DIE LIFE OPTIMISATION BY NUMERICAL MODELLING WITH SIMUFACT FORMING

Introduction

Die life is a major concern when for the forging industry. Fig. 1 shows the major failure mechanisms of forging dies of which cracking is the most dominating failure mechanism followed by wear.

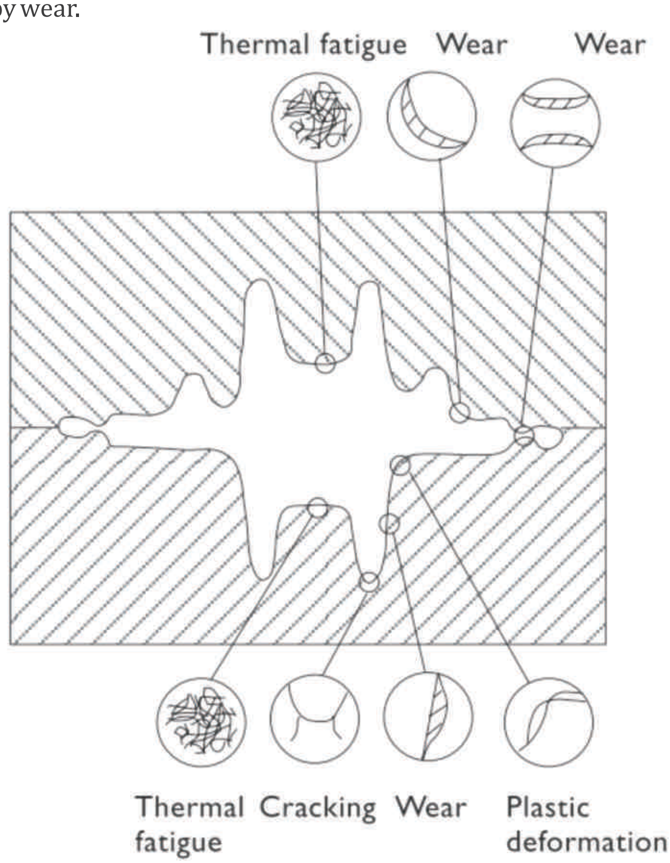

Fig. 1: Overview of forging die failure mechanisms [1]

Improving die life by premature die failure due to crack is a one of the dominating challenges most of the die and forging process engineers are facing. During the die design seminars which were jointly conducted by AIFI, Simufact India Pvt. Ltd. and Kadkraft Systems Pvt. Ltd. in February in four Indian cities, one third of the participants mentioned it as a major challenge in their company. This is not a representative result, but motivated us to write this technical article, in which we would like to demonstrate how the numerical process simulation tool Simufact.forming can be used to significantly increase die life by optimising the forging process by optimising the pre-shape produced in the blocker stage. This is achieved by removing excess material.

This has three major positive effects significantly reducing manufacturing costs:

- increased die-life
- material saving
- enhanced productivity due to lower die-change.

The optimisation can be done for components in production and for new products by introducing die-life studies during the forging die design phase.

Background

Complete die cavity filling too early before the final stroke of any forging press is reached results in high (hydrostatic) stresses in the forged workpiece, since the material can flow only into the flash area. This results in high (tensile) stresses in the forging dies. These stresses are so high, that after a limited number of forgings the dies will dies will fail at the point which experiences such high stresses resulting in a visible crack.

The life span of steels under high cyclic loading is described by S-N curves. This is a graph of the magnitude of a cyclic stress (S) against the logarithmic scale of cycles to failure (n) as shown in Fig. 2. It shows the expected number of loadings (number of parts that a blocker or finisher die can produce) depending on the stress (max. tensile stress) loads on the die for a particular die material.

