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A PARAMETRIC ANALYSIS OF DEFORMATION OF WORKPIECE, IN CLOSED DIE FORGING

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ABSTRACT

Under filling and folding are two major defects, resulting in defective parts at the forging stage or failure during service life. Folding may act as a potential starting point, for crack initiation and under filled components are straight way rejected, being unusable for further processing. In the present work, an effort has been made to study the quality of forged, components by variation of billet shape, size, temperature and coefficient of friction. The output parameters observed and analyzed were normal stresses, shear stresses, effective stress, effective plastic strain, effective strain rate, die wear, load and material flow rate. It was observed that, homogeneity of deformation was higher in small parts with deep die cavity, compared to big parts. Round billet shape was found to be most suitable for reducing die wear, effective strain rate and increasing material flow rate. The flash allowance of 10% was sufficient, to fill the die cavity, completely without folding when a round billet of proper size was selected. The paper gives an insight, into the generic design of the forging process, which could help in optimizing the forging process in industry.

***KEYWORDS:** Simulation, Forging, Material Flow Rate & Flash*

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Original Article

INTRODUCTION

Defects in forged components may be detected at the forging/ machining stage, or may remain hidden and result, in component failure with the passage of time. Forged components are preferred for fatigue strength and toughness, and are used in critically loaded conditions. The failure of forged component, during machining operation may be caused, by crack propagation due to defects at forging stage. In addition, the inefficient die design and selection of input parameters can result in rejection of forging components, at forging stage itself. Correct die and process design, can aid in organizing the flow of metal, which may produce parts free from the defects of under filling and folding [17]. Being critically loaded parts, any potential crack initiation site can be very hazardous. So, the production of a defect free part is crucial. Folding, a very prominent defect in forging has been dealt by many researchers [8, 10], using various case studies like connecting rod [5, 9], and turbine blade [15]. Optimization of the forging process has also been done, using various objectives like energy efficiency [6, 7], forging of nano structured material [9], and bi-metal forging [14], shape optimization [2], metal flow kinematics [12, 13] and variable flash thickness [16]. Various techniques have been used like equivalent static loads method [2], stochastic analysis [1], Smooth Particle Hydrodynamics [3], Monte Carlo simulation [4], Grey based Taguchi method [9], quasi potential field and response surface design [11] and slab method [12]. In the literature, the metal flow has been identified, as an important factor which results in defective parts. The quantifiable relationship between the input parameters and metal flow rate is not reported. In the present work, an effort has been made to analyses and optimizes the metal flow rate in the forging process.

METHODOLOGY

The analysis of the forging process was carried out, through simulation in virtual environment, for three parts using data from the industry. The details of three parts are given in Table 1. Three input parameters viz. coefficient of friction, temperature of billet and billet size, varying at three levels were designed into set of 20 simulations, using Response Surface Method. These 20 simulations were carried out, with different billet shape and flash allowance, as given below in Table 2.

Table 2: Different Cases for Simulation

	Part 1	Part 2	Part 3
			
Weight (kg)	2.075	3.5	2.5
Shape complexity factor	S1	S1	S2
Drop hammer capacity (tonne)	1.5	3.5	1.5
Current flash allowance	16%	25%	16%

Case No.	Billet Shape	Flash Allowance
Case 1	Square	>10%
Case 2	Round	>10%
Case3	Square	10%
Case 4	Round	10%

RESULTS

The results from these four sets were compared for the three parts graphically, for complete die filling and folding defect. The quantitative results were observed for effective stress, effective plastic strain, effective strain rate, die wear, load and material flow rate. The effective stress and strain were used, for comparison of deformation with different billet sizes and shapes. The effective strain rate and material flow rate, was used to compare the homogeneity of deformation, and hence the metal flow. The 3 parts were analyzed, for the effect of change of billet shape/ size and other parameters on various responses. The details are given below.

