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NUMERICAL AND EXPERIMENTAL INVESTIGATION OF FORGING PROCESS OF A CV JOINT OUTER RACE

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ABSTRACT

A constant velocity joint is an important load-supporting part in cars. Its geometry is very complicated and its required precision is high. Traditional hot and cold forging methods have their own limitations to produce such a complex shaped part; precision hot forging is exceedingly complex with many variables while cold forging is not applicable to materials with limited formability. Therefore, multistage forging may be advantageous to produce complex shaped parts. An actual problem in ironing sequence is the prevention of ductile damage and surface defects in final product. A damage criterion was applied to final ironing sequence and physical modeling is down using lead, in order to guarantee continuous quality of the specimen and to avoid possible damage on the forged parts.

KEYWORDS: *Outer race, Multistage forging, Damage modeling, Physical modeling*

1. INTRODUCTION

Much progress in forging technology including low production cost and fast production has allowed an intensive use of forging [1]. Manufacturing companies have especially focused on producing a complex shaped part with a tight dimensional tolerance and without the occurrence of a defect. Traditional hot and cold forging methods have their own limitations to produce such a complex shaped part; precision hot forging requires complex system with relatively higher manufacturing cost and special heat treatment, while cold forging is not applicable to materials with limited formability [1],[2]. Therefore, multistage forging may be advantageous to produce complex shaped parts. The multistage forging process makes it possible to produce net-shape products without intense machining after forming. However, great efforts in designing and analysis a delicate process sequence are needed in multistage forging of the net-shape products. An actual problem in this process is the possibility of damage occurrence in ironing sequences (at low temperature). Prediction of these defects can help manufacturer to achieve suitable tooling design and improve quality of the product. To successfully predict the occurrence of the ductile fracture, the theoretical failure criteria are important tools to be used in conjunction with practical experiments [3]

In this study, the process sequence in the near net shape forging of a CV joint outer race has been investigated by using the rigid plastic finite volume method and forging process sequence is designed which can produce a near net-shape housing without defects within a given press capacity. In order to guarantee continuous quality of the specimen and to avoid possible damage on the forged parts damage modeling has been done by using DEFORM 3D with Cockroft & Latham failure criterion. Finally physical modeling with lead is used to verify the reliability of numerical simulation results and predict the possibility of defect formation and to modify design of dies and pre-forms.

2. PROCESS DESCRIPTION AND FVM MODELING

Figure 1 schematically shows the suggested multistage forging for a CV joint outer race.

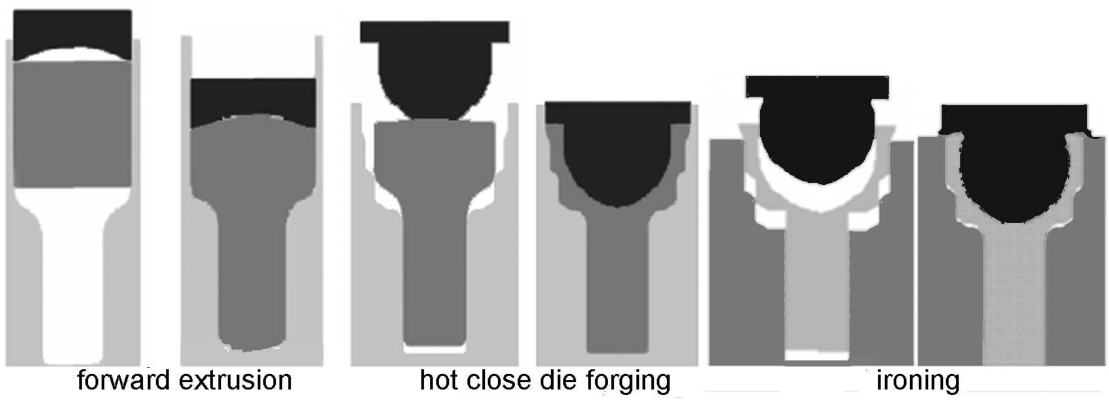

Figure 1. schematically shows the suggested multistage forging for a CV joint outer race

First process starts with the fast heating. The billet should be heated up to the forging temperature as fast as possible. In most cases, induction or resistance heating can best accomplish rapid heating. The billet should not be kept for a long time at this temperature. Protective atmosphere and protective coatings are also useful in preventing scale [2]. After heating the cylindrical billet is extruded forwards to form a shaft. In the second operation the head is compressed to form a flange with a radius approaching the outer diameter of the cup and then backward extrusion is started by closed die forging. During the operation, the flow stress of the material becomes large and a great deal of compressive stress is applied to the tools.