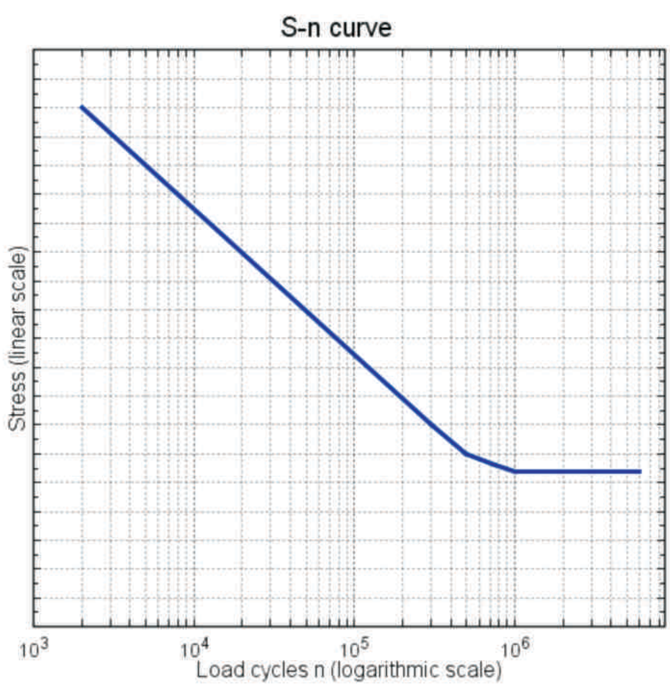

Fig. 2: S-N curve (schematic)

These curves give approximate indications how many load cycles a certain material can withstand.

Since these curves are determined in laboratory conditions (uni-axial stresses, uniform peak stresses, sinusoidal loading, constant temperature) the load cycle numbers given in the S-N diagram cannot predict the exact number of components a die can produce. Nonetheless, the principle behaviour is correct described and reveals the key to improve die- life.

At low stress values a certain value the material can withstand an infinite number of loads, which is called fatigue limit and equals about one million load cycles (10^6). Forging are subject to much higher loads and their life span is much shorter - a few hundred to approx.

40,000 load cycles (forgings) and their behaviour is determined by the low-cycle fatigue characteristics where slight changes of the stress can have an large impact on the life span. Hence, an even slight reduction of the stress by 20% of has a large impact on the die-life.

This mean:

If die-life is to be increased, the primary goal is to reduce the tensile peak stresses in the dies! For this task the precise information of the S-N curve is not even required.

The stresses in the dies reach their maximum when complete die filling is reached. Thereafter excess material can only leave the cavity through the flash which requires very high pressure (hydrostatic stresses) within the workpiece. These cause high contact stresses on the tools and finally high tensile stresses in the edges of the tool cavity.

This mechanism applies not only to complete die filling of the entire but also to locally premature die filling which can significantly increase the die stresses in a local region. An adjusted material distribution or pre-form is the key to reduce the excessive die stresses to significantly improve die life. Let's study this on an real life example.

Analysis of original process

Fig. 3 shows the workpiece geometries of the forging process analysed with Simufact.forming.

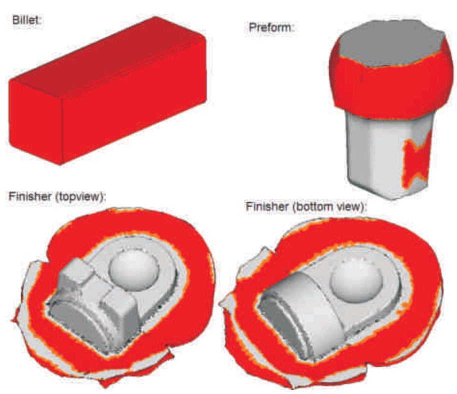

Fig. 3: Forged component
(Red = no contact to die, Gray = contact to die)

The finisher shows to the experienced reader that the flash area is rather large, but the experienced reader will also agree, that this is a common sight in forging shops.

Now let's have an look on the development of the die filling during the finisher stage in Fig. 4.

