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RESEARCH AND MEASUREMENTS OF VELOCITY FIELD DURING EXTRUSION PROCESS

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Abstract – Extrusion is one of the widest used and the most basic processes of plastic forming, and the metal flow in extrusion is affected by many factors, such as friction, die shape, billet temperature and so on. Among these factors, friction is the key boundary condition to determine the property of the extruded products. In this paper research and measurements of velocity fields and impact of friction on velocity distribution in forward extruded specimens of copper alloy were analysed using the visioplasticity method. The visioplasticity method was used to find the complete velocity distributions from the experimental data by the finite-difference method. Comparison was made between velocity distributions in the specimens extruded with different lubricants with different coefficients of friction. The results in a form of diagrams have shown that the influence of the lubricant's coefficient of friction on the velocity distributions in extruded material can be of great importance especially in some critical regions in the cold formed material.

Keywords: cold forming, velocity field, visioplasticity

1. INTRODUCTION

It is difficult to control accurately the extrusion forming processes used to make complicated parts because during the process, the degrees of deformation, the states of velocity and stress and the formability of materials vary greatly [1]. Due to its material savings, very high productivity, and increasingly reduced machining, cold forming has become one of the most promising manufacturing technologies in the mass production of different components especially in automotive industry.

When the technology and its parameters started to be understood better, the tools, material, lubricants and machinery became more reliable, and the process stabilised. The metal forming system depends on four major groups of influential parameters [2]:

- input material (physical and mechanical properties, micro- and macro- geometry)
- tools (shape, rigidity, surface quality, wear and load resistance, etc.)
- the forming machine (stiffness, kinematics, sensitivity to heat transfers, etc.)
- the forming process with parameters including the impact of lubricants, strain, strain rates, and stress distribution inside a workpiece, heat generation, etc.

To reach high quality of the metal forming process and full functionality of a product, the material properties, velocity, stress and strain rate distribution, etc., have to be analysed as precisely as possible. Lubrication is also of great importance in many metal forming processes due to its influence on tool wear, material flow, deformation characteristic and mechanical properties of the formed parts [3, 4].

Knowing the values of velocity and strain rates in the plastic zone of formed material under different lubrication conditions is very important for calculating stresses and predicting specimen quality. Although the theory of plasticity provides a sufficient number of independent equations for defining the mechanism of plastic deformation, it is not possible to obtain a complete solution for a general forming problem without simplification and approximations in the deforming mechanism.

Although some researches have been done, the impact of friction on velocity field in extruded specimens has not been studied thoroughly [4, 5]. A number of approximate methods have been developed for the analysis of metal forming problems [6, 7, 8, 9]. Different modeling methods and simulation methods have been used for determination of main parameters in metal forming, especially in extrusion processes.

Among them, the visioplasticity method, which is a combination of analytical and experimental method, gives the most realistic solution to various forming problems. Furthermore, this method can be used as a means of examining the approximations of other solutions. It is widely used also in combination with some other methods in cold and hot metal forming processes.

The visioplasticity method consists of obtaining the velocity field experimentally and calculating the complete velocity, strain rate, strain, and stress fields by considering the equilibrium and plasticity equations [10].

In this paper, impact of friction on velocity distribution in forward extruded specimens of copper alloy were analysed using the visioplasticity method. Comparison was made between velocity distributions in the specimens extruded with different lubricants with different coefficients of friction.

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2. CALCULATION OF THE VELOCITY FIELD BY VISIOPLASTICITY METHOD

Visioplasticity is a method of obtaining information on material flow by using experimentally determined displacement of velocity fields. This method has gained greater importance in the past decade because of quantitative measurements of nodal point displacement in stepwise deformation, describing the material flow pattern. The material flow can be determined by comparing un-deformed and deformed grids [10]. Mostly, square grids composed of line nets are used on longitudinally cut sections in bulk forming.

The grid can be inscribed on the specimen by mechanical means of etching, by photographic methods or pressing. The grid lines must be thin and sharp and the grid mesh should not split off, which would make the measurements difficult.