Usually an ironing operation with axial bending is carried out as the last operation so after cooling the third operation of ironing is performed [4]. The material flow during forging of the CV joint outer race is not axisymmetric after forward extrusion sequence. So the 3D finite volume model for forging simulation of the Outer race consists of work piece, punch, die, is performed. The process was simulated under the conditions shown in Table 1.

Table 1: process condition

Operation	Close die forging	ironing
Material	AISI1060	AISI1060
Velocity of punch	360	100
Temperature	1050-1100	27
Friction	.25	.1
Die material	H11	D2

2.1. PROCESS SIMULATION

The main objective of the process sequence design in this study is to obtain intermediate pre-forms which produce a near net shape product. Also design conditions, such as the limit of the press capacity and the avoidance of surface cracking and ductile fracture occurring, should be satisfied. The first operation shown in figure 2. is forward extrusion to form the shaft of the CV joint outer race. The plastic strain and effective stress at the end of sequence is shown in this figure. The reduction of area in the extrusion is 50%.

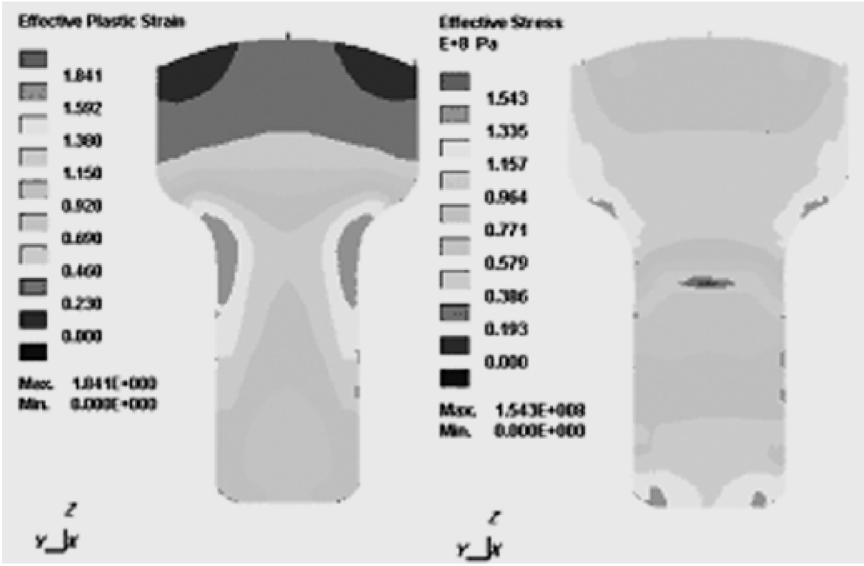

Figure 2. Effective plastic strain and stress at the end forward extrusion sequence

Complete filling in first sequence is not required. A small cavity appears at the corner between lower die and end of the part and the maximum extrusion load reached 220 tones that is shown in figure 3.

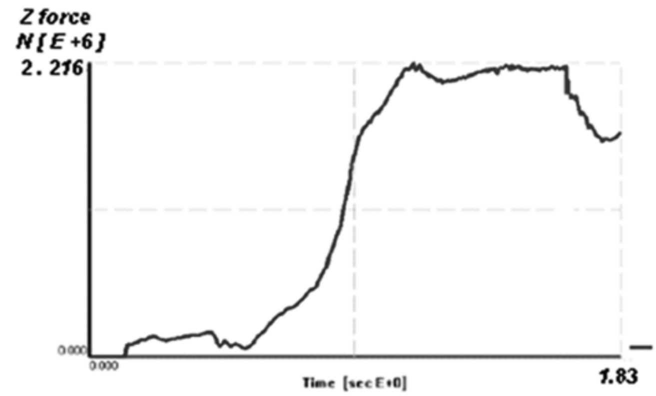

Figure 3. load diagram of first sequence

The simulation results for the second operation are shown in Figure 4 It is a closed die forging, and combines upsetting with the conventional backward extrusion. Figure 4 shows the effective stress at a punch stroke of 50% and at the end of the second operation.

