PROCESS SIMULATION BASED OPTIMISATION OF PRECISION FORGING PROCESS

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Industrial Summary

Precision Forging Design is conceived as interplay of intrinsic, extrinsic and interactive parameters within a constraint envelope in the design space. Designer is faced with a wide range of possible design options. Even after brainstorming and rationalizing the design, several combinations of design are still left for consideration of process plan and tool design. It will be practically impossible to physical verification and try out of all these options. Non-linear finite element analysis based process modeling methods have been successfully used for design, analysis, and optimization of precision forming processes. Quick and accurate response to precision forging design challenges demand an interdisciplinary approach spanning metallurgy, die & process design, equipment design, and component design. In the present paper, some case studies of precision cold forging, warm forging and near net shape forging of auto components as well as other non-ferrous forgings are discussed.

Parameters which effect the precision forging process include the workpiece, tool materials and heat treatment, the die design, the process selection, the choice of equipment, the shrink rings. In the present paper a commercially available forging software **DEFORM** is used as a **“virtual forge shop”** to study the metal flow, die behavior (die load, stress, and deflection). Modeling based forging design and optimizations have been carried out at **ProSIM** R&D center in Bangalore, India.

Precision Forging

Increased productivity, reduced cost, and enhanced properties of the forged component are the prime movers for the precision forging development. The emphasis in the precision forging technology is on geometric precision, to get near net shape forgings in the size envelope of the finished machined component. The techno-economical advantages of precision forging arise out of two primary issues. 1] The forgings become competitive and comparable to casting and p/m route and 2] enormous potential to have tailored high performance properties in the component. A range of automotive, aircraft and engineering components from ferrous alloys, aluminium alloys, Ni and Ti super alloys are produced by precision forging.

Crucial issues in precision forging are the process design, die design and die manufacturing. Depending on the complexity of the component, two-piece dies, shrink / interference fits, and wrap dies are used. In precision forging, internal surfaces of the die cavity have to be corrected for elastic deflections and thermal shrinkage / expansion.

Precision Forging Design Space

Figure 1 depicts a design space for precision forging, as a constraint envelope with fixed parameters (intrinsic variables), flexible parameters (extrinsic variables) and interactive parameters. Intrinsic parameters are those, which have no scope for modification. These include:

- *Component design,*
- *Component material grade*

The extrinsic parameters on which the designers have some control include:

- *Process (cold / warm/….)*
- *Equipment*
- *Die materials, design, coating*
- *Lubrication*
- *Preform design*

The interactive parameters include:

- *friction,*
- *interface heat transfer,*
- *metal flow,*
- *die load, die stress, die deflection,*
- *die life* and so on.

The "constraint envelope" is the space within which the design process is carried out. This includes:

- the cost and volume of production
- equipment available (load capacity, rigidity, axiality etc.)
- measurement & testing accuracy.
- desirable mechanical and geometric properties of forged component.

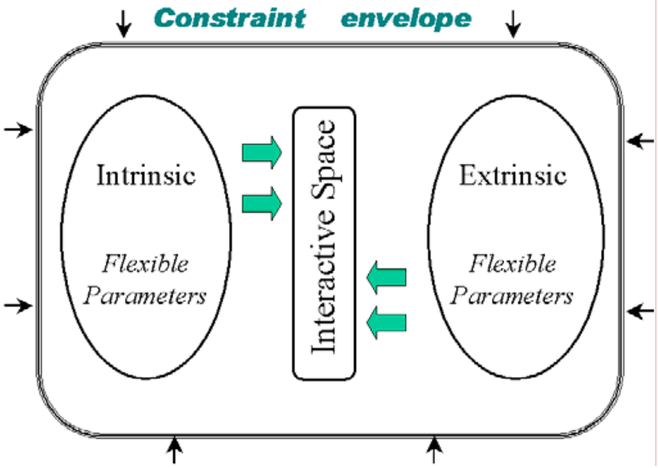


Figure 1 Design space for precision forging

A comprehensive treatment of the effect of all these parameters on forging design is not within the scope of this paper. It suffices to mention here that for a given component, there are several combinations of possibilities for process and die design of precision forging. In the current market condition the designers have to respond fast (very short lead time) and accurately with the design challenges of precision forging.

