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Lubrication and Friction in Hydrostatic Extrusion/Drawing

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The effects of extrusion speed, type of lubricant, and driving-stress ratio (extrusion-fluid pressure/drawing stress) on lubrication and friction have been studied in hydrostatic extrusion/drawing using the visioplasticity method. A computer programme has been developed to obtain from experimental data velocities, strains, strain rates, and stresses in the deformation zone. The results show that friction decreases with increasing extrusion speed and with increasing extrusion-pressure/drawing-stress ratio; also that the most favourable frictional conditions are achieved when the billets are lubricated with molybdenum disulphide grease and castor oil is used as the pressurizing fluid—followed in effectiveness by castor oil or Tellus 27 alone. The influence of extrusion speed and driving-stress ratio on friction was found to be more significant than that of the different lubricants used.

While in most metalworking processes hydrodynamic lubrication develops at high velocities, evidence exists suggesting that in hydrostatic extrusion/drawing this condition can be attained at relatively low extrusion speeds. The basic principle of the process is shown in Fig. 1. The billet is extruded by fluid pressure, assisted by tension applied to the product. One extreme condition is when the fluid pressure is zero (the process then being conventional wire or rod drawing), the other is when the drawing stress is zero (the process then becoming simple hydrostatic extrusion). Alexander and Lengyel[1] described a mechanism that could possibly assist the development of fluid or mixed lubrication in simple hydrostatic extrusion at low speeds when, in wire drawing, boundary lubrication would occur. Thus, a metalworking process now exists in which various lubrication conditions can be initiated and studied at conveniently slow speeds, merely by changing the ratio of extrusion-fluid pressure to drawing stress (driving-stress ratio), an advantage in experimentation that hardly requires special emphasis.

To differentiate between frictional effects and other process variables, plasticity theory is often applied in the study of friction in metalworking. This inevitably involves the use of simplifying assumptions, both to make the problem mathematically tractable and to overcome the lack of knowledge about the nature of the frictional process. Normally, an assumption is made, either that Coulomb friction is operative or that the frictional stress is in constant proportion to the shear yield stress of the material. Hydrodynamic lubrication has also been suggested for high-speed metalworking processes with a ready supply of lubricant.

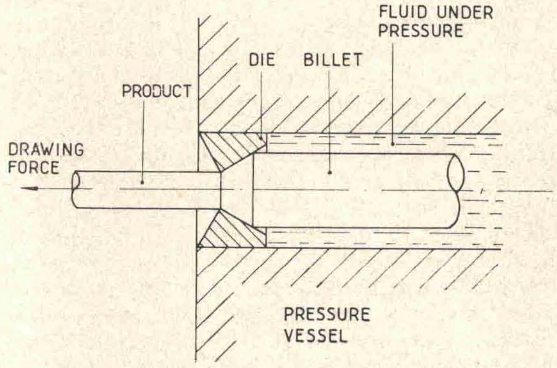

Fig. 1 Hydrostatic extrusion/drawing.

As alternatives, split or strain-gauged dies have been used both in wire drawing and in hydrostatic extrusion—methods that indicate mean values of coefficient of friction but give little or no information on the variation of friction along the die face.

A recent study of the temperature distribution in hydrostatic extrusion revealed the very significant influence of friction on temperature along the die face when the process is fast enough to be considered adiabatic.[2] It has been established that this condition is well within the range of practical speeds in metalworking. Thus, local temperature rise due to friction could well be responsible for transition from one lubrication condition to another such as that shown by the 'bamboo' effect in wire drawing or hydrostatic extrusion. Also, there is evidence to suggest that various lubrication conditions could coexist simultaneously along the die face in hydrostatic extrusion and that these could be responsible for local temperature increases and consequent changes in

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lubricant properties and frictional conditions. From these considerations it follows that methods giving information on mean values of friction along the die face can contribute little to the thorough understanding of lubrication in hydrostatic extrusion.

The semi-empirical method of visioplasticity appears capable of giving the type of detailed information required to assess the temperature and pressure of the lubricant layer and its pressure distribution over the billet/die interface, which would be needed for a detailed study of lubrication conditions in hydrostatic extrusion. This method involves experiments on billets split along their central planes and having lines scribed on these planes parallel with the billet axis. In extrusion these lines become flow lines and their co-ordinates can be used as input data to a computer programmed to obtain velocities, strains, strain rates, and stresses throughout the deformation zone, including the billet/die interface, from which conclusions relating to lubrication conditions can be drawn.

This paper describes the application of the method to the study of friction and lubrication in hydrostatic extrusion.

