Design of multistage forging processes by numerical simulation and experimental verification

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Abstract: The Variety of components with different shapes & Sizes with different materials can be formed using Multi stage hot forging processes. In previous times, forging process in multi stage was designed on basis of experience gained in the previous forging practices. Nowadays, many software packages based on FE (finite elements) and FV (finite volumes) method are developed. This enables creation of forging process in more effective and accurate condition. The paper insight is given in the design of multi stage hot forging process for a critical geometry of Socket Forging in a multi-step forging process. The main criterion is to minimize the number of forging stages, proper filling and stressing of the dies by analysing the contact pressure. The Theoretical derivation & Numerical Simulation results are verified with practical, industrial environment.

Keywords: Hot forging process, Multi-stage Forging Process, DEFORM.

1. Introduction

Forging is a metal forming processes which is the key industrial production technologies that can create parts which are stronger than any other manufacturing processes. Components that are produced by forging have a high structural integrity, provide good fatigue life, maintain uniformity and withstand high impact strength. The reliability and human safety are also highly demanded. The High flexibility in the process provides the act of manufactured the great variety of different profiles (Size & Shapes) and materials like steel, aluminum, titanium, alloys.

Every year different forged components are produced in worldwide. In the most cases those components are assembled into automobiles, airplanes, vehicles, ships, missiles and others. The study case says that the modern car design includes 250 forged components. In average, large airplane contains over 18000 high precision forged components [1].
The Current field of forging technology is characterized by a high research work in a number of different areas such as metallurgy, material science, heat treatment, tooling design, environmental issues, etc. Number of papers has elaborated the problem of forging-set up [2, 3, 4, 5, 7]. Complex profiles or geometries are produced in multi-stages [8,9]. In such cases it is essential to determine optimal process design which has a minimum number of forging stages. For a long time set-up of process, Sequences has to be experimentally generated by trial and error method which is highly time and cost consuming. This also inevitably reflects high on forging quality and costs [6].

Instead to those problems, the greater solution is numerical simulation and optimization, which has been grown rapidly in the last years. This software packages based on FE (finite elements) and FV (finite volumes) offers a high possibility to perform forging multi-Stage process designing in more efficient and qualitative way.

In this paper Optimized design of Multi Stage hot forging processes of a complex profiled socket are presented in terms of minimal number of forging stages, complete die filling and minimum material waste. Verification of the obtained and optimized solution has been performed in production environment forging plant, using Friction Drop hammer.

2. Hot forging technology of socket forging

Socket Forging as shown in figure.1, made from Alloy Steel Material EN-8D (BS Standard)[14][15], is a Forged component which is used in the steering mechanism of a vehicle. Due to the high dynamic load getting exploited in the part is produced by forging and by additional Heat Treatment Process for the high load withstanding. The part is also included in the metal cutting operations for the assembly requirement.

The Material in extra is added with the billet for the proper filling of the Cavity which is provided in the Dies. This Excess material which is added with the billet is known as the Flash. A flash is used as a carrier for the impact to blow from the cavity of the die restricting the outward direction flow of the metal which helps in the filling of all such thin ribs and bosses in the upper die cavity. The Excess flash gets to flows along the forging parting line of the Socket Forging considered. The flash is to be provided uniform around the Socket forging peripherals around the parting plane. The minimum flash allowances suggested are given in equation 1. [8]

![Figure 1: Socket forging drawing](image-url)
\[ T_f = 1.13 + 0.89 \ W^{0.5} - 0.017 \ (W) \] ........................ (1)

\[ W_f/T_f = 3 + 1.2 \ e^{(-1.09 \ W)} \]

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

There for thickness of flash for Socket Forging is:
\[ T_f = 1.13 + 0.89 \ (0.6)^{0.5} - (0.0170 \times 0.6) \]
\[ = 1.979 \ mm \]

Flash land ratio
\[ W_f/T_f = 3 + 1.2 \ e^{-1.09 \times (0.6)} \]
\[ = 3.624 \]

Therefore
\[ W_f = 3.624 \times 1.979 \]
\[ = 7.172 ~ 7.2 \ mm \]

With addition of flash provided, A Provision for the material to get flowed outward from the cavity should also be given and this helps in the proper closed stroke of the dies which is known as gutter. This gutter should always be provided more than the flash getting outward from the billet. The most preferred gutter size with the comparison of billet size is getting presented in the table 1. The flash land provided in the die should always be more than 3% of the maximum forging thickness of the Socket Forging [12]. If the flash land is provided less than that, then the Stroke energy required for the forging process get increased because of the excess flash getting trapped in the finishing impression of the die, Also the flash land gets wear out quickly and also the cavity remains unfilled.

| Billet size (mm) | Flash | Gutter |
|-----------------|-------|--------|
|                 | Width (mm) | Thickness (mm) | Width (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          |

The Maximum Width and Thickness of the Socket Forging is:
\( T_{max} = 28.5 \ mm \)
\( W_{max} = 245 \ mm \)

Therefore the area of Cross Section of the billet is:
= 6982.5 mm²

By adding the Flash Thickness and Width
= 28.5 + 1.979
= 30.479 mm

Width = 245 + 7.2
= 252.2 mm

The Total Area of Cross Section of Billet is:
= 30.479 X 252.2
= 7686.8 mm²

Approx. Volume of Socket forging is:
\[ V_{c} = \frac{\pi \times 40^2}{4} \times 28.5 + \frac{\pi \times 19.3^2}{4} \times 51.5 + (15.5 \times 19.1 \times 180) \]
\[ V_{c} = 104169.634 \ mm^3 \]
Volume of flash:

\[ V_f = 1.979 \times 7.2 \times 245 \]
\[ = 3490.956 \text{ mm}^3 \]

