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Experimental and Numerical Analysis of Side Forces in a Forging Die

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Though hot forging dies are subject mostly to forces acting in the direction of moving tool/slider, some side forces are also developed in the die cavity according to the flow of material in various directions. These forces would be relatively high especially in the cases of non-axisymmetrical or extended forgings what could result in an offset of upper and lower dies causing geometrical inaccuracy of the forging. This paper presents two ways of determining side forces by means of numerical and physical modeling. Two industrial forging processes for the bracket lever and the valve lever were chosen for the analysis. As the result, values and directions of side forces from the beginning up to the end of deformation stage were obtained. Hence some changes in die design or process stages which would minimize the influence of side forces on geometrical inaccuracy of forgings could be introduced. As an example, some ways to minimize the side forces by changing the inclination of parting surface (bracket lever forging) or changing the positioning of perform (valve lever forging) were shown.

Keywords: forging, forging dies, geometrical inaccuracies, numerical modeling, physical modeling

0 INTRODUCTION

Hot forging has been regarded as one of the main processing techniques due to high productivity and possibility of getting high deformation combined with very good mechanical properties of products. However, a competition from the other techniques has been quite severe and new developments in hot forging are still very crucial. In spite of organizational changes and automatization of processes, further developments in hot forging have been connected mainly with an increase of geometrical accuracy of forgings and with approaching at least a near-net shape in the as-forged condition [1] to [4]. The savings obtained by the reduction of machining allowances and machining operations can be quite substantial. What more, mechanical properties of a precision forging are usually superior to those of a forging subjected to extensive machining. This is because the forged microstructure is preserved intact in the precision forging and the fibre orientation is not disrupted.

Geometrical inaccuracies of forging may be affected by the design of the as-forged product, the process planning and practice of the operational sequence, the properties of the stock material and billet, the lubricant and control of lubrication, the tool and machine, precision of the set-up, control of working temperature, the finish machining and heat treatment. Precision forging is the closed die or fleshless forging. Relatively high geometrical accuracy of forgings could be obtained also by means of hot forging with a flesh. However, it requires an optimization of tool design and tool loading. In this paper some tooling design considerations will be taken into account in order to minimize side movement of the different parts of die and hence to minimize geometrical inaccuracy of forging.

Fast development of computer methods and computer software has been very important in realistic modelling of forging processes. Many features of the forging process have already been covered. There are still some of them, such as inter-stage heat treatment or post-process thermal behaviour, which have received little attention [5]. However, detailed modelling of the forging process sequences and deformation conditions would provide a possibility to control heat exchange and changes in mechanical and physical properties of deformed material as well as to control exactly a flow of metal and tool loading conditions. This leads, for example, to exact determination of deformation force components including side (or

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lateral) forces in the forging die [6] and [7]. Side forces are relatively high in production of non-axisymmetrical or extended forgings what results in an offset of the upper and lower dies. This offset introduces geometrical inaccuracies into forgings or increased wear of some parts of die cavity.

There are many well known ways to prevent sideways movement of the different parts of die caused by side components of force [8] and [9]:

- If possible, the parting line should be in the same plane as the forging plane, at a right angle to the direction of deformation; this simple way works well mainly for axisymmetrical impressions.
- The impression must be cut in the die block in such a way that the parting line takes into account local differences in slope angle to the forging plane in order to compensate side component of force.
- Forging of components in pairs in order to achieve symmetry.
- Side lock – step to counterbalance side forces.
- Guiding of forging dies, common in close-die forging, with cylindrical guideways, guide pins and lateral or corner guides.

Most of the above mentioned methods complicate the design of forging tools and increase cost of the tools. For that reason application of any method must be carefully considered. So far, special experience and know-how have usually been crucial for such a tool designing. Generally, determination of directions and values of the side forces would be very helpful in the design procedure. This paper presents two ways of determining side forces by means of numerical and physical modeling. Two industrial forging processes for the bracket lever and the valve lever were chosen for the analysis.

1 FORGING OF BRACKET LEVER

1.1 Numerical Modeling

MSC/SuperForge software based on finite volume method has been used in numerical modeling of the processes. Geometrical models were prepared by means of Solid Works software. The dies were assumed as stiff bodies. Combined thermo-mechanical numerical analysis has taken into account all stages and blows of the forging processes. Geometrical changes, residual stress and temperature fields have been imported for all subsequent stages.

The forging of the bracket lever, shown in Figure 1, was performed on a crank forging press. The lever was made of medium carbon dispersion hardening ferritic-pearlitic steel. In industrial practice, this bracket has been forged in several steps from a round bar of 20 mm in diameter.

