Optimum Preform Design in Close Die Hot Forging

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Abstract. In conventional hot forging process of complex parts, about 20-40% of material is wasted as flash. Several research groups have investigated the design of preform die. The idea is based on a simple primitive geometrical shape that provides complete and flawless die filling with not more than 20% of waste. In this paper, a geometrical based method for preform design is presented. The proposed method is based on the idea of constant volume in the plasticity. Considering this idea, a python script was implemented in ABAQUS package which can design the preform based on the shape of the final part. The advantage of this implementation in ABAQUS is that the finite element capabilities of the ABAQUS can be used for simulating the forging process. To check the efficiency of the proposed method, an industrial part called "electric tension rod" was used. First, the optimum preform was designed based on the proposed method. Then, several finite element simulations were performed to find out the optimum geometry instead of the simple cylindrical rods which is normally used in industry. To validate the numerical results, the same preform geometries were machined and used in closed die hot forging. The experimental results show that by using this method, a reduction of 35% in flash material can be achieved which is in good agreement with numerical results.

Keywords: Optimization, Preform design, Close die hot forging

1. INTRODUCTION

Many efforts have been devoted in forging industry to improve hot forging processes with regard to the items such as the number of deformation steps, higher accuracy of the forged parts, minimizing the billet mass by forging without flash in closed dies, saving of clipping operations by forging without flash, and reduction of the final machining operations by near net shape forging.

In recent years, many techniques have been developed to find appropriate prefoms. Among them, empirical equations, UBET method, model material, analogy method, continuum shape sensitivity method, fuzzy logic and step-back step-forward are notable.

Kobayashi et al. [1] developed the backward tracing method for preform design on the basis of rigid visco-plastic finite element method. Kim and Kobayashi [2] applied the FEM backward tracing scheme for the design of preform shapes for a H-shaped cross-section of an axi-symmetric forging problem. Kang et al. [3] established systematic approaches for the preform design in forging of an airfoil section blade as a two-dimensional plane strain problem using the FEM-based back-tracing scheme. Kang and Kobayashi [4] have also applied this preform design method in three-dimensional ring rolling processes.

Han et al. [5] applied an optimization method in the back-tracing. Zhao et al. [6] established a detachment criterion for a backward simulation and the related preform design according to forging shape complexity control and applied the method in preform design of axisymmetric deformation problems. Zhao et al. [7] also contributed an inverse die contact tracking method for designing the preform shape.

Badrinarayanan and Zabaras [8] developed a sensitivity analysis method for large deformation of hyperelastic viscoplastic solids. Similar to the backward tracing method, this method designs the preform or intermediate shape of the workpiece. They applied this method to an axisymmetric disk upsetting. However, the axisymmetric preform shape had a concave lateral section which is not easy to forge.

This paper is organized as follows. First, the proposed preform design method was presented. To check the efficiency of the method, several numerical simulations for the closed die forging were performed. Finally, the experimental verification was presented.

2. PREFORM DESIGN METHOD

The proposed preform design method is based on the idea of constant volume in the plasticity. In this method, the preform design process is started from workpiece final shape. To show the design process, an industrial part called "electric tension rod" was selected. Figure 1 shows the engineering drawing of the selected part. For forging this part, the conventional preform is a cylindrical billet. Figure 2 shows the forged electric tension rod, its final shape and the amount of flash.

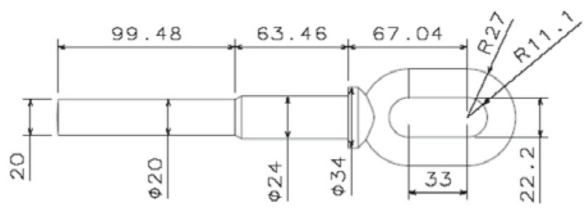

Figure 1. Engineering drawing of the electric tension rod

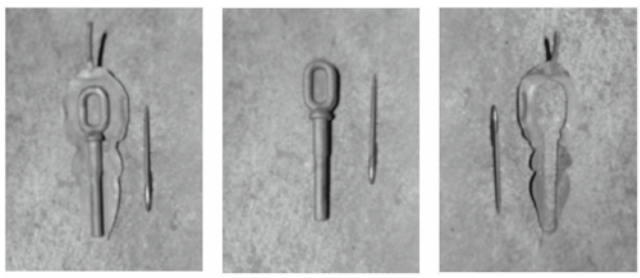

Figure 2. Forged electric tension rod, (a) including flash, (b) after cutting and (c) the flash