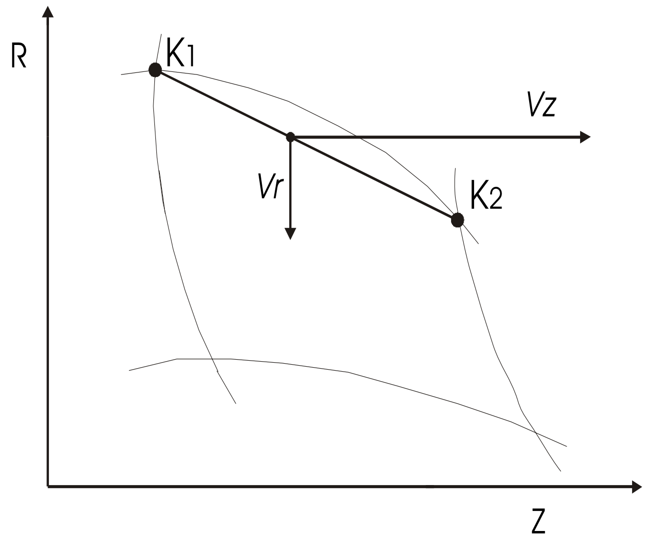


Fig. 1. Determination of the velocity field from deformed grid.

In Fig. 1 point K_1 which is a particular workpiece element, moves to K_2 during deformation and follows a path – motion line. In our case the motion line is also the streamline because of quasi-stationary material flow.

If the deformation step is small, the line joining the start and end points (K_1 and K_2) is also a measure of the magnitude and the direction of the velocities at these two points. In reality the velocity changes between one point and the next on the same streamline. An average velocity is therefore assumed between the points K_1 and K_2. If this procedure is carried out at all points in the grid mesh, an approximate velocity field for the process can be determined.

From velocity field the strain rates and the stresses can be determined by using plasticity equations. For steady-state flow problems in which the flow field does not vary with respect to time, it is possible to introduce a flow function θ by measuring the coordinates of the points located along grid lines after steady-state conditions are reached.

In the steady-state axi-symmetric extrusion, the velocity field can be expressed by the flow function $\theta\ (r,\ z)$ as follows [10]:

$$v_z = \frac{1}{r} \cdot \frac{\partial \theta}{\partial r}$$
$$v_r = -\frac{1}{r} \cdot \frac{\partial \theta}{\partial z} \qquad (1)$$

where v_z and v_r are the velocity components in axial and radial directions.

Further, when the velocity components v_z and v_r are known at all points in the deformation zone, the strain rate components can be obtained according to [7]:

$$\dot{\varepsilon}_r = \frac{\partial v_r}{\partial r}$$
$$\dot{\varepsilon}_\vartheta = \frac{v_r}{r}$$
$$\dot{\varepsilon}_z = \frac{\partial v_z}{\partial z}$$
$$\dot{\varepsilon}_{rz} = \frac{1}{2} \cdot \left(\frac{\partial v_r}{\partial z} + \frac{\partial v_z}{\partial r} \right) \qquad (2)$$

From the calculated strain rate fields, the stress fields can be calculated easily, from the integral equation in visioplasticity.

3. EXPERIMENTAL WORK

In the experimental investigation rods of special copper alloy CuCrZr were used. The initial dimensions of specimens were Φ22 mm x 32 mm. 1 mm square grids were scribed on the meridian plane of one-half of a split specimen. The specimen was extruded through a conical die having a 22, 5 ^{0} half-cone angle and a 73 % reduction in area.

Three different lubricants were used with different coefficients of friction (μ= 0, 05, μ= 0, 11 and μ= 0, 16). The major difficulty was that extremely high pressures were involved in cold extrusion process and forming speeds were relatively low. Thus, liquid lubricants have to be used very attentively with thin but equally accumulated lubricant film [11].

Coefficients of friction for all lubricants were determined in the ring tests [10, 12]. The forward extrusion was carried out at a punch speed of 12 mm/s and the extrusion process was stopped when a sufficient length of specimen was extruded to ensure the establishment of a steady-state motion. The deformed grid of the specimen after forward extrusion is shown in *Fig.2*.

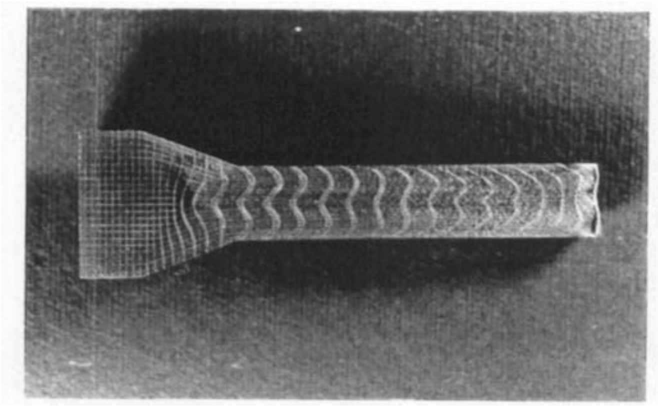


Figure 2. Deformed grid on the cold extruded alloy (μ =0,05, v_{punch} = 12mm/s, R_{area} =73 %).

