A New Approach for Experimental Evaluation of Contact Stresses

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Abstract: In metal forming operations, the intensity and distribution of stresses at the tool/material interface have great influence on the pattern and mode of deformation. This is due to the effect of frictional forces in being resistive to material movements and hence affects material flow and the directionality of volume distribution of material inside die cavities. This paper explores the use of the pressure pin technique for the measurement of tool stresses at the interface between the tool and the deforming workpiece material. It also introduces a new experimental methodology for the measurement of stresses where the measuring device is concealed inside the tool and not subjected to the severe conditions at the interface surface. Each tool containing measuring devices is split into two parts, one part has the shape to be formed (industrial die), while the second part includes the pressure pin measuring column. Friction resistance and friction coefficient are evaluated across the billet surface and at different stages of deformation.

Keywords: Pressure pin, Interface Friction, Tool Stresses, Contact Stresses

1. INTRODUCTION

In metal forming operations contact conditions, tool stresses and friction forces in particular, have great influence on the behaviour of material deformation and the mode by which material flow is directed. This applies to almost all contact forming processes, from simple geometry operations like compression, extrusion and rolling to complex forming patterns such as those produced by forging. Under industrial conditions, little is known about the local variation in contact properties and their effects on wear, surface cracks, tool deflection and tool damage. Surface stresses are also important in the tool design process with respect to tool definitions and features. When considering the nature of material deformation and the introduction of full numerical simulation to metal forming analysis, accurate description and characterisation of contact properties become necessary for obtaining a realistic solution.

Measurements of contact stresses using sensitive pins, usually incorporating strain-gauge circuitry and mounted in the pressing tool, have been used to provide estimates of tool stresses at the interface in forming operations, including extrusion and rolling [1,2]. Piezo-electric and optical device sensing techniques have been used in the basic pin construction for signal detection [3,4]. Use of a three-pin system has been introduced so as to evaluate frictional stresses and the coefficient of friction at the tool/material interface [5].

This paper investigates the design of a new experimental set up incorporating the pressure pin technique. Stress components are measured at different angles to the surface of contact and compared with those obtained from the slab analysis technique. The proposed experimental set-up is adaptable to both cold and hot forming operations.

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2. SENSITIVE PRESSURE PIN DESIGN

In order to measure stresses along contact surfaces, sensors must be attached to the tool and have presence at such particular location. Some of the conditions at the interface are complex or severe for the use of sensitive devices, for example the application of lubricants and heat, the presence of scale, and material shearing actions are some of the elements that could seriously affect the measurements.

2.1. Sensitive Pins

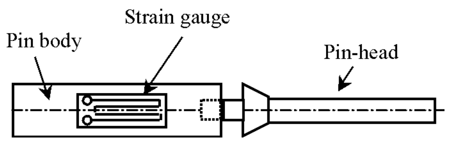

Figure 1. Sensitive pin typical construction

One of the methods that showed some resilience to surface conditions is the use of the sensitive pressure pins. They are made of similar material to that of the tool, therefore they could be considered as part of the tool. Figure 1 shows the shape and construction of a typical sensitive pressure pin. Because of its small size and its deformation characteristics, being similar to the tool, its presence is always assumed not to affect the measurements or the deformation process. The pin-head transmits the load to the main body of the pin, which contains a load cell. Strain gauge bridge or small commercial load cells are commonly used with such pins. The load cell may be insulated from the pin head by introducing a layer of low thermal conductivity material, such as Zirconia, between the two parts.

3. A NEW STRATEGY FOR MEASUREMENTS OF TOOL STRESSES

Figure 2 shows the construction of a two-die system where the pin-head is embedded and concealed inside the forming tool. For this designs, the pin is made from harden tool steel with 2mm diameter pin-head and positioned 1 mm below the contact surface. Therefore, temperature, lubrication and scale will have diminishing effects on the measurements. The stress at the interface may be composed of the vertical component, that is normal to the interface and the horizontal component acting along and parallel to the surface of contact; it may be expressed as ‘friction stress’. Using a die with oblique pins, the two components can be evaluated as a function of the oblique angle α, as shown in Figure 3. For this work two inclined pins are used and positioned at *45*^{0} and *30*^{0} degrees with the vertical. The forces, *F1 & F2*, acting on a two pins system, may be expressed as shown in Figure 3

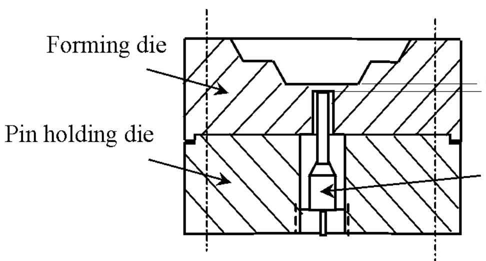

Figure 2. Two-die system

$$\begin{cases} Pin1 \Rightarrow F_1 = A(P\cos\alpha_1 + \tau\,\sin\alpha_1) \\ Pin2 \Rightarrow F_2 = A(P\cos\alpha_2 + \tau\,\sin\alpha_2) \end{cases}$$

Where,
A : Contact area of the pin head
P : Vertical pressure component
τ : Shear/Friction component
α : Pin angle with the vertical

