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Forming single and double-flange components using differential heating

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Abstract: A non-traditional material deformation method is introduced as an alternative approach to the production of parts of complex geometries. The deformation mechanism, which relies on selectively increased metal flow in locally heated regions, gives advantages to part strength and fatigue properties. Compared to closed-die forging, the reduction of heating and loading requirements has a positive effect on tool life, tool design and loading requirements. Furthermore, the method can be applied to near-net-shape production in an open-die forging environment, thus reducing the cost of the production forming dies. The work presented in this paper examines the effects of heating duration, compressed profile, and the number of forming steps on the mode of deformation. A simulation model of the differential heating forming process has been characterised, and a Finite Element Analysis was performed using various operational parameters.

Keywords: Metal Forming, Local Heating, Induction Heating, Finite Element Analysis

1. INTRODUCTION

The general methodology described by the term differential heating is to control free metal flow by selective application of heat to the workpiece at locations where deformation is desirable [1,2]. When a billet is locally heated, a temperature gradient is induced within the billet volume, with the yield stress decreasing the higher the temperature. When load is then applied, material flow becomes predominant inside the heated regions, whilst very little deformation takes place near the tool material interface. Since this localised deformation is achieved under conditions of free metal flow, the loading requirement is considerably decreased. Therefore, the dies are subjected to reduced frictional contact and thus to low stresses. Also, flat dies can be used for the production of various shapes and profiles, hence considerable saving in tool cost and reduction in lead time can be achieved.

Combination of cold and hot forming processes were applied to increase the deformation at selected bulk sections of the billet [3]. The process of local heating has been used for the production of tapered pipes [4], and laser bending of plates [5]. Preliminary Finite Element Analysis was constructed and applied to compressed billets that heated locally by an induction coil [6]. It was demonstrated that local heating could be modelled through the effect of heating on the material yield stress.

This paper presents the results of experimental and analytical research in the area of differential heating aided metal forming operations. Multiple sequential forming operations are conducted on cylindrical steel billets that were heated using an induction heater. Various profiles are produced at different locations of the billet. FEM simulations are also performed and their results are compared with those obtained from experiments.

2. PRACTICAL CONSIDERATIONS AND EXPERIMENTAL SET-UP

For the differential heating experiments, cylindrical steel billets (BS 970 230M07) of ∅25mm and 50mm height were used. Temperature distribution inside the billet, that would be generated by the heating method, is an important parameter for effecting the differential deformation throughout the billet. In this research a circular induction heater is used as a method of heating. Initial tests were conducted to obtain the time-dependent temperature distribution within a billet, as shown in Figure 1. The maximum temperature difference along the billet axis is approximately 470°C, that is the effective parameter that would enforce local deformation for this material.

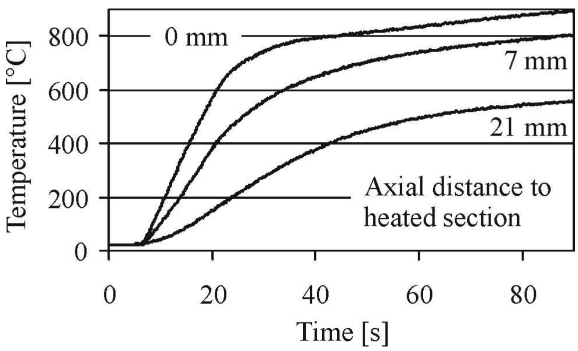

Figure 1. Temperature distribution inside billet vs. heating time

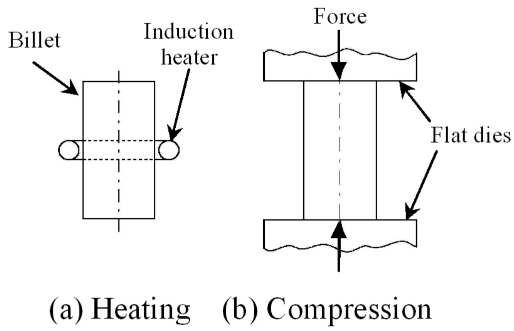

Figure 2. Experimental Set-up

Figure 2 shows the induction heating method and the loading method used through-out the experiments. Flat dies are used to effect the compressive load. Following the heating cycle, the billet is transferred to the press then compressed. It is evident that because the heating is axially symmetrical around the billet, the deformation will take place forming a flange type profile around the circumference of the billet. Instantaneous compressive force and die displacement are measured using a calibrated load cell and a height gauge respectively. The results are recorded by a data acquisition computer system attached to the press.

3. HEATING-COMPRESSION CYCLES

The deformation pattern produced by the heating-compression sequence and following the principle of differential heating, the maximum flow should occur at the surface with the highest temperature. Duration of heating and retention of differential heating profile through processing are utilised through three experimental programmes.