Comparison of Deformation on the Basis of Billet Shape

The deformation of the billets was observed, by using the flow lines feature of Simufact. The part wise detail is given in Figure.1. Part 1 and 3 have deep die cavities, so the metal flow seems to be similar in both cases, when the billet shape is changed. The metal flow is mainly lateral with small square billet since, it gets placed inside the die cavity easily. The bigger square billet size has larger cross-section, which requires minimal lateral movement of material, to fill the die cavity completely with minimal blows. It can be observed that, there is more lateral movement of the material when round billet is used, because all three billet sizes get inside the die cavity, easily and the material flows, evenly in all the directions. For part 2, the cross-sectional area of die is large, which makes the lateral flow of material more prominent. Thus, the deformation with square and round billet shapes has not much difference, in the flow of the metal.

Comparison on The Basis of Flash Allowance

The results of reduced flash allowance are shown in Figure. 2. It was observed that, with the reduction of flash allowance, about 6% of the material was saved.

Graphical Results

The graphical results were checked for complete die, filling and folding defect. The quantitative results were used for comparison, between the deformation, using different billet sizes and shapes. The details for Figure 3, 4 and 5 are explained below.

Effective Plastic Strain and Effective Stress

The variation of effective plastic strain is found to be exceptionally less in parts 1 and 3, which indicates under filling defect. For part 1, when the square billet is used, the metal deforms easily into a hexagonal contour, while, the round billet has to undergo larger deformation, to get into that hexagonal contour, which increases the value of effective stress with the round billet. With the reduced volume of square billet, the peak values for effective stress correspond to under filling defect. Corresponding values of effective stress are very high, at the same points. For part 2, the variation is similar, but, there is no clear indication of under filling, in the given graphs. The effective stress decreases, when the volume of the billet is reduced, irrespective of the shape of the billet. It is because, lesser amount of material is to be handled, by the die cavity. The maximum value is observed, with the smaller billet because, it has to flow laterally to fill the die cavity.

Effective Strain Rate

For part 1 and 3, the square billet with large cross-section undergoes minimum deformation, with prominent metal movement in longitudinal direction, by shearing action and minimal in lateral direction, to fill the die cavity completely. Square billet was found to get deformed easily into hexagonal contour, than round billet, thus, reduces the variation of effective strain rate. On the other hand, the square billet smaller in cross-section requires a larger lateral flow of metal, to fill the die cavity which maximizes the variation. Maximum value implies less homogeneity in deformation. The variation of effective strain rate reduces, when flash allowance is reduced with both billet shapes. This implies that, the deformation becomes more homogenous when a lesser volume of material is to be managed, within the die cavity. The low values of effective strain rate, with square billet at 10% flash allowance, correspond to under filling defect. On the contrary, for part 2, the variation in effective plastic strain, increases when the volume of the billet is reduced. This is due to, unfilled die cavity, which is revealed by the graphical results. The same points correspond to large values of effective plastic strain, as well. However, the results are better when the round billet is used.

Material Flow Rate and Die Wear

The results clearly reveal that, the square billet requires minimal movement of material, to fill the die cavity, while round billet requires maximum movement of material. The movement of material is less at lower temperature and coefficient of friction and vice-versa. The very low values of material flow, rate with reduced volume of square billet, correspond to under filling defects. It is found that, the lower value dips significantly, when the flash allowance is reduced, because of the lesser volume of material that has to be managed, by the die cavity. The parts in which under filling is observed are having lower material flow rate, with square billet and 10% flash allowance. Corresponding die wear is also less, when the material flow rate is less.

Load

The square cross-section larger billet requires minimal force for deformation, while, and round billet of smaller cross-section requires maximum force. The minimal load dips significantly, when the volume of billet is reduced because, lesser volume of material is to be managed, by the die cavity. The dip in the values of load indicates underfilled parts. Load increases, when the temperature is low.

It can be observed that, for part 1, the under filling is obtained only, when square billet with 10% flash allowance is used. It is because; the billet material does not spread out evenly, due to the square shape. The under filling defect is indicated, by small values of effective plastic strain, high effective stress, low effective strain rate, low material flow rate and less load. There is no under filling with round billet at 10% flash allowance, most cases of defect free part are obtained, with this case.