This method is ideal for billet-shape parts. Suppose that there is not any material flow in longitudinal direction and the main material flow is perpendicular to this direction. To reduce the amount of flash and considering constant volume condition, the cross section area of perform in each longitudinal position should be same as final part. Based on this hypothesis, a python script was written in ABAQUS/CAE which can simply draw the preform for each particular workpiece part. First, the script cut the workpiece in an arbitrary number of parallel sections, figure 3. Then, the cross section area of each portion is calculated accordingly. Based on final shape of workpiece, two options can be considered: circular perform and rectangular perform. After selecting cross shape, an equivalent circular or rectangular cross section is calculated for each longitudinal point. These circular or rectangular sections are connected together with a loft command, figure 4. Finally, a correction scale factor is applied to take account thermal expansion, finish allowances and etc.

Figure 3. Cutting the workpiece with a finite number of parallel planes perpendicular to its longitudinal direction

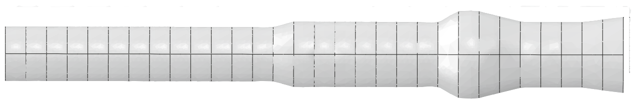

Figure 4. Connecting the circular section together using loft command

3. NUMERICAL SIMULATIONS

To check the efficiency of the method, several numerical simulations were carried out. Because of large deformation in forging, finite volume method was selected. Six different preforms were selected for simulations, figure 5 (the geometry of perform 4 is presented in experimental section). All the simulations were performed by Super forge package. Figure 6 shows the deformed configuration of all six preforms after forging. In this figure, preform 4 is optimum preform and preform 6 is cylindrical preform respectively.

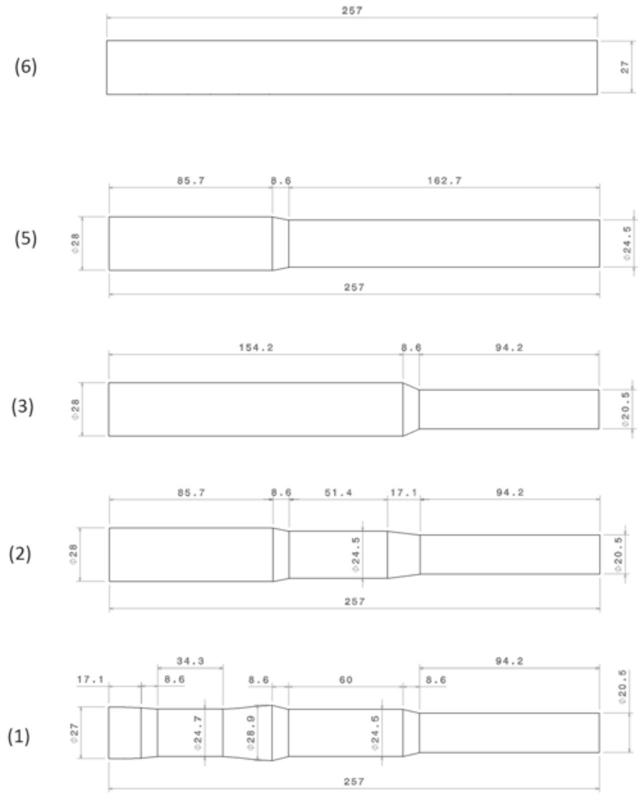

Figure 5. The geometry of preforms which were used for simulations

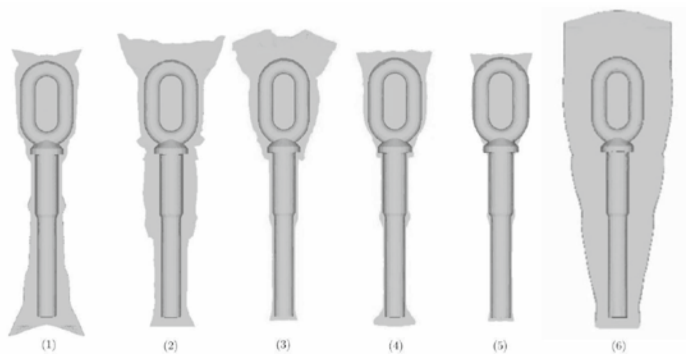

Figure 6. The final configuration of the forged preforms

Figure 7 shows the effective stress and the effective plastic strain for the optimum preform (preform 4).

