm), α the die half angle (◦), *H* the billet height (mm) and *k* is the maximum tangential stress at die–billet interface (N/mm^2).

The simulation program FORGE is based on the finite element method for cold and hot metal forming. It enables the thermo-mechanical simulation of the plastic deformation processes of metals in an axisymmetric, homogeneous and isotropic state of deformation and obeys the von Mises criterion. The calculations of the metal flow, stress field, strain, strain rate and temperature are conducted on the assumption of the viscoplastic model of the deformed body.

The geometries of the billet, die, container and ram were generated in SolidWorks and the meshes within their space domains in FORGE 3D. The physical properties of the aluminium alloy used in the computer simulation are given in Table 1. The billet was considered thermo-viscoplastic while the tools rigid, and both of these material models neglected the elastic deformation. The shear-type friction conditions at the workpiece and tooling interfaces were imposed as part of the boundary conditions.

Table 1.

Properties	Material Lead
Density (g/cm^3)	11,34
Heat capacity ($J/g\ ^0C$)	2,39
Thermal conductivity (W/m^0C)	35
Emissivity	0,08

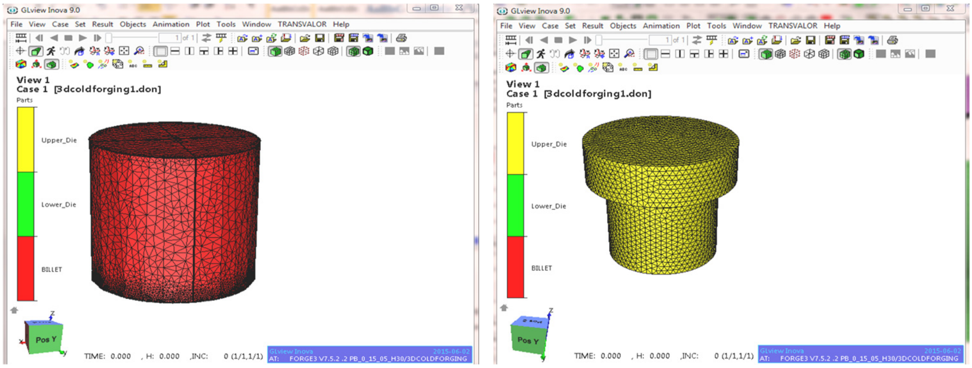
The process parameters used in the simulations are given in Table 2.

Table 2.

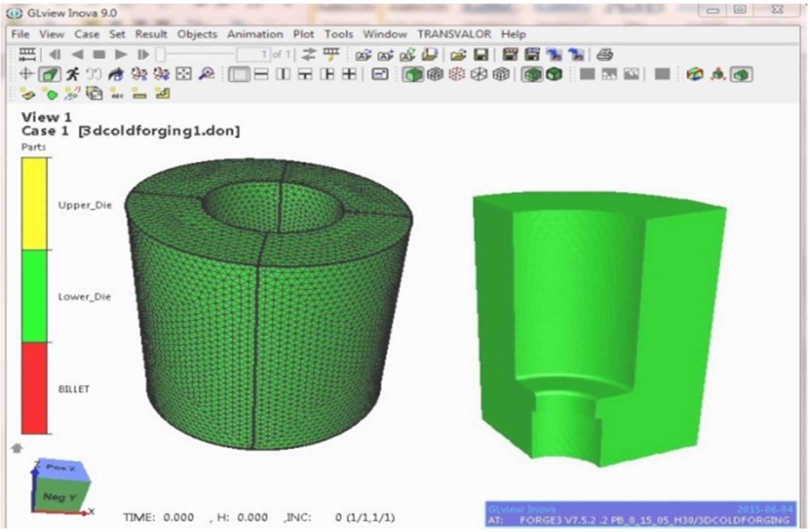
Billet height [mm]	30
Billet diameter [mm]	30
Die semi angle α [^{0}]	60,90

Extrusion ratio	2
Billet temperature [^{0}C]	20
Container and die temperature [^{0}C]	20
Ram speed [mm/s]	0,5
Friction factor at the workpiece–die interface	0,1; 0,3

Fig. 8 shows the initial meshes of the billet and the tooling, together with a cross-section cutting through the die.



a. billet b. ram



c. die and container

Fig.8. Initial meshes of the billet, container, die and ram and the cross-section of the die.