In this paper, only the operation in the final impression has been examined. The inclination α of parting surface of lower and upper dies corresponding to 0, 10, 20, 30 an 40 degrees was a variable for the analysis of forging in the final impression (Fig. 2). Initial temperature of the workpiece was 1100 °C and the dies were preheated to 300 °C. Friction conditions were defined by Coulomb's law with friction coefficient 0.1.

A change in the inclination α of the main part of parting surface from 0 to 40 degrees resulted in changes in the maximum side force X (direction x – Fig.2) as shown in Figure 3. Calculated force components were presented as relative values, i.e. the maximum values of side force X and forging force Z found for the inclination α=20 degrees were assumed as 100%. It should be pointed out that the

Fig. 1. *Bracket lever*

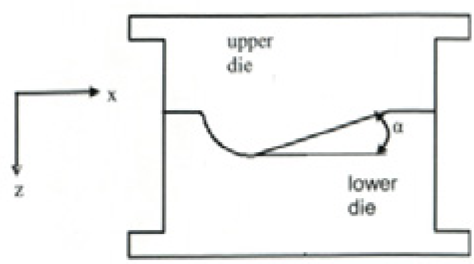

Fig. 2. *Schematic presentation of bracket lever forging dies; α - the inclination of parting surface*

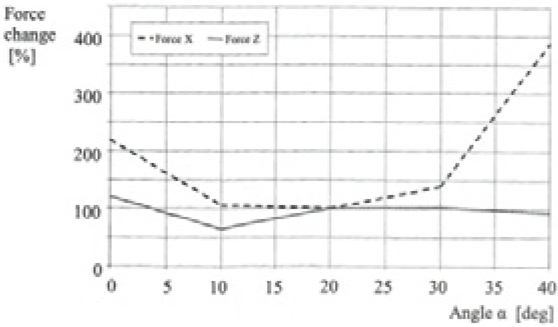

Fig. 3. *Influence of parting surface inclination on changes (%) in maximum values of side X and vertical Z forces (forging of bracket lever)*

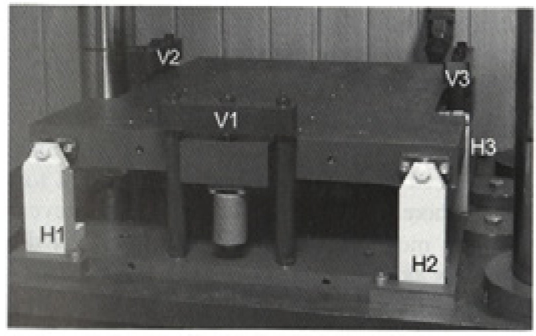

Fig. 4. *6-axis force transducer with vertical and horizontal supporting elements*

smallest side force X has been just for this angle. Values of the angle α lower or higher than 20 degrees caused considerable increase of X. On the other hand, the forging force Z was the smallest for α=10 degrees. Generally, the values of side force X were equal to about 10% of the values of forging force Z. These calculated data open the possibility to design tools in a proper way. For example, if a side force X should be as small as possible then the inclination of parting surface would be about 20 degrees. If both forces X and Z should be as small as possible than α=10 degrees would be the best solution.

1.2 Physical Modeling

It has been essential to validate the results of numerical simulations and to get greater confidence in the application of side forces analysis. As for hot forging, physical modeling has been a valuable alternative to numerical modeling [10] to [14]. Physical modeling based on wax is faster, easier and less expensive than a subscale production process. To take all the advantages of using physical modeling, the modeling press and 6-axis force transducer have been used. The modeling press is very stiff in both lateral and angular directions. Its elastic deflections do not influence the material flow. The 6-axis force transducer consists of the upper and lower plates (Fig. 4). The transducer is mounted to the base plate of the press and the modeling tool is located on the upper plate of transducer (Fig. 5). The upper plate of the transducer is supported vertically by three carrying elements V1, V2, V3 and the other three elements support the plate horizontally – H1, H2, H3. Hence, the vertical force Z loads mainly the vertical carrying elements whereas the side forces X and Y