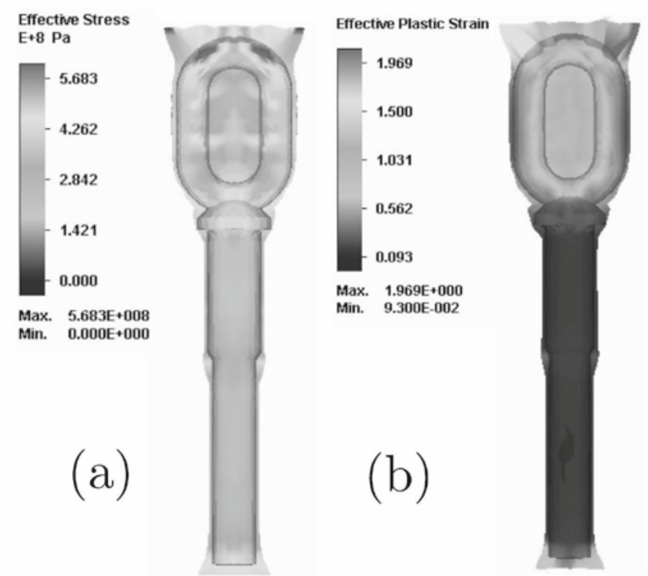

Figure 7. Distribution of the effective stress (a) and the effective plastic strain (b) for the optimum preform

A very important factor in closed die forging is to make sure that the preform filled the die completely. For all preforms, the filling analyses were performed by slicing the preform in different directions and positions. Table 1 shows the flash percentages and the filling condition for all designed preforms. Except preform 5, all other preforms filled the die completely. Figure 8 shows the unfilled areas of preform 5 between dies.

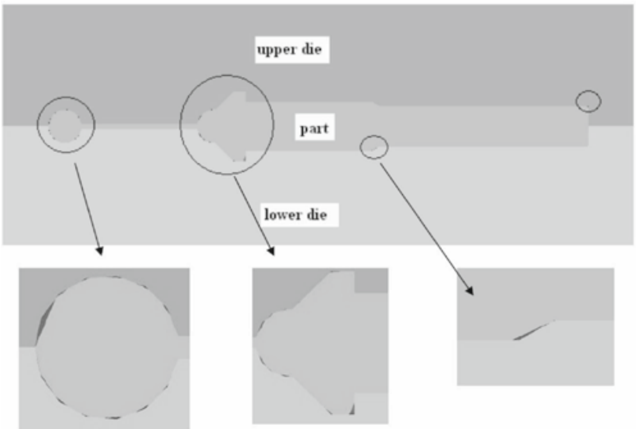

Figure 8. The unfilled areas of preform 5 between dies

Table 1. The flash percentage for different preforms

Preform Number	Flash Percentage (%)	Filled Die
1	23.43	Yes
2	19.12	Yes
3	13.73	Yes
4	10.2	Yes
5	3.55	No

4. EXPERIMENTAL INVESTIGATION

Beside the numerical simulations, several experiments were also conducted. For these experiments, a complete set of forging die was machined. Eight different preforms were considered for experimental verification. Figure 9 shows the geometry of the different groups. Figure 10 shows these eight preforms after forging.

