Design and Analysis of a Forging Die for Manufacturing of Multiple Connecting Rods

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ABSTRACT: This paper demonstrates to utilize the hammer capacity by modifying the die design such that forging hammer can manufacture more than one connecting rod in a given forging cycle time. To modify the die design study is carried out to understand the parameters that are required for forging die design. By considering these parameters, forging die is designed using design modelling tool solid edge. This new design now can produce two connecting rods in same capacity hammer. The new design is required to validate by verifying complete filing of metal in die cavities without any defects in it. To verify this, analysis tool DEFORM 3D is used in this project. Before start of validation process it is require to convert 3D generated models in to .STL file format to import the models into the analysis tool DEFORM 3D. After importing these designs they are analysed for material flow into the cavities and energy required to produce two connecting rods in new forging die design. It is found that the forging die design is proper without any defects and also energy graph shows that the forging energy required to produce two connecting rods is within the limit of that hammer capacity. Implementation of this project increases the production of connecting rods by 200% in less than previous cycle time.

Keywords: Forging, Forging Die, Connecting Rod, DEFORM 3D.

1. Introduction:

Forging is a manufacturing technique in which metal is plastically deformed from a simple shape like billet, bar, ingot into the desired shape in one or more stages. Deformation takes place by means of applying compressive forces between the dies in machine tools like hammers, presses, horizontal forging machines, etc. The wide range of alloys and sizes, combined with excellent mechanical and physical properties has made forgings the design choice for nearly all product areas. The most common application areas are Automotive, Aerospace, Bearings, Construction, Mining Equipment, Pipeline Fittings, Valves, Pumps and Compressors.
The drop forging industry has been an important partner of the automotive industry and thus of a vivid branch for a very long time. On the one hand, this intensive focus guarantees a high level of capacity utilization in the forging industry, on the other it leads to a strong dependence and to considerable economic pressure. The international competition, new production technologies, as well as the omnipresent trend to more complex shapes and simultaneously reduced tolerances requires serious efforts of the drop forging industry to reduce the production costs and to increase the productivity to meet the increasing demand.

2. Methodology:

- Extensive study is carried out to understand the die design and forging process.
- Die 3D modeling for various values of parameters using solid edge software.
- Export the model to STL format, which is used to analyze the design using Deform-3D.
- Simulate the model to study the metal flow.
- Modify the design if there are any defects.

3. Design considerations:

3.1 Forging die design:

The first step in the design of a drop-forging die is the decision regarding parting plane and what impressions are necessary to achieve the necessary fiber flow direction to obtain the requisite strength. Normally, fullering, edging, blocking and finishing impressions are necessary.

3.2 Parting plane:

A parting plane is the plane in which the two die halves of the forging meet. It could be a simple plane or irregularly bent, depending on the shape of the forging. The choice of a proper parting plane greatly influences the cost of the die as the grain flow in the forging. In any forging, the parting plane should be the largest cross sectional area of the forging, since it is easier to spread the metal than force it into deep pockets. A flat parting plane is more economical. Also, the parting plane should be chosen in such a way that equal amount of material is located in each of the two die halves so that no deep die cavities are required. It may be required to put more metal into the top die half since the metal would more readily flow in the top half than in the bottom one. The parting line is chosen such a way that the equal amount of material is located in each of the two die halves of the connecting rod.

3.3 Steps in forging:

A blocking impression become a necessity only when the component is to be accurately made or the component has deep pockets or thin ribs, which are difficult to obtained in a single finishing impression. A bending impression is required when the part is of bend nature and the grain direction is to be along the bend line. In such a case, the bending impression is to be obtained before the blocking impression or finishing impression when no blocking is used. Similarly, a flattening impression is used when the component is thin and perpendicular to one plane. By using flat billet here we can avoid fullering. Before starting design of impressions lets calculate flash dimensions and billet size.
3.4 Flash:

The excess metal added to the billet to ensure complete filling of the die cavity in the finishing impression is called flash. A flash can act as a cushion for impact blows from the finishing impression and also help to restrict the outward flow of metal, thus helping in filling of thin ribs and bosses in the upper die. The amount of flash depends on the forging size and may vary from 10 to 50 per cent. The flash flows around the forging in the parting plane. The flash is provided uniformly around the periphery of the forging in the parting plane. The minimum flash allowances suggested are given below. [6]

\[ T_f = 1.13 + 0.89W^{0.5} - 0.017W \]
\[ W_f/T_f = 3 + 1.2e^{-1.09W} \]