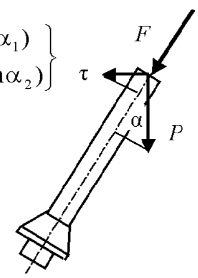

Figure 3. Forces on Pin-head

4. EXPERIMENTAL RESULTS

The new two-die arrangement design, where the pins are split between the industrial and measuring dies, were used to compress, under dry conditions, soft commercial 99.5% purity aluminium. Cylindrical specimens of 25 mm diameter and 30 mm height were used in all experiments. The material yield strength was found to be 100 MPa. The position of the pins is fixed inside the tool and therefore the stress distribution across the interface with the billet is obtained by using several billets. When inclined pins were used flush to the contact surface [5], an anti-rotation mechanism was fitted to the pin column to prevent the pin elliptical cross sectional area from being locked with the die surface. Such complication has been eliminated in the two-die arrangement where the pin-head is not subjected to any rotational force. The calibration of pins was carried out by applying different loads to dies that were perfectly closed on a thin disk of aluminium. Also, a comparison has been performed between the load applied by the press and the total load obtained from the measured local distribution of normal tool stresses to ensure comparability, sensitivity and conformity of the pin calibration.

Using the die with oblique pins, billets were compressed with load of 400kN to reduce them to approximately 8mm in height. Eight billets were used for the measurement of local stress distribution across the deformed billets.

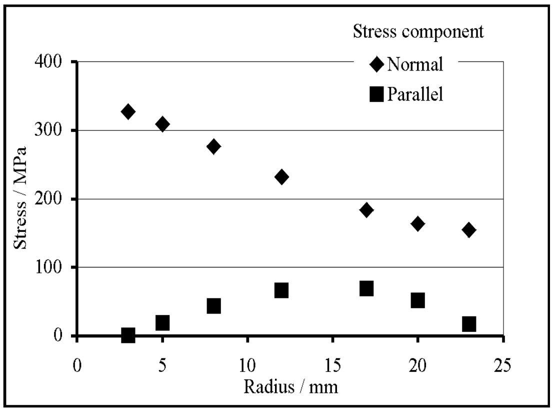

Figure 4. Stress component from angled pins

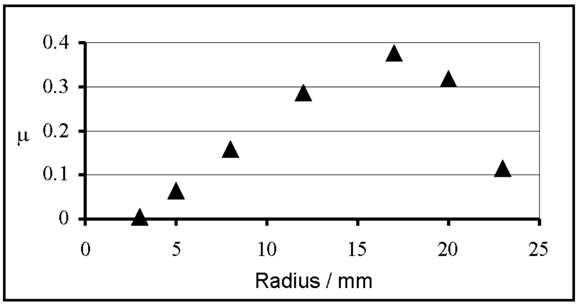

Figure 5. Distribution of friction coefficient

Figure 4 shows the distribution of the two components of stress at the interface. The normal pressure curve exhibits increasing values from the centre of the billet and lower values near the end of the billet. In particular, the pressure value measured near the external radius is close to the material yield stress, this is in agreement with the Tresca criterion [6]. On the other hand, the parallel/friction stress distribution shows a low value, near to zero, in the vicinity of the billet centre. The normal and parallel measured components of stress given in Figure 4 were used to evaluate the coefficient of friction. Figure 5 shows the variation of the coefficient of friction across the surface of the billet. It steadily increases, reaching a peak near $\mu = 0.4$ then decreases towards the end of the billet.

Figure 6 shows a comparison of the measurements of the normal pressure distribution, using the vertical pins, at an early stage of the process (20mm billet height), and at the end of the process (8mm billet height). The figure also includes the results of the oblique pins and the theoretical distribution of the normal component of stress, calculated by the classical slab method [6] using 0.2 as friction coefficient.

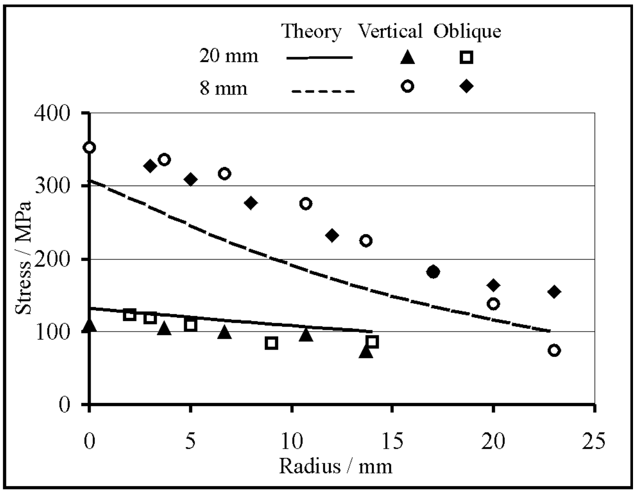

Figure 6. Tool normal stresses oblique/vertical pins and theory comparison

Knowledge of the state of stress and the shape of the friction function at the interface is of significance in many material forming processes. Also, it could be combined with analysis to give better prediction of metal flow, tool stresses and assist in the tool design process.

5. CONCLUSIONS

A new die design methodology, incorporating embedded sensitive pressure pins was introduced. The method provides a set up where industrial dies could be used within laboratory conditions to evaluate contact stresses at the interface between the tool and the deforming material. Experiments showed and demonstrated that friction varies along the tool material interface.

The normal stress component was compared with the results obtained from the classical slab method of analysis, the comparison was favourable but it was noted that the slab method employs a constant friction coefficient and has many limitations. It is therefore concluded that this technique is capable of providing experimental data for the simulation of complex metal forming operations for practical use and under industrial conditions.

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