CONCLUSIONS

Based on the simulated experimentation, the following conclusions have been made.

- The weight of the component is important in deciding the deformation energy, homogeneity of deformation and die life. More weight implies that, more energy is required for deformation.
- A uniform effective strain rate implies that, the deformation is more homogenous. The rate of the change of effective strain must be uniform. It requires a billet shape, which spreads out evenly in all directions, into the die cavity. Further, the size of cavity decides the uniformity of flow. A large size cavity will not give a uniform flow, while a medium size and small size cavities get filled up quickly, at a steady rate.
- A square billet was found to get sheared on the corners, while filling the die cavity, which increased die wear. The round billet gave better results, because the unnecessary shearing was eliminated.
- A part with larger surface area is affected significantly, by the value of coefficient of friction, while that with a smaller surface area is affected by the temperature of billet, rather than the coefficient of friction.
- Round billet requires more time in filling up the die cavity, with high stress and strain. But, the deformation is homogenous. The die wear is also less because, the material of billet flows out uniformly in all the directions.
- Higher flash allowance increases the normal and shear stresses, during deformation.
- Large size billet fills up the die cavity quickly, with minimum die wear and less material flow rate. But, the size should be accommodated inside the die cavity, without any unnecessary shear stress, which may increase the die wear.
- The complex cavity requires more forces, for deformation with round billet than with square billet.
- For a proper die design, ISO recommended flash allowance of 10% is sufficient, to manufacture the part without any defects. A generous flash allowance increases stresses, strains, die wearing and wastes a lot of material.

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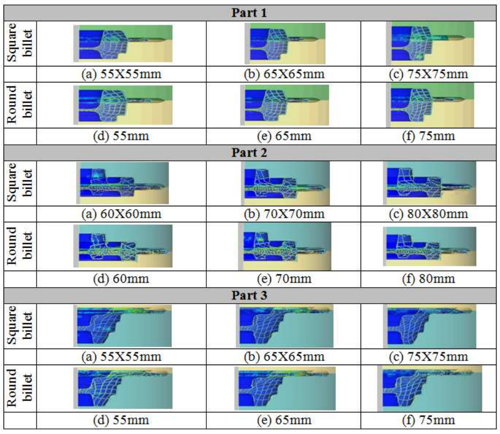