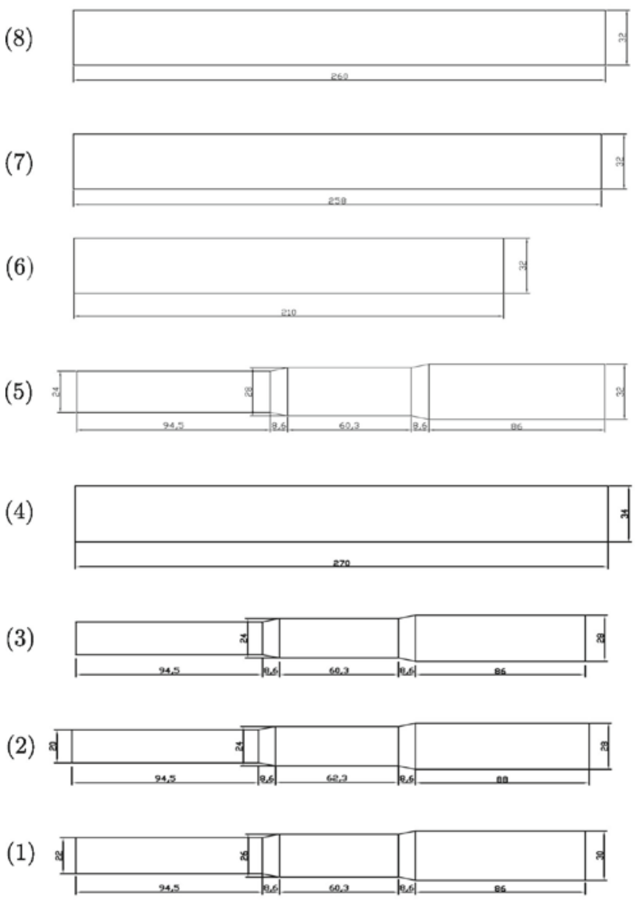

Figure 9. The geometry of preforms which were used for experimental tests

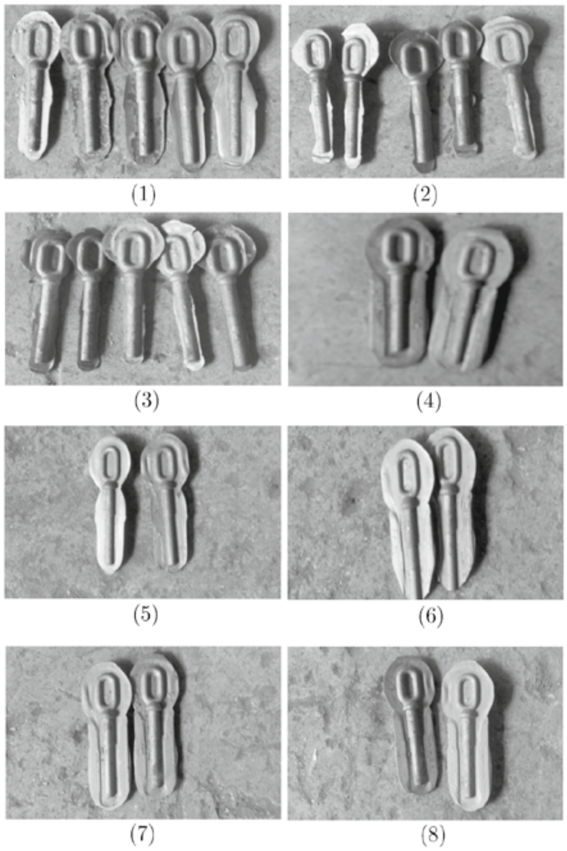

Figure 10. The geometry of preforms after forging

Figure 11 shows the forging die and cutting die which were used throughout of this study.

Figure 11. Forging die and cutting die used for forging electric tension rod

Table 2 shows the amount of flash percentages and filling condition of each preforms. As can be seen from the table, except two cases, all preforms filled die completely.

The best results belong to group one, which is the same geometry as the optimized preform. In this case, the preform filled the die completely and uniformly and the amount of flash is in acceptable range.

Table 2. The flash percentage for different preforms in experimental tests

Preform Number	Flash Percentage (%)	Filled Die
1	15.2	Yes
2	2	No
3	0.4	No
4	51.4	Yes
5	25	Yes
6	29	Yes
7	42	Yes
8	42.7	Yes

5. CONCLUSIONS

In this study, a geometrical based method for preform design is presented. This method is based on the idea of constant volume in the forming process. This idea was implemented by a python script inside ABAQUS/CAE. This method was implemented on an industrial part called "electric tension rod". The optimum preform geometry was designed and used in several numerical and experimental tests. The results were compared with simple cylindrical rod which is normally used in industry and some other geometries. The numerical and experimental results show that with using this method, an acceptable flash reduction can be achieved in closed die forging.

6. REFERENCES

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