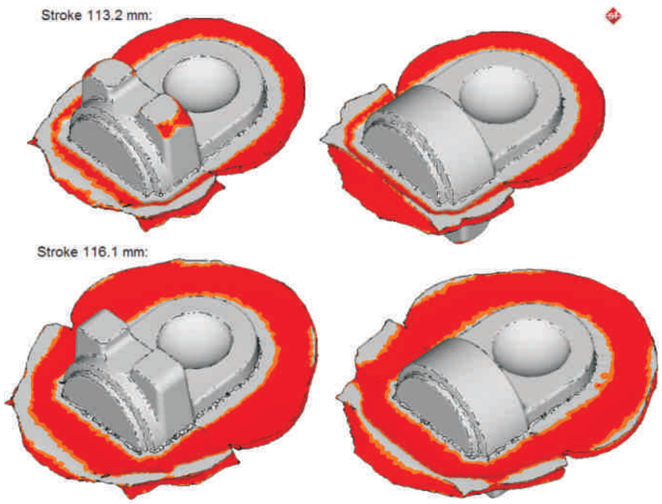

Fig. 4: Die filling finisher die
(Red = no contact to die, Gray = contact to die)

These simulation results reveal that complete die filling occurs 2.9 mm before the final stroke is reached in this forging process. This is too early and indicates excessive flash which is wasted material.

But this is not the only negative effect. Fig. 5. shows the force development as a function of stroke for the last 3 millimetres of stroke in which the press force is rising from 5,000 T to 10,000 T. Due to excessive material which has to flow from the cavity into the flash the force requirement is very high. This results in high stresses in the dies and therefore poor die life.

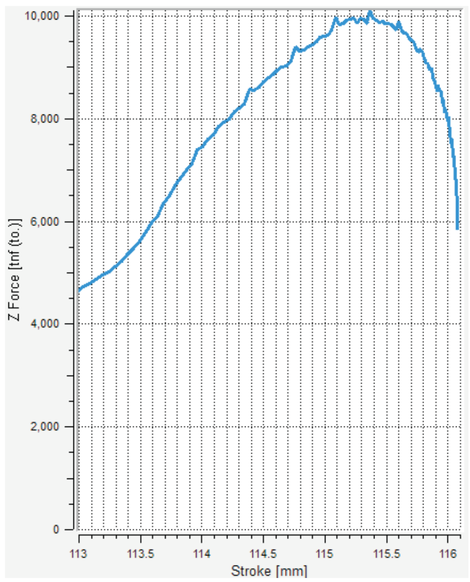

Fig. 5. Force development during the last few millimetres of the stroke

The total time to carry out this simulation including all forming stages, the initial heating and intermediate cooling times during the transport was less than 6 h using a single Intel i7 CPU on a laptop computer.

1. Modification: billet length

The top view of the finisher (Fig. 6) shows that the largest flash extension is in the lower half of the component. This flash pattern is used to calculate the excessive material which volume can be approximately calculated as follows:

Area of flash = Area of outer box (300mm x 400mm) - Area of inner box (165 mm x 240 mm) Area of flash = 80,400 mm^3

Given a flash thickness of 3 mm the flash volume is 2,41,200 mm^3

Since we cannot remove the flash entirely, let's remove 40 % of the flash volume. This is 144,000 mm^3. This is 4 % of the billet volume.

Our initial billet is 110 mm square, with edges rounded with r=5 mm and a length of 305 mm. Its volume must be reduced by the volume as calculated. Its new length is then 293 mm. Since only the length of the billet is modified and not its cross-sectional geometry, this modification can be easily carried out.