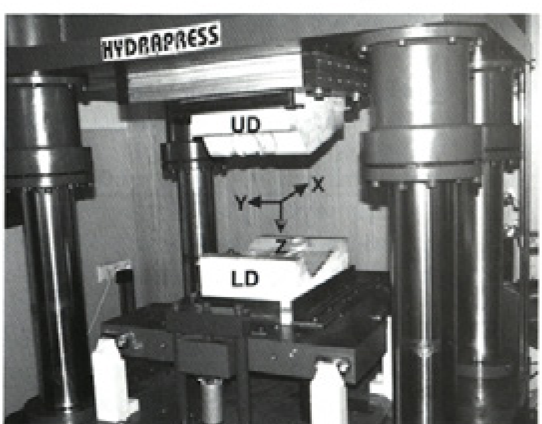

Fig. 5. *Upper die (UD) and lower die (LD) arrangements on the modeling press*

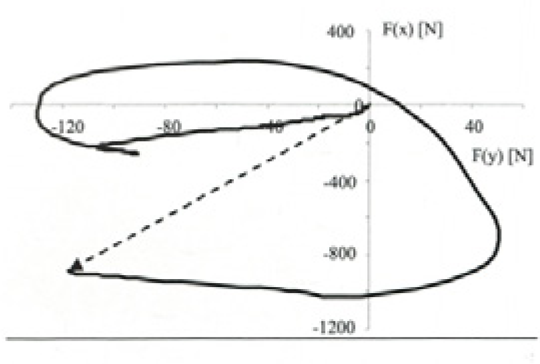

Fig.6. *History of changes in side forces X and Y as a result of physical modeling; parting surface inclination 20 degrees*

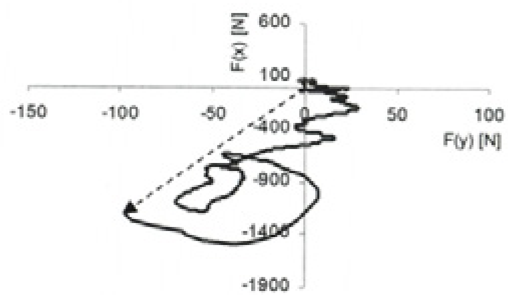

Fig. 7. *History of changes in side forces X and Y as a result of numerical modeling; parting surface inclination 20 degrees, material for physical modeling*

load the horizontal carrying elements. Upper and lower dies for physical modeling of bracket lever forging were made of tool resin. Preforms were made of wax composition for which a shape of stress-strain curve was in a reasonable agreement with the curve for the real material. During deformation of preform between upper and lower dies, vertical Z as well as side X and Y forces were measured. Side force X has been much higher than side force Y.

The history of changes in side forces X and Y is shown in Figure 6. It is presented in a form of changes in resulting side force in order to point out the direction and value of the force from the beginning up to the end of deformation. Broken line shows the resulting side force just at the end of forging. It has changed the direction over 300 degrees during the whole forging process. Hence, the side lock design in the die should counterbalance the side force from different directions. The results shown in Figure 6 were in a quite good agreement with the results of numerical simulation carried out for modeling material (Fig. 7). The direction of the final resulting side force is almost the same as in physical

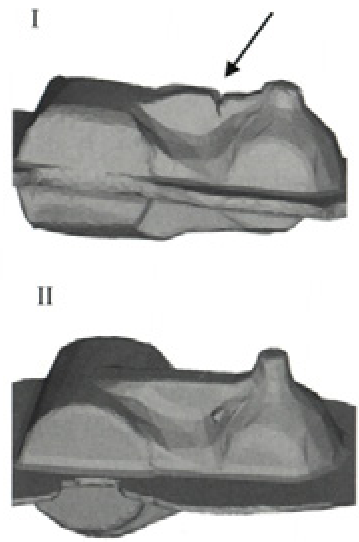

Fig. 9. *A forging with overlapping (case I) and a forging without any defect (case II)*

modeling. There are some differences between these two curves in the initial stage of deformation when the forces are relatively small. It could be caused by slight differences in placement of preforms and friction conditions.

2 FORGING OF VALVE LEVER

Forging process of valve lever was analysed by means of results of numerical modeling. The process was performed on a forging hammer. Initial temperature of preform was 1100 °C and the dies were preheated to 250 °C.

The upper and the lower dies were designed as to have fuller, blocker and finisher impressions (Fig.8). The full process consisted of the following stages:

- Initial upsetting (1 blow),
- Fullering (2 blows),

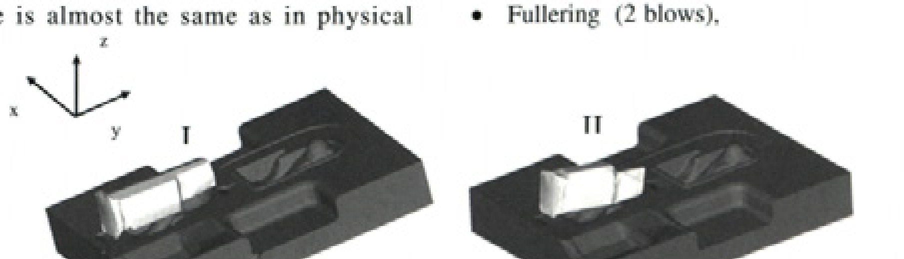

Fig. 8. *Pre-forms placed in the blocker impressions of the lower dies for forging of valve levers (case I and II)*