In order to examine material flow against heating time, billets were heated to different durations of 20, 25 and 30 seconds respectively, and compressed by 10mm. The heating-compression cycle was effected on one end of the billet, then repeated to the other end of the billet. The 25s heating experiment turned out to produce the most distinct bulge profile. This time was then taken as the optimum heating time under the current experimental conditions. However, it is also evident from Figure 1, that the rate of increase in surface temperature reduced considerably beyond 25s. The deformation at both ends in each billet are very comparable.

Relationship between compression stroke and deformation was investigated in four experiments. These were carried out sequentially on both ends of billets, as described in previous section but with the press stroke set to values of 5 mm, 10 mm, 12.5 mm and 15 mm respectively, for each end. Figure 3 shows the deformed billets. For the 5 mm and 10 mm compression strokes, billets exhibited almost identical deformation pattern at both ends. At 12.5 mm height reduction, the bottom flange is slightly larger in diameter than the top one. During the second 15 mm compression, the first deformed top bulge seemed to have acted as a punch penetrating through the bottom bulge. Hence, it could be seen that the billet length could be a limitation for applying a comparatively large displacement.

Figure 3. Double compression with different compression stroke

Figure 4. Billets formed with different forming step: 1, 2, and 4 strokes

Forming sequence showed that when billets were subjected to a total height reduction of 20mm, differential heating between steps has been essential. Single step, two steps of 10mm each and four steps of 5mm were employed on the billets shown in Figure 4. It is observed that the more the deformation steps, the less the deformation in the heated zone, and the transition between the heated part and the rest of the billet is much smoother the higher the number of deformation steps. This has been quite significant in the four steps specimen. After three deformation steps, it was concluded that the bulge is too wide to sustain heating of the billet top section by the same induction coil.

4. FINITE ELEMENT SIMULATION

Numerical Analysis has been applied to modelling differential heating by means of the Finite Element Method. Advantage of the geometric and loading symmetry of the forming process has been taken into consideration by modelling only a quarter system. Suitable element types were chosen to account for the rigid behaviour of the die material and the non-linear behaviour of the billet material. The friction factor (m) for the contact between the billet and dies was determined from experimental data and preliminary numerical runs as $m = 0.2$.

The temperature gradient within the workpiece was modelled by dividing the billet along its length into five cylindrical sections, with increasing mesh density towards the sections of anticipated deformation. Different temperatures, obtained from the experimental temperature distribution, were applied, as body loads, to these sections. The material properties were modelled as temperature dependent so that the effect of the temperature gradient on the yield stress is enforced throughout the solution.

The simulation results for the top heated billet show that deformation is greater in the heated region than that in the unheated region, as shown in Figure 5. Comparison between the FEM and experimental results in a diameter-height diagram is given in Figure 6.

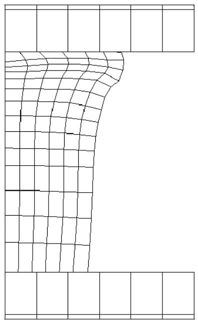

Figure 5. Finite Element deformation pattern on meridian plane and experimental profiles

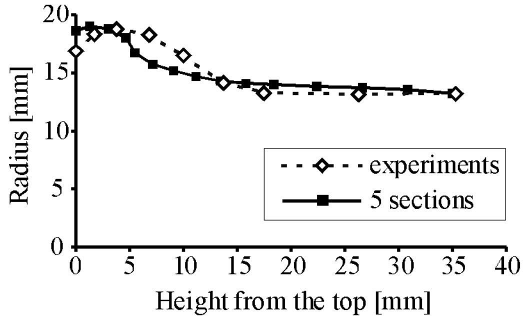

Figure 6. Comparison between FEM

The maximum diameter measured experimentally is similar to that predicted by the Finite Element Analysis. However, it is marginally offset from the top surface of the billet in the axial direction. This could be due to cooling at the billet tool interface, and a maximum heating effect slightly below the top surface of the billet. The increased flow stress caused by this has not been considered in the simulation. This is also evident when comparing the experimental loading requirement, 343kN, to the theoretical FEM result of 299kN.

5. CONCLUSIONS

Thermal differential flat-die forging has been demonstrated to provide a viable method of producing profiled parts. Shaft-flange type geometries are readily produced by this method if sufficient temperature gradient is maintained. Experiments showed that local deformation could be promoted and increased by multiple- stroke operations. More and accurate control of processing parameters e.g. heating time, heat energy, speed of deformation would make the process potentially attractive for the production of near net shape parts. For example laser heating could provide improvement to heat control with respect to positioning and intensity. FEM simulations were also carried out and results were found very comparable to those obtained from experiments. The research carried out in this paper provides the basis for the use of local heating to produce controlled free deformation by simple processing.

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