Where \( T_f \) is flash thickness in mm
\( W_f/T_f \) is flash land ratio
\( W \) is weight of forging in kg

Therefore for thickness of flash for connecting rod is:

\[ =1.13+0.89(0.015)^{0.5} - 0.0170.051 \]
\[ =1.330 \text{ mm} \]

Flash land ratio= \( 3 + 1.2e^{-1.09(0.051)} \) = 4.135

Therefore: \( W_f=5.4996 \text{ mm} \)

![Figure 1. Connecting Rod with Flash.](image)

In addition to flash, provision should be made in the die for additional space so that any excess metal can flow and help in the complete closing of the die. This is called gutter, a flash may become excessively thick, not allowing the dies to close completely. The gutter should be more than the flash provided. The preferred gutter sizes are presented in table 1. The flash land provided in the die should be about 3% of the maximum forging thickness. If the flash land is too small, then the energy required
for the forging increases because of the excess metal trapped in the finishing impression, and the flash land wears out quickly. Similarly, too high a flash land lets the work material to flow into the gutter, and thus, the die cavity gets unfilled.

Table: 1 Gutter Size.

| Billet size (mm) | Flash With (mm) | Thickness (mm) | Gutter With (mm) | Thickness (mm) |
|------------------|----------------|----------------|------------------|----------------|
| Up to 35         | 4.5            | 0.8            | 25               | 3.0            |
| 36 to 50         | 5.3            | 1.0            | 25 to 32         | 4.5            |
| 51 to 65         | 6.5            | 1.5            | 32 to 38         | 4.5            |
| 66 to 75         | 8.0            | 2.0            | 32 to 38         | 4.5            |
| 76 to 100        | 10.0           | 3.0            | 38 to 44         | 6.5            |

3.5 Billet size

As a rule, drop forgings do not get upset and therefore the billet size to be chosen depends on the largest cross-sectional area of the component. To get the billet size, the necessary flash allowance is to be provided over and above the billet volume. The stock to be used is either round, rectangular or any other section depending on the nature of the component. Having decided on the cross length of the billet, and from the total volume of the component and the flash, it is possible to find the length of the billet. The billet in the die is to be moved from one impression to the other, and hence a tong hold is provided in addition to the billet length.

The maximum width and thickness of connecting rod are:

\[ T_{max} = 13.7 \text{ mm} \]
\[ W_{max} = 23 \text{ mm} \]

Therefore cross sectional area of billet is:

\[ = 315.1 \text{ mm}^2 \]

Now adding flash thickness and width

\[ \text{Thickness} = 13.7 + 1.33 = 15.03 \text{ mm} \]
\[ \text{Width} = 23 + 5.5 = 28.5 \text{ mm} \]

Cross section area of billet:

\[ = 15.03 \times 28.5 = 428.355 \text{ mm}^2 \]

Approximate Volume of forging is:

\[ \text{V}_c = \frac{x^2}{4} \times 13.7 + \frac{x^2}{4} \times 9.2 + (4.8 \times 31.5 \times 7.7) \]
\[ \text{V}_c = 9290.6 \text{ mm}^3 \]

Volume of flash

\[ \text{V}_f = 1.33 \times 5.5 \times 74.5 = 544.97 \text{ mm}^3 - 545 \text{ mm}^3 \]
Adding volume of forge and volume of flash we get

\[ =9290.6+545=9835.6 \text{ mm}^3 \]

Now dividing this volume with the cross section area of billet to get the length

\[ L = \frac{9835.6}{428.355}=22.96\text{mm} \]

3.6 Edging Impression:

The edging impression or perform, gathers the material as required in the final forging. As explained earlier, this is the most important impression in a die. This gathering helps in the proper flow of metal and complete filling of the die cavities in the later impressions. The perform shape also helps in proper location of stock in the blocking impressions.

For irregular shapes with large variation in cross section, and which are extra long compared to other dimensions, it is very difficult to gather the material. In such case, it would be desirable to have two edging impressions.

In an edging impression, the area at any cross section should be same as that of the corresponding section in the component and the flash allowance. For simple shapes, it can be very easily calculated. For complex shapes or with continuous variation in cross section, it may be desirable to adopt a graphical approach.

The following procedure may be used for arriving at the perform shape.

1. The plan and elevation views of the forging should be drawn side by side to a convenient scale, preferably full size. On the same views, the flash outline around the component is to be laid out.

