Use of concealed pressure pins to determinate contact stresses in ring compression

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ABSTRACT: A new flexible experimental technique is introduced where a tool base that incorporates sensitive pressure pins is used. An industrial-tool that contains the forging geometry can be placed on top of the base tool that includes the measuring devices. The two tools are inter-linked together and pressure pins are inserted through them but concealed from the contact sever conditions. This paper examines the application of measurements of stresses during the deformation of cylinders and rings. Stresses normal to the tool are measured by using pins that are perpendicular to the surface of contact. Friction stresses are obtained by using inclined pins. Friction characteristics in metal forming operations are usually evaluated by the use of the ring compression test and an average estimate of the friction resistance for the whole pattern of deformation is estimated from the deformation of the inner and outer profiles of the ring. The neutral radius, which exists inside the deformation pattern, is identified in both experiments and theory. Also, experimental measurements of stress components compared favourably with those values obtained theoretically.

Keywords: Tool stress, Measurement, Pressure pin, Ring test

1 INTRODUCTION

Friction forces acting over the contact surface of the tool during the plastic deforming of a working material play an important role on how material flows into the tool cavity profile. Also friction forces significantly influence wear, surface cracks and tool balance. In order to obtain good quality products, detailed knowledge of the contact stresses provide essential data to the process design technology. Surface stresses are also decisive in the tool design process with respect to the definitions and features of the tool. This applies to simple processes such as compression and becomes critical in industrial processes where complex forming patterns are produced.

Average measurements of the friction characteristics along the tool/material interface in forging processes can be obtained using the ring test[1]. With regard to this technique, a simple ring specimen of outer diameter : inner diameter : height ratio of 6:3:2, is manufactured from a material similar to that being formed. The ring is then compressed to a particular height reduction where the change in its dimensions is attributed to the effect of the interface friction between the die and the ring. Three distinct patterns of deformation may result. A significant decrease in the ring inner radius and little change to the outer radius indicates high level of contact friction. If the ring final deformation shows an increase in both the outer and inner radii, it follows that the friction coefficient is particularly low, and this is the case of well lubricated contact surfaces. The third pattern of deformation is characterized by increase in the external radius and decrease of the internal one. That is the case where friction level is moderate. Theoretical and experimental simulation of the relationship between the ring characteristics and friction may be tabulated or given in charts[2]. The ring deformation pattern is of interest when considering the stress distribution in the ring. The deformation pattern of the ring is effected by the existence and position of a neutral radius that divides the flow between the inner and outer surfaces of the ring. Associated with the position of the neutral radius is a condition where flow diminishes and stress is a maximum at such a location. However the neutral radius may exist inside or outside the ring volumetric boundary.

Frictional resistance could also be evaluated through the measurements of contact tool stresses using sensitive pins[3]. A 3-Pin system methodology was also introduced where surface stresses are measured concurrently for the same point on the interface[4].

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This paper investigates the design of a new experimental set up incorporating sensitive strain-gauge pressure pins. The pins are concealed inside the die so as to achieve the desired reliability and repeatability of measurements, even under extreme contact conditions. Components of contact stresses during the compression of rings and cylindrical billets have been investigated theoretically and experimentally. Accurate evaluation of contact stresses and hence the friction characteristics enhance the reliability of numerical simulation when applied to industrial processes.

2 A PRACTICAL TECHNIQUE FOR THE MEASUREMENTS OF TOOL STRESSES

In order to measure tool stresses along contact surfaces during the deformation of material, sensors have to be attached to the tool and be as near as possible to the interface. Sensitivity and stability of the output signal and insulation from the extreme metal working conditions are essential requirements for an efficient design of measuring techniques. One of the methods that showed some comparability with such requirements is the sensitive pressure pin technique.

2.1 Inter-changeable tool set-up methodology

In order to incorporate measuring sensors into the forming process, it is a common practice to embed them into the working tool. Hence, each set of tools is designed to include the full configuration of the measuring devices. A two-die system, shown in Figure 1, is designed to include a die that contains the sensitive pressure pins, and a forming die that includes the product cavity. The sensors holding die is inter-changeable, i.e. could be used with different forming dies.

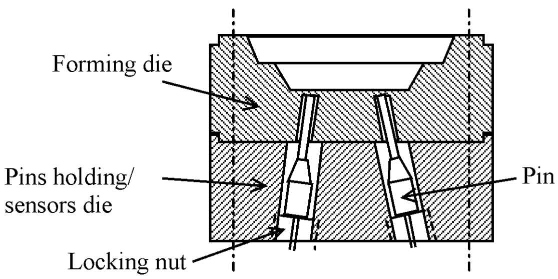
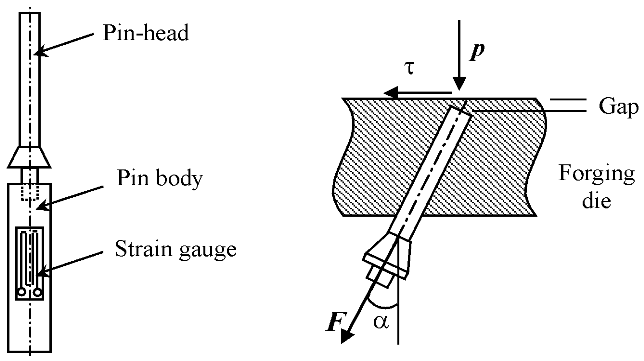


Fig. 1. Tool set up with a two-die system

Under hot forming conditions, the die holding the pins can be insulated from the forming tool using a thin layer of a thermal insulating material. Also, the pin-head could be insulated in a similar manner[4].