Experimental Apparatus and Technique

The apparatus was designed to perform experiments at constant speed and constant extrusion pressure. This technique was thought to be more likely to produce constant frictional conditions than the alternative method of setting a constant load and building up a pressure sufficient to cause extrusion.

The high-pressure vessel, described in detail earlier,[3] has recesses at each end of a horizontal bore to accommodate a die and a plug. The plug embodies four insulated terminals so that measurements of pressure and temperature can be taken inside the vessel with a Manganin coil and a Chromel/Alumel thermocouple, respectively. An air–oil accumulator was charged with nitrogen on one side of the piston; the other side was filled with oil and connected to the low-pressure intensifier, which in turn was attached to the high-pressure vessel. A closely controlled stress was applied by means of a screw jack driven by an induction motor via a variator. The speed could be varied between 8·4 and 84 cm/min. The drawing head was designed to exert a maximum of 50 kN (5 tonf) measured by a strain-gauge load cell.

The drawing-head displacement was recorded by a multiturn potentiometer actuated by a rack-and-pinion device. The electric signals were fed into an ultraviolet galvanometer recorder and all extrusion/drawing parameters were continuously recorded vs. time.

Throughout the experiments the material, die, and billet geometry were the same, i.e. fully annealed high-conductivity copper billets, 1·27 cm in dia., RA ratio 2·56, and die semi-angle 10°.

Great care was taken in the manufacture of the copper billets to ensure that the split was in their central planes. The billets were lathe-turned to a fine finish, annealed, cleaned on their outer surfaces by polishing in the circumferential direction on 600-grade emery paper, and finally washed in carbon tetrachloride. The billets were nosed to an angle 2° less than the die angle. During annealing the two halves were firmly clamped together to ensure minimum distortion. The median surfaces were polished with 6μm diamond paste on a flat polishing table. After this treatment the flat surfaces were highly reflective. The roughening of the split surface in extrusion was less than the depth and thickness of the scribed lines and so did not interrupt their paths.

The lines were scribed and measured on a precision machine, the maximum scatter of readings taken from different directions being 0·004 mm, which represents only one-tenth of the original line thickness. In every case the centre of the lines was taken as the co-ordinate.

Tellus 27 mineral oil and castor oil have been used as high-pressure fluids, the former without additional lubricant, the latter occasionally with Molyslip (a MoS_2 lubricant), which was applied to the outside surface of the billet. A collar was used to hold the two halves of the billet together during extrusion and also to guide the billet into the bore of the high-pressure container. This collar was made to give a sliding fit over the billet and in the container bore. Longitudinal grooves were cut in the collar to equalize pressure behind and in front of it.

Computer Programme

After extrusion, the two halves of the billet were separated; the co-ordinate points of the flow lines were then measured and employed as input data for the computer programme.

The theory on which the visioplasticity method is based has been proposed elsewhere[4–6] and need not be repeated here. It involves numerical calculations carried out at intersecting grid points in the deformation zone. As the numerical differentiations and integrations inherent in the method are extremely time-consuming if carried out by hand, the method was in abeyance until the development of the digital computer.

The difficulties involved in computer application have been discussed by Shabaik *et al.*[7] They stem from the fact that when computations are carried out by hand and a smooth curve is drawn through the velocities so established before strain rates are calculated, the results of the analysis are automatically smoothed. When calculations are carried out on a computer, the errors in reading the flow lines and in the numerical fitting methods can cause the higher-order difference quotients to be both large and erratically varying.

Previous applications of the visioplasticity method have made use of rectangular or square grids for the calculations. The difficulties involved if the die half-angle is $\leqslant 45°$, which is usually the case in hydrostatic extrusion, have been described elsewhere.[8] Furthermore, in hydrostatic extrusion, deformation can commence before the billet reaches the die and, if the present method is to be successful in predicting surface conditions, this effect cannot be ignored by assuming a sharp change of slope on the surface of the billet in contact with the die.

For these reasons it was decided that a grid having a constant step length in the axial direction but a variable step length in the radial direction should be used. This type of grid is shown in Fig. 2. Polynomial fitting and smoothing methods were employed to determine the values of the flow function at the grid points from the measured co-ordinates along the flow lines and also to find the derivatives of this

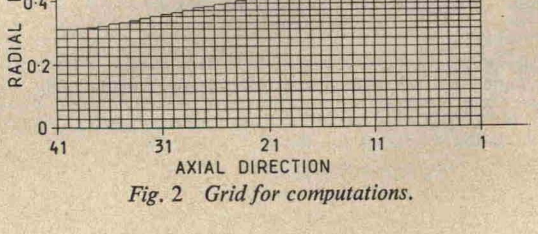

Fig. 2 Grid for computations.