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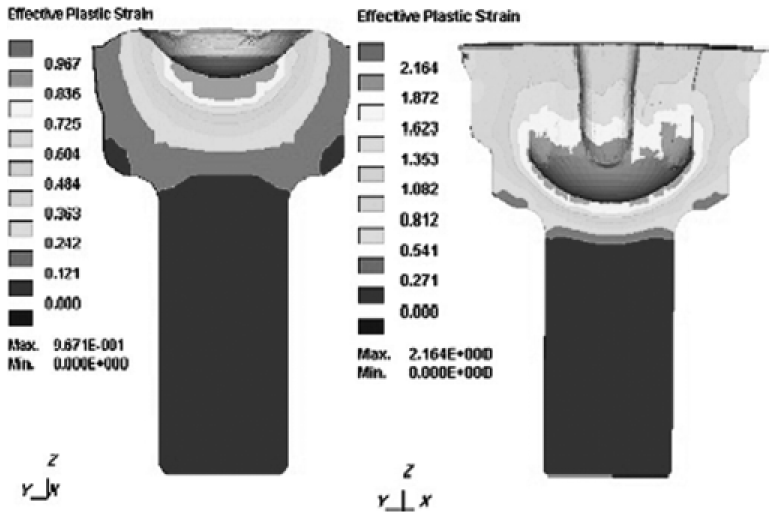

Figure 4. effective plastic strain in 50% of course and at the end of deformation

The pre-form obtained from the second operation is assumed to be satisfactory as preparation for the next operation. The high value of effective strain near to the punch tip reflects severe plastic deformation as shown in Figure 4. The maximum effective strain in Figure 4 is 2.164. The maximum forging load is 830 tonnes that is shown in figure 5. In this operation, the dies should be designed carefully, since the backward extrusion process affects, directly, the precision forming of the final product. After close die forging sequence, cooling is needed. Scale formation during the cooling process can be reduced with suitable atmosphere and accelerated cooling [3].

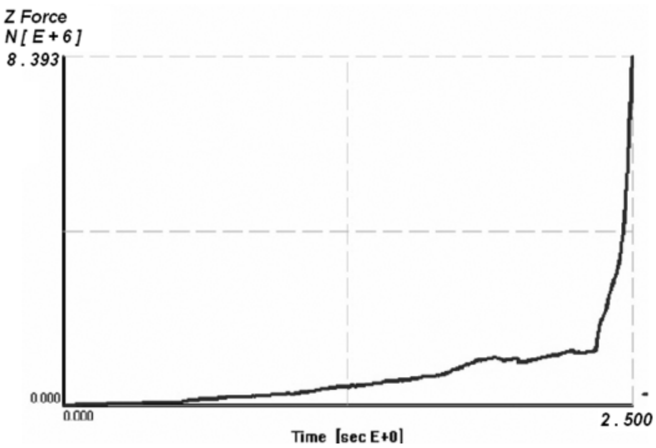

Figure 5. Load curve of close die forging

Last operation is an ironing process. Figure 6 shows the die configuration designed and plastic strain of the following ironing process .The ironing process maximum forging load is 600 tones. The maximum effective strain reaches 0.22 in this sequence.