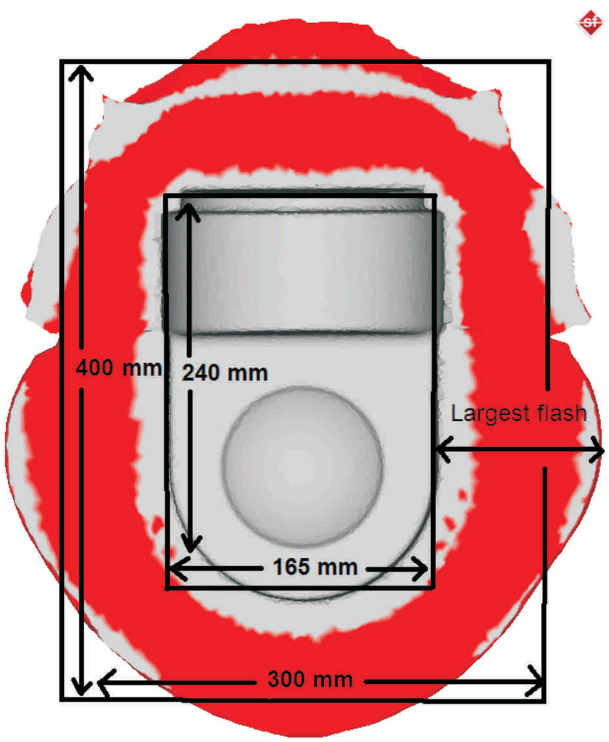

Fig. 6. Flash pattern of the finisher and approximate calculation of flash area

2. Modification: Lower die for preforming operation

The second modification requires a die modification. As Fig. 6 indicates there is more excessive flash in the lower part of the workpiece. To keep the costs of modifications as low as possible as few as possible dies should be modified. To have a more balanced pre-distribution of the material it was decided to slightly modify the lower die of the preforming operation, which is shown in Fig. 7.

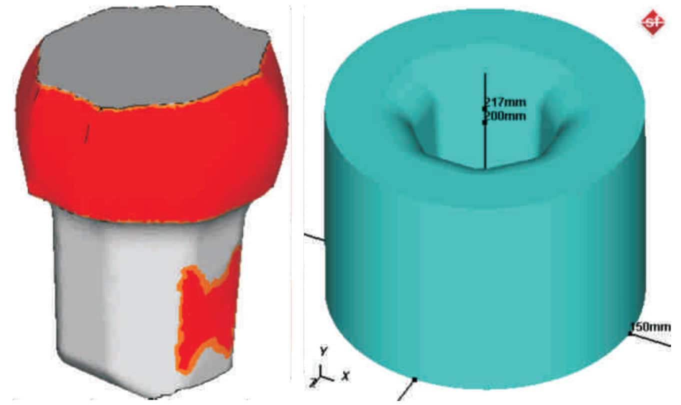

Fig. 7. Preform and the lower die for the preforming operation

The lower die geometry was scaled in x and z direction by a factor of 0.978 which reduced the volume of the cavity by approx. 4 %.

Verification of optimised process

These two modifications require only a few minutes of pre-processing work in Simufact.forming and then the modified process was simulated.

Fig. 8 shows the die filling of the finisher and compares it to the original process. It is clearly visible, that the excessive flash was reduced and the part is still completely filled and surrounded by flash around the its entire circumference. The die cavity is filled at 0.9 mm stroke before the final stroke is reached.

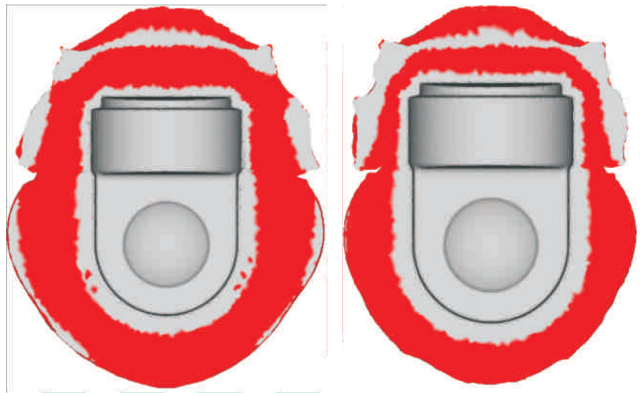

Fig. 8. Finisher at final stroke with original (left) and optimised (right) process

The simulated press forces are shown in Fig. 9 for the optimised process layout of the finisher. The peak force is now just below 7,000 T, whereas the peak force of the original process was 10,000 T as shown in Fig. 6. The 4 % smaller billet volume effectively reduced the peak force by 30 %.