4. RESULTS AND DISCUSION

The position of every node of the deformed grid after forward extrusion (*Fig.2*) was measured by measuring microscope. These values were put in the special computer program for visioplasticity, developed in laboratory for material forming of Faculty of Mechanical Engineering Maribor, as well as every node of initial grid, distance between initial grid nodes, flow curve of the material to be formed and the punch speed. By measuring the difference between initial grid nodes and nodes on the deformed grid it was possible to calculate velocity of every point in r- and z- direction. Results of the velocity distribution in the deforming region of the specimens are presented in diagrams in *Fig. 3* and *Fig.4*.

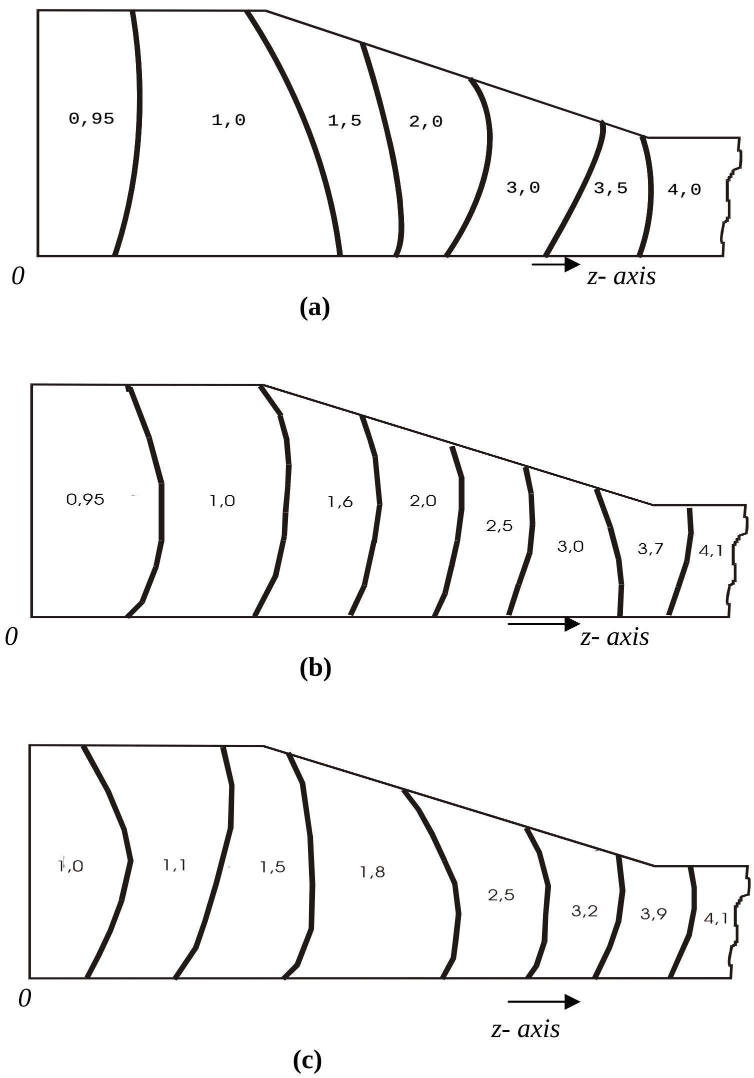
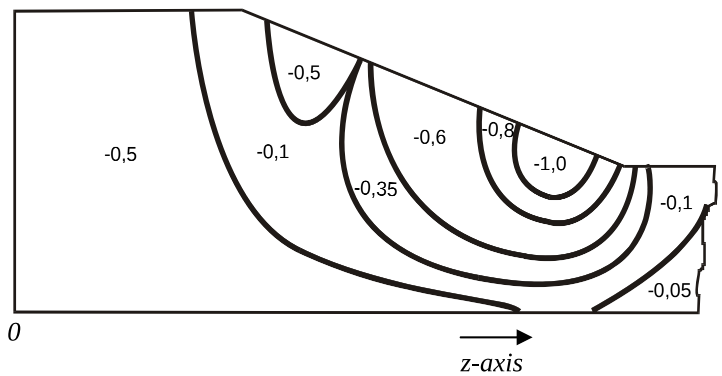
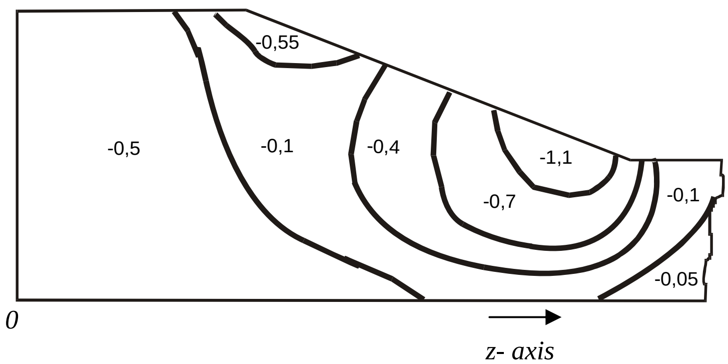