SIMULATION RESULTS

The results obtained for effective strain, equivalent von Mises stress, extrusion force and friction power distribution in different extrusion conditions are presented in figures below.

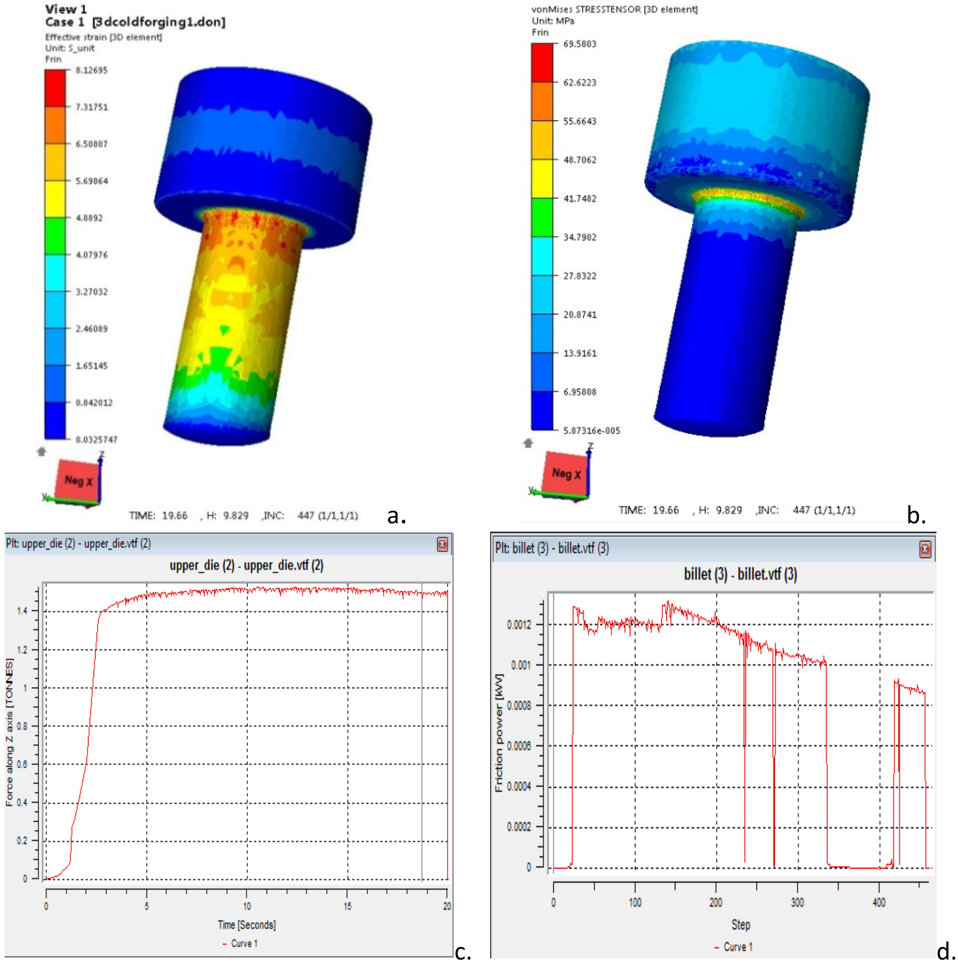


Fig.9. Deformation parameters for die angle 90^0 in unlubricated condition
a. effective strain; b. von Mises stress; c. force; d. friction power.