Adding volume of forge and volume of flash we get

\[ = 104169.634 + 3490.956 \]
\[ = 107660.590 \text{ mm}^3 \]

By dividing the volume with area of billet to get the length

\[ D = \frac{107660.590}{3490.956} = 30.84 \]
\[ D \sim 31 \text{ mm} \]

So, it is a primary need to provide enough provision of about 10 to 15 mm between the both die impressions. If the space is provided less, upsetting of the die block will not take place properly. The clearance between the two die cavities depends on the depth of the die cavity and is given as follows:

Die Cavity depth (h) = 0.5 T

Where T is the Maximum thickness of Socket Forging

\[ (h) = 0.5 \times 28.5 \]
\[ = 14.25 \text{ mm} \]

Cavity Spacing

\[ W = 3.1 \times (h) 0.7 \]
\[ W_1 = 3.1 \times (14.25) 0.7 \]
\[ = 19.91 \sim 20 \text{ mm} \]

Die Cavity distance at edges is given as

\[ (E) = 3.4 \times (h) 0.76 = 3.4 \times (14.25) 0.76 \]
\[ (E_1) = 25.61 \sim 26 \text{ mm} \]

The realization of the Socket forging is done by the designed dies as per the multi-stage principle, i.e. complete stages in one single die. Process of socket forging was simulated by DEFORM 3D software [7,10,11,13,16] and the forming of all stages of work piece. The initial data considered for the multistage process are as follows:

- Billet rod - 80mm in diameter and 160mm long
- Preheating temperature of the billet: 1250°C
- Die preheating temperature: 400°C
- Hammer capacity: 80KJ

2.1. Operation 1 – Free Upsetting:

This is a preparatory step in which billet (rod) is compressed on one side for the amount of 32mm as shown in figure.2a & 2b. This operation is foreseen for the mass distribution along the longitudinal axis of the work piece in order to enable better die filling in successive [11], following operation.

![Figure 2: Free upsettingForging a) CAD Deformation b) Actual Formation](image-url)
2.2. Operation 2 – Bending Forging:

This operation is done to form the bending profile in socket forging as shown in figure 3a & 3b. The bended part is placed in the next stage in order to get the part filled. For the proper contact of the billet in the preforming stage, the bending operation is carried out. This process will also eliminate the more material usage.

2.3. Operation 3 – Preforming Forging:

This operation is designed in order to prepare the work piece for the final forging step, i.e. for the creation of preformed forging shape [10]. In this way in final die cavity only minimal filing of required profile of the work piece geometry is to be imposed.

Preforming operation is performed in special preforming die as shown in figure 4a & 4b. Operation is completed after 3 strokes of hammer. Die filling after this operation is 100%. Contact stresses at the work piece after preforming operation of cross-section (figure 4a & 4b) are significantly lower than the allowed values (maximum 786 MPa), which is a good starting point for final forging. Maximal allowed values of contact stresses in hot forging are 2000 MPa.
2.4 Operation 4 – Final Forging

In final forging operation work piece obtains the final shape and dimensions as shown in figure.5a & 5b.

![Figure 5: Initial and end configuration in final forging operation](image)

To achieve this, two strokes are needed. Simulation results show that maximal contact pressures in final forging operation are lower than 900 MPa (figure.5a & 5b). Also, die filling has got completed. Based upon the above facts it can be concluded that by the implementation of optimized manufacturing of Socket Forging component of high quality can be obtained. The die stressing is significantly lower than allowed.

Conducted numerical simulation of socket forging produced by Hot Forging process has been verified in practical industrial environment, in forging plant “Punch Ratna Fasteners Pvt Ltd”. Friction Drop Hammer is used in hot forging process was Rattan Hammers with capacity of 1.25 Ton, weight of the top die and Bottom Die was 3150 kg. Applied lubrication: Friction Release Lubricant oil. In figure.6, 3D model of both top and bottom die of the forging process, created using Siemens NX Cad software with all the multi stages optimized improvements getting imposed in the die design.

![Figure 6: CAD version of the bottom and upper die](image)

Forging parameters were identical with those applied in the numerical simulation. Results obtained in practical forging experiment confirm simulation results, i.e. complete die filling and relatively low contact pressure between the die and forging component.
3. Conclusion:

Hot forging technology is indispensable process for producing high quality parts for different applications. This technology is applied for the manufacture of automotive components, turbine discs, gears, bolts, and structural components for machinery, railroad and other transportation equipment. Due to its comparative advantages, hot forging finds wide spread implementation in metal industry all over the world.

Effective and qualitative design of forging technology requires application of modern informational technologies in all stages, starting form work piece design, multi -stage forging design, optimization of the process, die design, etc. Numerical simulation of the forging process makes possible to perform optimization of forging phases, die wear, material structure, elastic deformation of die and machine, essential for the precision of forgings.

Current paper enlightens the optimization and process design (forging multi-stage) of hot forging process for the production of Socket Forging. The aim was to determine all relevant parameters which result in correct forged part (complete die filling) and low die stressing.

Results obtained in numerical simulation were verified in practical industrial environment. By inspection of final forging component it has been concluded that they possess high quality and dimension accuracy. Also, those forgings are free of surface cracks, material overlapping and insufficient die filling.

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