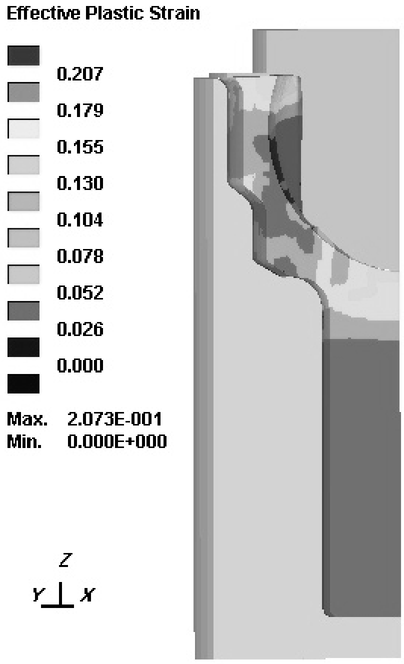

Figure 6. Configuration of tooling in ironing and effective plastic strain at the end of process

An attempt has been made to produce near net shape products without surface defects and other damages in internal critical regions of specimen after ironing sequence. A Cockroft&Latham failure criterion is used to model ductile fracture occurrence of specimen after cold forging. Upsetting of cylinder is the simplest and the most widely used tool for workability test and defining threshold values for failure criteria [3]. In this study, threshold value of criteria is archived from published information of upsetting of AISI1060 steel. Cockcroft and Latham's criterion states that fracture will occur when the cumulative energy due to the maximum tensile stress exceeds a certain value. This criterion has provided good agreement at predicting the location of a tensile failure based on a maximum damage value. The model is based on the equation:

$$\frac{1}{\sigma_y}\int_0^{\bar{\varepsilon}_f}\sigma_1 d\bar{\varepsilon} = C$$

Where σ_y is the yield stress of material and σ_1 is maximum principal stress and dε is incremental effective strain and C is threshold value of the criterion at the instant of fracture initiation [3]. The steps offered to avoid possible damage on the forged parts after dies and process stages design are schematically illustrated in Figure 7

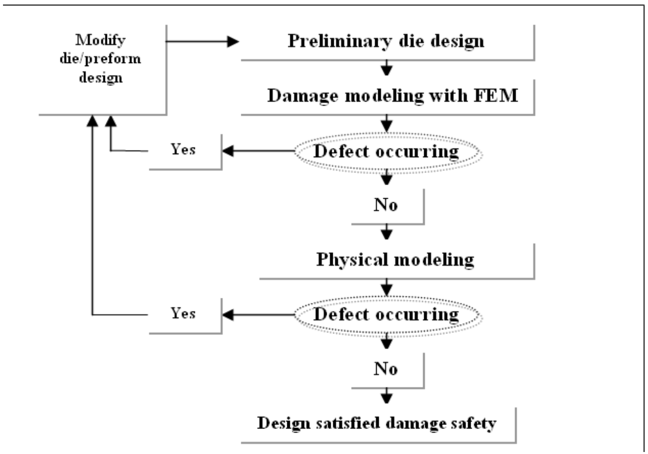

Figure 7. The steps offered to avoid possible damage on the forged parts.

The failure criteria were incorporated into DEFORM 3D. The distribution of defects in work piece is achieved by DEFORM 3D for this criteria. Figure 8 shows defects distribution at the end of ironing sequence. Damage value in internal regions of specimen is near 0 and the figure shows that maximum damage value is 0.3 near the flash .after ironing; this region will be machined and trimmed.

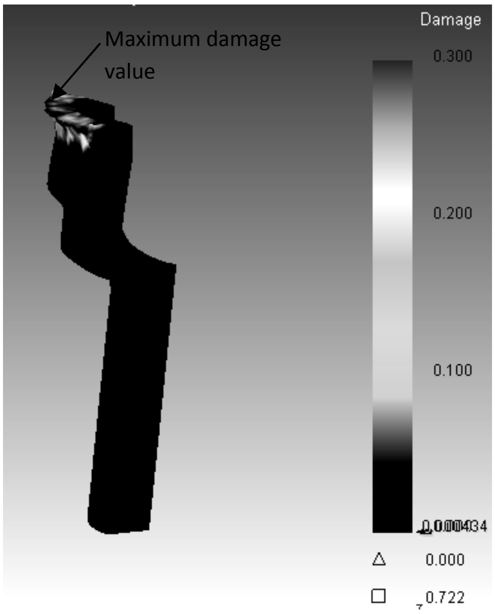

Figure 8. The regions that defects may occur according to damage modeling

3. PHYSICSL MODELING

In general physical modeling involves the use of model materials like lead, plasticine or wax, which can be deformed easily and could be used to study and predict the deformation of metals. Compared with a final trial, physical modeling is low in cost, and can be used to: test and verify the reliability of numerical simulation results and predict the possibility of defect formation; .Therefore, physical modeling has been widely applied to the field of plastic forming [5]-[7].