2.2 Pressure pins for two-die system

To achieve the inter-changeability of the forming tool shown in Figure 1, a sensitive pressure pin consisting of two parts, made out of harden tool steel, is designed and shown in Figure 2(a). A pin-head of a 2mm diameter stem is to be located into the forging die while the body of the pin, that contains the strain gauges, is to be positioned inside the sensors die.



(a) Construction (b) Forces on pin-head

Fig.2. Sensitive pin construction and forces

The pin-head slides into the pin body thus enabling the two-die system to join together as shown in Figure 1. The pin column is finally pre-stressed, to ensure contact, and fixed in position using a locking nut. The strain gauge on the body of the pin is the most sensitive part of the measuring column and should be kept independent from the surrounding working conditions so that only the effective stress component is transmitted through the pin axis.

In the current tool construction methodology, the pin can be positioned normal or inclined to the surface of interface and concealed inside the die as shown in Figure 2(b). The pin-head remains in contact with the tool but positioned at a gap of approximately 1 mm below the interface. The system of forces at the interface produces two stress components; one parallel to the surface of interface and one normal to it, τ and p respectively. If the pin is positioned at an angle α with the normal stress component and its cross sectional area is A, the equilibrium equation along the pin axis may be written as;

$$F = A\,(p \cos \alpha + \tau \sin \alpha) \qquad (1)$$

where F is the force acting along the axis of the pin and measured through a strain-gauge bridge circuit.

3 ANALYSIS AND EXPERIMENTS

Ring compression and cylinder compression are two basic tests for the determination of friction and material strength. The normal stress distribution on the interface between the tool and material being formed is known to be sensitive to friction. In ring compression the position of a no-flow-through neutral radius gives a measure of friction while in simple compression of a cylinder friction hill characteristics prevails.

3.1 Ring compression

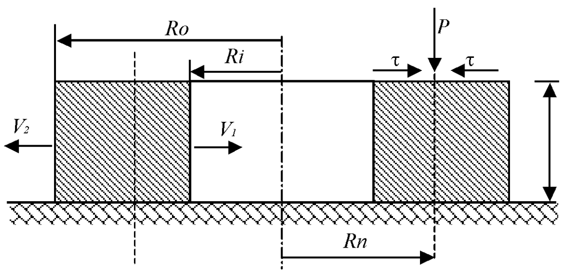


Fig. 3. Flow and surface stresses in ring compression

Figure 3 shows a ring of an inner radius R_i and outer radius R_o and height h. During the compression process and at moderate friction levels, both inner and outer radii move with velocities V_1 and V_2 respectively as shown in Figure 3. If they travel opposite to one another then a neutral radius R_n prevails where V_1 and V_2 diminishes at its location. The normal stress remains compressive but the friction stress τ at the interface change sign at both sides of this position. The Neutral radius location, may vary during the compression stroke. The normal pressure at both ends of the ring reduces to the material yeild stress and increases to a maximum at the neutral radius, R_n, similar to the case of a solid cylinder where the maximum normal stress occurs at the centre line and the minimum at the outer surface. In the ring compression analysis Tresca criterion can be applied using;

$$\sigma_r + p = \sigma_o \qquad (2)$$

Where σ_r is the radial stress component, σ_o is the material yield stress and p is the normal pressure at the interface. Also, the stress equilibrium conditions[5], expressed in terms of the neutral radius R_n, ring height h, and the coefficient of friction μ, the radial stress σ_r as a function of the radial distance, r, may be given by the following expressions;

For $R_n \le r \le R_o$

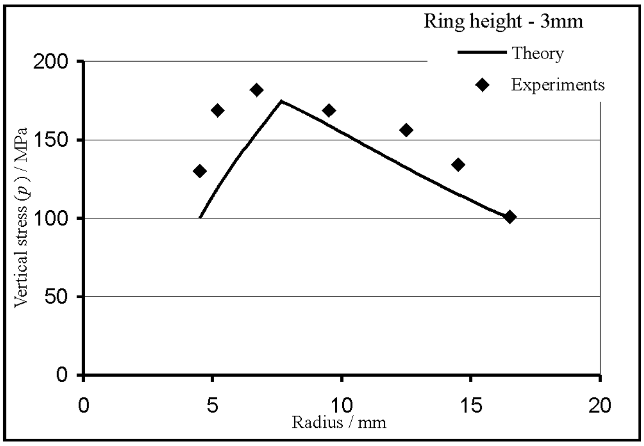
$$\sigma_r = -2\sigma_0 e^{-(2\mu/h)r} \int_{R_o}^{r} \left[\frac{1}{r} - \frac{3r}{3r^2 + R_n^{\,2}} - \frac{\mu}{h} \right] \cdot e^{(2\mu/h)r} dr \qquad (3)$$