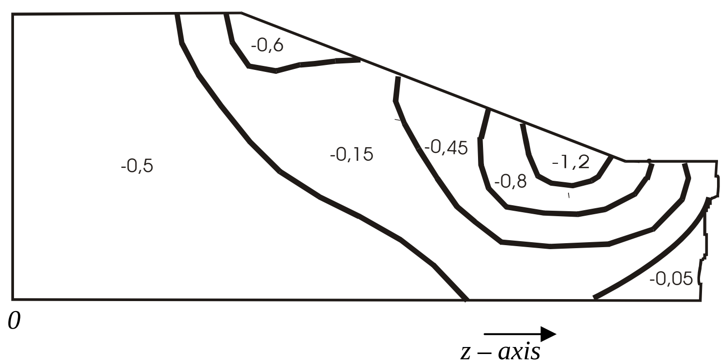
Fig. 3. The contours of axial velocity v_a [mm/s] (v_{punch} = 12 mm/s, R_a= 73%) for:
(a) coefficient of friction μ = 0,05, (b) coefficient of friction μ = 0,11
(c) coefficient of friction μ = 0,16.



(a)



(b)



(c)

Fig 4. The contours of radial velocity v_r [mm/s] (v_{punch} = 12 mm/s, R_{area}= 73%) for:
(a) coefficient of friction μ = 0,05, (b) coefficient of friction μ = 0,11
(c) coefficient of friction μ = 0,16.

In *Fig. 3* and *Fig. 4* the axial component v_a and the radial component v_r of the velocity are shown for three different coefficients of friction used in cold forward extrusion process.

The axial component (*Fig. 3*) is increasing with strain and reaches the highest value on the exit zone (v_a= 4 mm/s). By using the lubricants with higher coefficients of friction (μ = 0,11 and μ = 0,16) for extrusion process, the axial velocity values differ slightly at the exit zone where the axial velocity increases for 6% to 10% compared to values where a lubricant with a lower coefficient of friction was used (μ = 0,05).

The largest radial velocity v_r (*Fig. 4*) was reached along outer side of the cone at the exit zone. In this area the largest value has increased for about 20% (from –1, 0 mm/s to –1, 2 mm/s) when the lubricant with coefficient of friction μ = 0,16 was used.

Generally, the distributions of axial velocity (and radial velocity, too) in specimens extruded under different lubrication conditions are very similar in the major area of the specimens, except in a small area at the end of the deforming zone.

5. CONCLUSION

The axial and radial velocity distribution in the workpiece during the deformation process, determine the strain rate distribution, stress state and the achievable deformation limits. Advanced plasticity theory can be used to determine the velocity and strain rate values in the deformation zone from the local strains obtained from material movement. Such method is visioplasticity, which is very useful in providing a detailed analysis of the distribution of the major field variables such as effective strain, strain rates and stress in any section within the plastically deformed region.

The material flow is mainly influenced by the strain distribution, strain hardening effects, the geometry of the tooling and the friction conditions between workpiece and tool**.** Knowing the velocity distributions in plastic region of the material and the choice of the right lubricant, its proper application and its influence on wear, forming force, temperature, material and geometric properties is very important for prediction of specimen quality and can also promote production efficiency.

In this article the influence of different lubricants with different coefficients of friction on the axial and radial velocity components in forward extruded copper alloy CuCrZr was analysed. Velocity fields in axial and radial axis were determined by visioplasticity method. The experiments have shown that the influence of the coefficient of friction on the velocity components in extruded specimens is small in most measured regions of the deformed zone.

Significant differences were obtained in some regions at the exit of the deformed zone. In those regions higher values of velocity components could be expected when using a lubricant with a higher coefficient of friction. This finding is important especially because of the influence of velocity values on strain rate and stress distributions in the cold formed material and quality of the formed specimen.

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