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To verifying simulation results and damage modeling, metal forming simulation was performed for commercial lead. The true stress–strain curves of the work metal is obtained using published information of compression tests in [8] The stress-strain equations for lead billet is:

$$\sigma = 38.964\,\varepsilon^{0.4358} \quad \text{[MPa]},$$

Figure 8 shows the final lead part after forging. physical modeling shows that ;There are not any ductile fracture and surface damage and other defects in internal regions of lead specimen. There are some wrinkle on the edge of specimen that is conform to damage modeling. The flash will be trimmed and this defect is not important.

Figure 9 shows another view of specimen. As seen in figure 9, there are some surface defects like lapping near the flash of specimen. This defect is occurred due to sever plastic deformation and bad flow pattern in this area. By changing geometry of last pre-form, this defect can be modified.

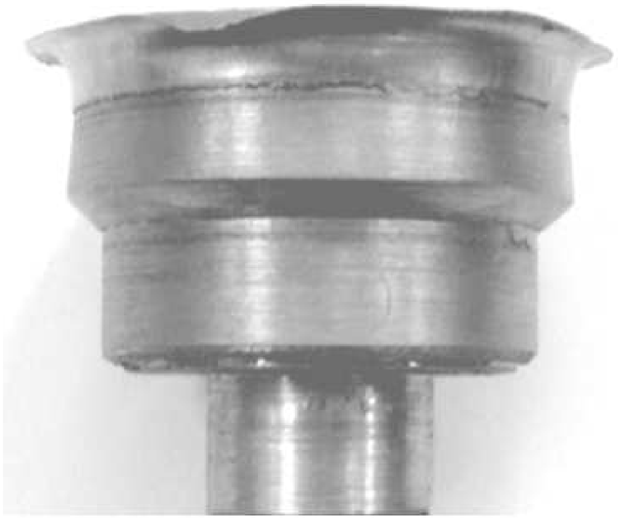

Figure 10 shows a lead specimen with different pre-form geometry and none of mentioned surface defects are seen after ironing.

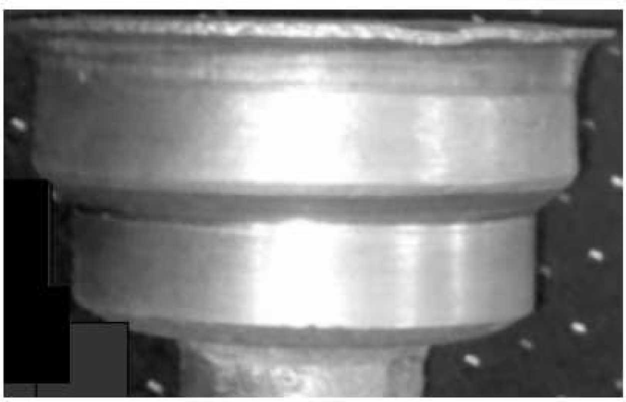

Figure 1. Avoidance of surface defects by modifying pre-form geometry

4. CONCOLUSION

In the study presented in this paper process analysis of multistage forging has been performed by FVM and damage modeling is done using DEFORM 3D software and physical modeling has been performed with lead alloy and following conclusions are obtained: Multistage forging process sequence has been analyzed by the rigid plastic finite volume method, solving actual problems such as damage occurring and surface defects after ironing sequence, the slope angle, and the press capacity. It has been shown that physical and numerical modeling is helpful in the current design practice of forging processes due to the following reasons:

Modifications to the tooling model (CAD design or soft tooling) are cheaper and less time consuming than modifications of the actual production tooling and equipment.

Physical modeling provides more information about the process like: damage occurring and surface defects and metal flow at different stages of the process.

Based on simulation and experiments; no ductile fracture and surface damage occurred in internal region of outer race.

Physical modeling and damage modeling with FEM have good conferment in predicting damage at the edge of flash in final specimen.

A systematic approach is offered for satisfying damage safety of final product.

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