Figure 1: Comparison of Metal Flow With Different Billet Sizes and Shapes

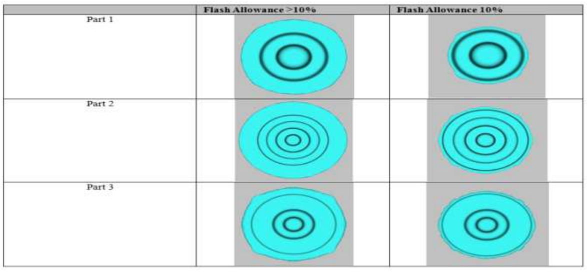

Figure 2: Comparison of Flash with Different Flash Allowances

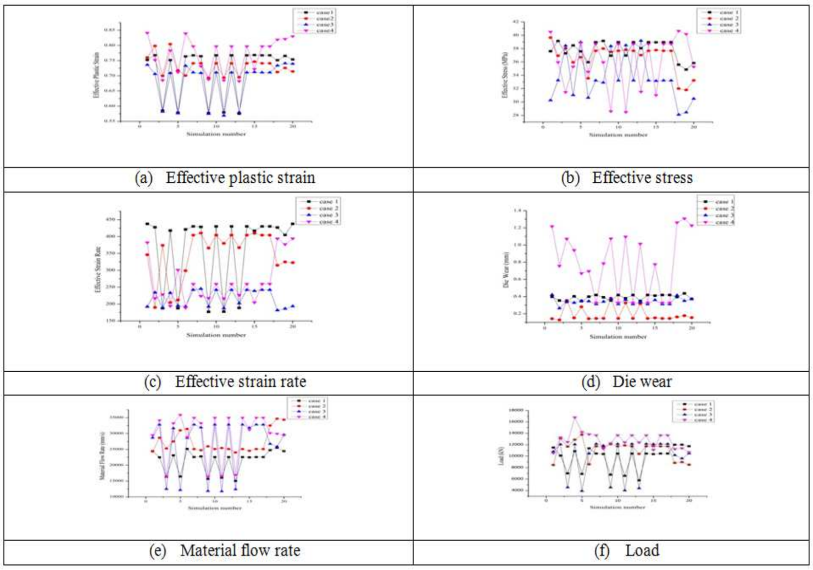

Figure 3: Response Variation in 4 Cases for Part 1

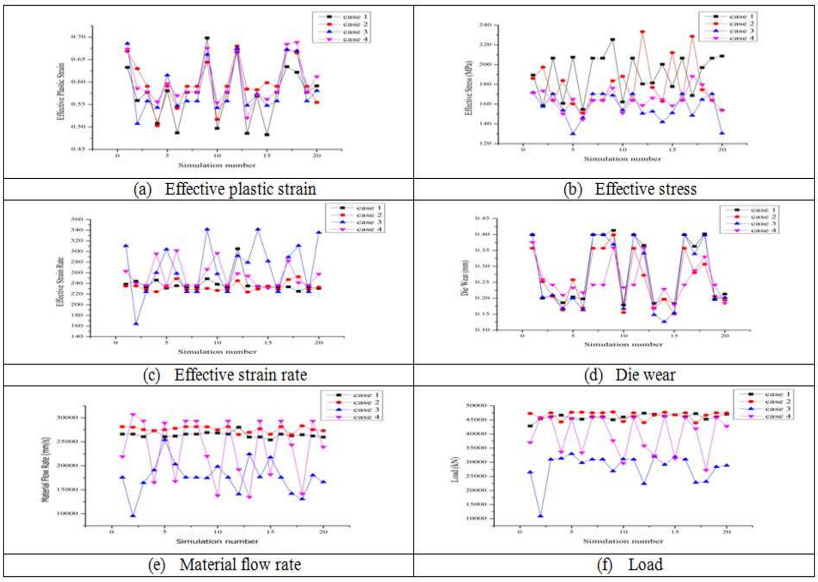

Figure 4: Response Variation in 4 Cases for Part 2

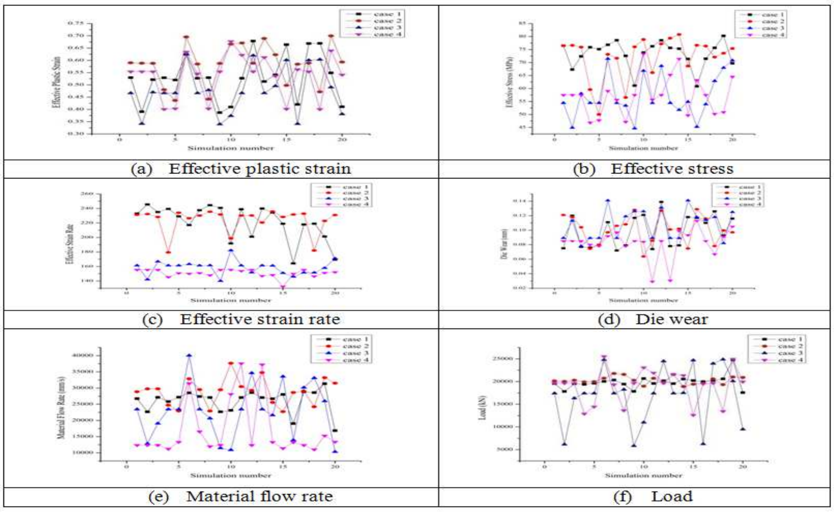

Figure 5: Response Variation in 4 Cases of Part 3