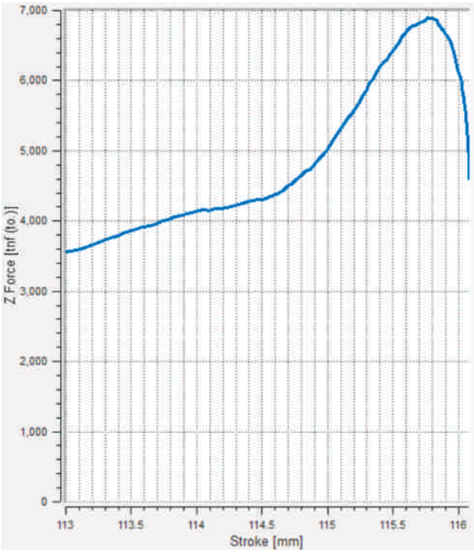

Fig. 9. Force during the last few millimetres of the stroke (optimised process)

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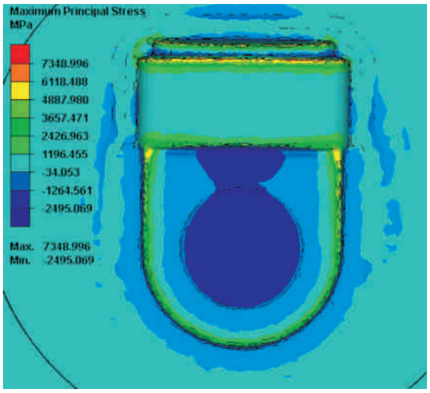
A de-coupled die stress analysis was carried out to compare the max. tensile stresses in the dies for the original and the modified process. The max. tensile stresses of the original and the optimised process are compared in Fig. 10.

Overlap to outer tool to optimise pre-stressing conditions was left unchanged - this bears some additional optimisation potential to further reduce the tensile die stresses, but the most effective way is to reduce too early die filling and excessive flash.



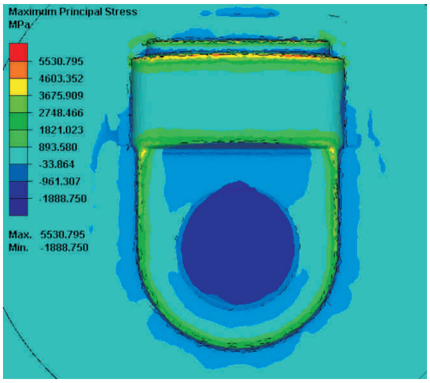


Fig. 10. Comparison of tensile stresses of lower die, left original, right optimised process

Reducing excess flash as studied here requires the initial billet geometry to be cut or crop- sheared with higher precision to match the optimised input volume. Neglecting this requirement might result either in more frequent underfills or reduce the die life gains.

Conclusions & Outlook

This study shows several benefits which can be easily achieved for the forging processes which have been laid out manually without the help of modern simulation tools by optimising the initial billet size and preforming operations. In this study three main benefits have been achieved:

- 4 % lower material requirement per forging
- 30 % lower press force requirement in the finisher stage
- 25 % lower dies stresses increasing die life five to ten times

Not only these, but also secondary benefits are achieved as follows:

- The efforts and costs to handle the trimmed flash will be reduced
- The lower press force requirement also results in energy saving. It also allows to use a smaller press which has lower operational costs. Furthermore, larger forgings can be produced on the same press, which will increase the product range which can be produced on the available presses
- Lower die wear due to reduced contact stresses and lesser material which needs to flow into the flash.

  Since this optimisation can be done already in the design phase for a new forging component as well as for products already in production the utilisation of the simulation software will be high and a fast return on the investment can be such that the investment in this simulation software can be recovered within a year.

Besides the fundamental optimisation of the billet volume and optimisation of the preform geometry numerical simulations can be used for further optimisations like:

- Optimisation of the position of the cavity within the die to reduce excentric forces acting on the press
- Optimisation of pre-stressing of the die by optimisation of the shrinkage assembly to further increase die life.

The importance of tight billet weight tolerances have been briefly discussed.

A detail study of the impact of the cutting weight tolerances during the shearing / cutting of the billets will be the content of our next publication in the Focus magazine.

Source:
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