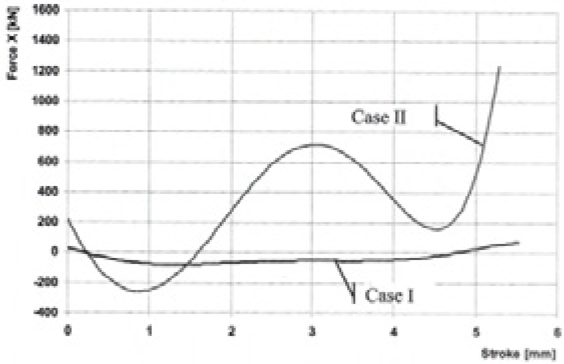

Fig.10. *Changes of the lateral force in X direction for two cases of preform orientation*

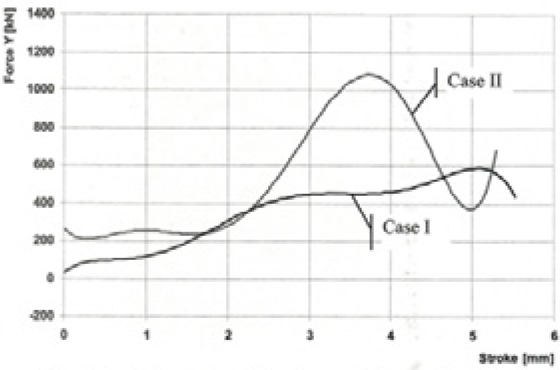

Fig.11. *Changes of the lateral force in Y direction for two cases of preform orientation*

- 90^0 counter-clockwise (case I) or clockwise (case II) rotation of preform and additional fullering (2 blows),
- Forging in the blocker impression to get the general final shape (3 blows),
- Forging in finisher impression to get the final overall shape (1 blow).

As an example, forging in the blocker impression has been chosen for analysis [7]. As in the case of bracket lever modeling, all of the previous stages and number of blows were taken into account during numerical simulation. Geometrical changes and temperature fields have been imported for all subsequent stages. The forging obtained after deformation of preform characterized by case I showed a forging defect in the form of overlapping (Fig. 9). As for the case II,

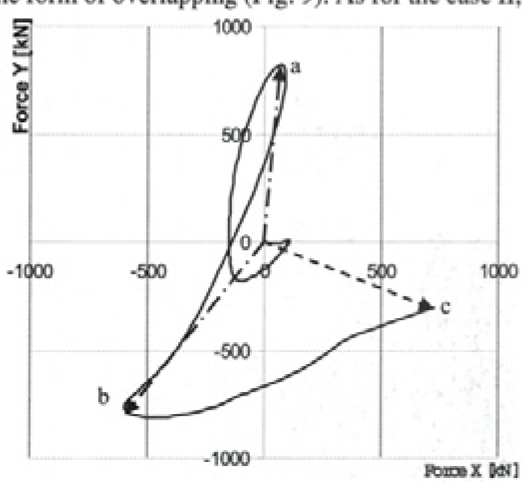

Fig.12. *History of changes in side forces X and Y in finisher impression of die (case II); a,b,c – high values of the resultant side forces at different stages of the forging process*

the forging did not show any defect. Figures 10 and 11 present changes in lateral forces X and Y as a function of upper die stroke (third blow). The lateral forces have been much smaller for the case I than for the case II. It means that the necessity to change the preform positioning for getting the forging without overlapping lead to a considerable increase in values of lateral forces (case II). What more, the directions of the highest resulting side forces were different during the course of the process as shown in Figure 12 for the finisher impression (case II). It means that the guiding of the upper and lower dies is necessary in the analysed forging process for getting a high geometrical accuracy of forgings.

3 CONCLUSIONS

- There are many ways to prevent sideways movement of upper and lower dies caused by side forces. Choice of the way would be supported by the results of numerical modeling.
- Numerical modeling of the bracket lever forging for various inclinations of the parting surface has been helpful in minimizing the lateral force. The lowest values of lateral force and forging forces have been found for the inclination angle of about 10 degrees.
- The results of bracket lever numerical modeling have been in a good agreement with the results of physical modeling. Hence, a method of numerical modeling with taking into account all stages of forging process and changes in physical and mechanical properties of deformed bodies has been a valuable tool for finding force components, including side ones.

- Necessity to avoid the overlapping defects in valve lever forging resulted in a considerable increase in values of lateral forces.
- The ratio of lateral to vertical forces was up to about 10% in the two forging processes analyzed in this paper.

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