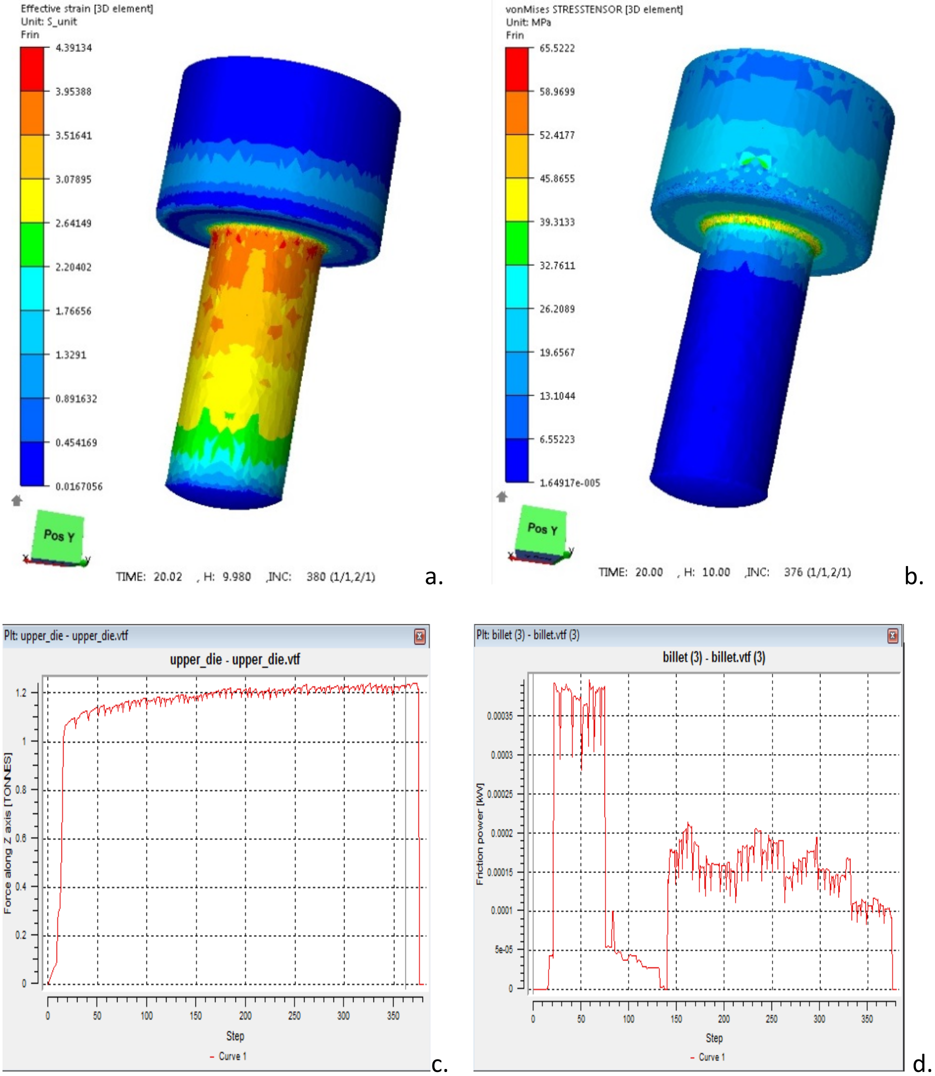


Fig.10. Deformation parameters for die angle 90^0 in lubricated condition
a. effective strain; b. von Mises stress; c. force; d. friction power.

Lubrication plays an important role in cold extrusion process since good lubricants prevent direct metallic contact, with the reduction of extrusion load and the improvement of product quality and tool life.