For $R_i \le r \le R_n$

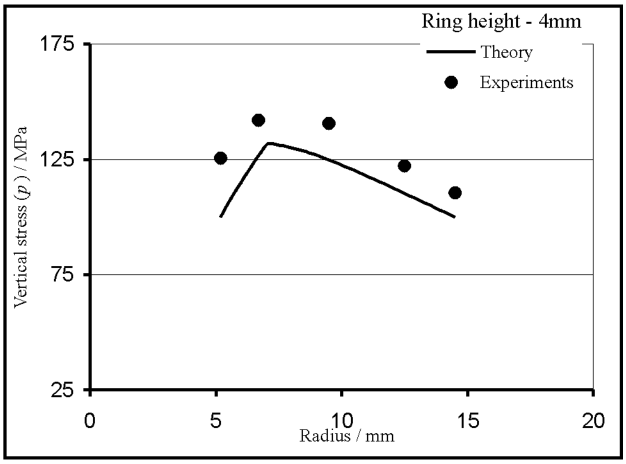
$$\sigma_r = -2\sigma_0 e^{(2\mu/h)r} \int_{R_i}^{r} \left[\frac{1}{r} - \frac{3r}{3r^2 + R_n^{\,2}} + \frac{\mu}{h} \right] e^{-(2\mu/h)r} dr \qquad (4)$$

In order to experimentally evaluate the stress component normal to the tool at contact surfaces, the two die-system shown in Figure 1 was used, with vertical pins, i.e. α = 0, concealed inside the die. Axisymmetric rings made out of 99.5% soft-aluminium of a yield stress of 100MPa were compressed between flat tools. The initial dimensions of the inner diameter, outer diameter, ring height are 13mm, 25mm, 9mm respectively. The calibration of the pins was carried out in such a way that the registered readings were those that occurred at the interface. For the purpose of the calibration, load was applied to dies perfectly closed on a preformed thin disk of the working material.

The distribution of the normal stress component over the ring contact with the tool was obtained using several specimens. A compressive load of 100kN was applied to all rings reducing them to a thickness of 3mm. Figure 4(a) and (b) show the experimental and theoretical results of the distribution of the normal component of stress in ring compression, at two different stages of the deformation process. In both cases, the deformation process appears to have taken place where the internal diameter of the ring decreases and the external diameter increases. The neutral radius in both cases is found to be within the volumetric material of the ring. Also, the peak in the normal stress occurs at the position where the neutral radius lies. Coefficient of friction used in this case is μ = 0.12. Both, theoretical and experimental values follow the same trend and show the location of the neutral radius.



(a) Ring final height = 3mm



(b) Ring final height = 4mm

Fig. 4. Stress distribution in ring compression

3.2 Compression of a cylindrical billet

In the case of simple compression of cylindrical billets the two components of stresses at the surface of contact were measured. The two-die system, with pins inclined at an angle, α, of 30^0 and 45^0 with the vertical was used to compress, under dry conditions, cylindrical soft-Aluminium billets of 25mm diameter and 30mm height. Eight billets were compressed with a load of 400 kN to a height of approximately 8mm. Figure 5 shows the distribution of the two components of stress at the interface. The normal pressure is a maximum at the centre of the billet then decreases towards the edge of the billet and becomes closer to the material yield stress. This is in agreement with the Tresca criterion when applied to billet compression[6]. On the other hand, the radial component of stress, parallel to the interface, shows a low value, near to zero, at the vicinity of the centreline. It is not possible to measure the radial component of stress at the centre of the billet because it changes its direction at that location.

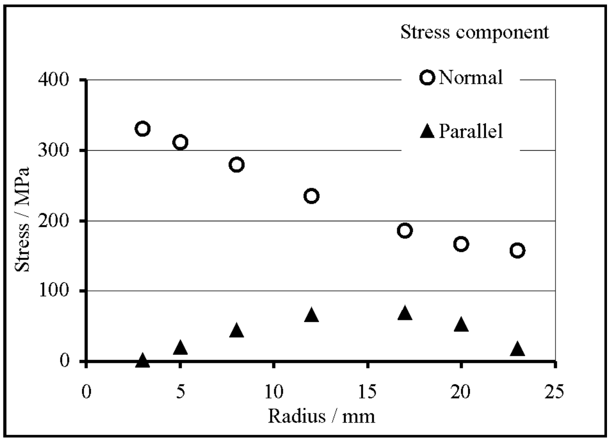


Fig. 5. Inclined pins results for billet compression

4 CONCLUSIONS

A two-die design methodology has been introduced which incorporates sensitive pressure pins with sliding pin-heads that is concealed from the sever contact conditions. The die holding the sensors is inter-changeable and may be used with many different forming tool configurations. Two processes were investigated, ring and cylindrical billet compression, where the components of stress at the surface of the interface were estimated. In ring compression, the position of the neutral radius was investigated experimentally and theoretically. It was also demonstrated that the concealed device gives results with repeated consistency.

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