2. A baseline is to be drawn parallel to the longitudinal axis of the component, at a small distance from the component.

3. Next, the component is divided into a number of elements, as shows by the horizontal lines. The choice of the elements is based on the geometric shape of the component and the variation in the cross section. If the cross section is uniform over a length, then only one section is enough. When the cross section is changing drastically then it may be necessary to divide the component into a large number of sections over the change.

4. The cross section of each of the elements chosen are calculated by simply multiplying the elements in the two views of the component. The areas of these various elements from the base line to any appropriate scale may be plotted. These plotted points are joined with a smooth curve. In this process, if there are any abrupt variations in the areas then some more sections may be chosen to get a smooth curve.

5. The flash area provided at each of these elements are calculated and added to the areas already plotted.

6. Having known the cross sectional area of the component an flash at each of the elemental sections, the radius of perform at these elements is given by the formula

\[ R = \sqrt{\frac{\text{area}}{\pi}} \]

7. These radius values plotted on either side of a reference line drawn to the same scale as that used for drawing the component; provide an approximate contour that would promote smooth flow of metal into the final forged component.
3.7 Blocking Impression:

Blocking or semi-finishing impression resembles the final shape with liberal radii corners. No gutter is provided in blocking. The area at each section is roughly 15% to 20% greater. The height of the blocked forging is large and the breadth is smaller by an amount of the order of 0.8 to 1.5 mm. The length of the blocking impression remains the same and the centers correspond to that of the finishing impression. The edge and fillet radii are generously provided to aid the flow of metal in the blocking impression. For very complicated shapes with rapid changes in section, deep pockets or thin ribs, it may be necessary to include more than one blocking impression.

3.8 Finishing Impression:

The dimensions of the finishing impression are same as that of the final forging desired with the necessary allowances and tolerances. A gutter should be provided in the finishing impression.
3.9 Location of Impressions:

The various forging impressions should be located in the die block in such a way that the forging force be as nearer to the center as possible. This will minimize the likely mismatch of the two die halves, reduce the wear on the ram guides of the drop hammer and will help to maintain the thickness dimensions of the forging. To do this, the operation requiring the maximum forging force should be placed at the other impressions distributed as nearly equal on either side of it in the die.

It is the normal practice to provide the fullering impression on the left-hand side and the edging impression on the right-hand side with the blocking and finishing impression at the center. It is necessary to provide enough clearance of the order of 10 to 15 mm between the impressions in the die. If too little space is provided then upsetting of the die block is likely to take place, which would decrease the thickness of the final forging. The clearance between the cavities depends on the depth of the cavity and it is determined as follows

Cavity depth \( (h) = 0.5T \)

Where \( T \) is part maximum thickness

\[ h = 13.7 \times 0.5 = 6.85 \text{ mm} \]

Cavity spacing \( (w_1) = 3.1x(h)^{0.7} \)

\[ W_1 = 3.1 \times (6.85)^{0.7} \]

\[ = 11.921 \text{ mm} \]

Cavity edge distance can be given by

\( (E) = 3.4 \times (h)^{0.76} \)

\( (E_1) = 3.4 \times (6.85)^{0.76} \)

\[ = 14.68 \text{ mm} \]

Evaluation of forging profile is done using DEORM 3D simulation software.

4. Result and Discussions:

Simulation is careered out to analyze the metal flow in die cavities and checked for energy required to deform the metal.

Simulation:

**DEFORM-3D ANALYSIS:** Deform-3D is a computer simulation technique used in engineering analysis. It uses a numerical technique called the finite element method (FEM). Deform-3D consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design and existing product refinement. For an existing product or structure, it is utilized to qualify the product or structure for a new service condition. In case of structural failure, Deform-3D may be used to help determine the design modifications to avoid failure. Deform-3D uses a complex system of points called nodes which make a grid called a mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. The mesh looks like a spider web in that from each node, there extends a mesh element to each of the adjacent nodes.
Fig 4a: Final shape of Connecting Rods

Fig 4b: Energy Required for Finishing Process.

5. Conclusion:

The main focus of this work is to attempt to increase the production to meet the increasing demand of the forging products by complete utilization of underutilized forging hammer. By eliminating fullering process in forging step, this design can reduce the cycle time. Complete utilization of machine capacity with proper forging die design can increase the productivity. Reduced production cycle time of connecting rod allows the machine to forge other parts which increases the production.
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