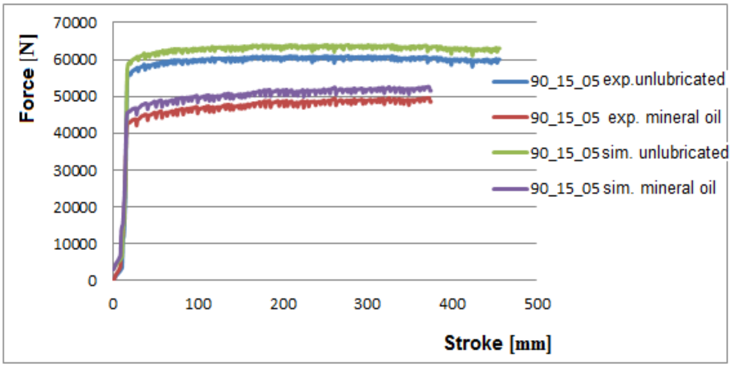


Fig.11. Experimental and simulated force distribution for die angle 90^0, in unlubricated and lubricated condition.

The forward extrusion process was carried out on 99,5 lead with unlubricated and lubricated with mineral oil. The experimental study was conducted to highlight the importance coefficient of friction of plastic deformation processes. Coefficient of friction in the processes of plastic deformation depends on many factors such as: the angle of the die, lubrication conditions, forming speed, the geometry of the tool. To highlight the friction coefficient, measurements were performed on a particular method of forming namely by cold extrusion deformation under certain conditions and with different die angles.

The first measurements took place on a die with an angle of 90° unlubricated, highlighting the flow of the material. The right angle causes the material to flow more unfavorable and the presence of the dead zones namely that the material in this area does not flow and friction between the billet and the die is high. Because of the obstruction caused by the sharp corner of the die, material flow through this area it is visible from the heavily distorted form of the discretized network. The surface of the discretized network elements is different in the area of contact with the walls of the die than in the central portion of the sample, suggesting a non-uniform distribution of the deformation. Due to the friction between the preform and the container material tends to flow more rapidly into the material than on the surface

CONCLUSIONS

The force required for the extrusion process is greater if the case of die with angle 90^0 and lower extrusion force required if case of mineral oil lubrication.

In the extrusion with 60^0 die angle both in unlubricated and lubricanted states the forces are lower than in extrusion with 90 ° angle of die.

The flow of material in this case is greatly influenced by the angle of the die and the friction is reduced for mineral oil lubrication.

Comparisons were made for the experimental extrusion load with simulated extrusion load. It is found that for all conditions, experimental extrusion load is minimum, simulated extrusion load is maximum.
The average error between the experimental and simulation is below 10%.

The close agreement between the simulation results confirms the validity of the extrusion for evaluating conditions.

REFERENCES

1. Altan, T., Ngaile, G., Shen, G., Cold and hot forging, Fundamentals and applications, ASM International, 2004;
2. M.S. Joun, H.G. Moon, I.S. Cho, M.C. Lee, B.Y. Jun, Effects of friction laws on metal forming processes , Tribology International 42 (2009) 311–319;
3. Friction, lubrication and wear technology, ASM Handbook, vol. 18;
4. Zienkiewicz O.C., Jain P.C., Onate E., Flow of solids during forming and extrusion: some aspects of numerical solutions, Int J. Solids Struct 1978; 14:15–38;
5. Hirai T., Ishise T., Plastic metal flow under frictional boundary in forward extrusion die and stress distribution of the die, Int. J. Mach Tool Des Res 1986; 26:217–29;
6. Coupez T., Soyris N., Chenot J.L., 3-d finite element modeling of the forging process with automatic remeshing. J Mater Proc Technol 1991; 27: 119–33;
7. Oh S.I., Wu W.T., Tang J.P. Simulations of cold forging processes by the DEFORM system. J Mater Proc Technol 1992; 35:357–70;
8. ASM International, Handbook of Workability and Process Design, Ed. by George E. Dieter, Howard A. Kuhn, S. Lee Semiatin, 2003;
9. Dragan I., Tehnology of Plastic Deformation, EDP, Bucharest, Romania, 1981.