The objective of the efforts at PROSIM is to arrive at rationalized and accelerated design strategies for precision forging producers by using process modeling and simulation as a tool.

Process Modeling

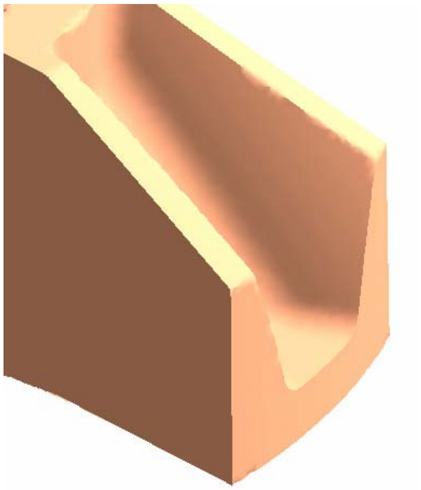
Process modeling is a technique where the computer is used as a *'virtual forging shop'*. Large number of 'simulated' experiments can be done on the computer at remarkably higher speeds and relatively low costs. Although different mathematical techniques are available for computer simulation, finite element method is the most preferred because of its mathematical robustness and accuracy. Process modeling is used as a virtual computer aided try out laboratory.

In the present paper, some examples of application of process modeling are presented.

Metal Flow and Defect Prediction:

Figure shows the metal flow in warm forging by using pressure cushions. Figure 2a shows the formation of lap due to the defect in design. Figure 2b shows a defect free component.

Figure 2 Net shape forging of gear a) fold formation



b) perfect forging design.

Figure 3a shows the lap formation in a multi stage cold drawing operation. Elimination of this lap required the punch and die in the previous stages of the operation.

Figure 4a shows the underfill of die cavity of a cold forged component from the actual try-out and Figure 4b shows the predicted results by process modeling. Proper die filling was subsequently achieved by modification of perform and die shape using simulation.

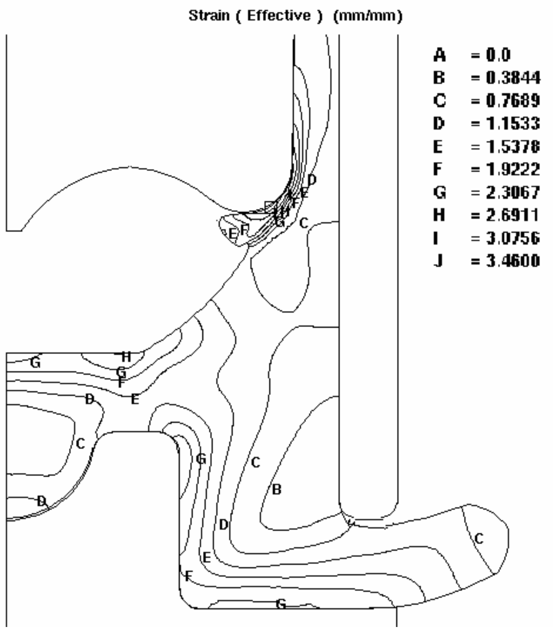


Figure 3a – Lap formation in the final stage of cold drawing operation.

Die Failure:

Using process modeling, the state of stress in the dies (as well as in the components) can be estimated. Several creative design options are possible to overcome unfavorable stress domains.

Figure 4a Underfill in the forged component

Tensile maximum principal stress is known to cause die failure catastrophically or by low cycle fatigue. Using shrink rings of different interferences and tapers this stress state is altered. Figure 5 shows the stress distribution in a cold forging in the die. Regions of tensile and compressive stresses are seen. While the peak tensile stress exceeding the UTS of die material causes die fracture, the stress level also influences the life due to low cycle fatigue.

Die Wear

The hydrostatic component of the stress (mean stress or pressure), especially at the die surface characterizes the die wear. Figure 6a shows the mean stress evolution with stroke time at two locations in the die one at billet contact point on the die (point –1) and other in interior die surface (point –2) explained in Figure 6b. Although the points 1 & 2 are close in the die, their stress level is remarkably different. The point close to the surface is severely stressed causing high wear.

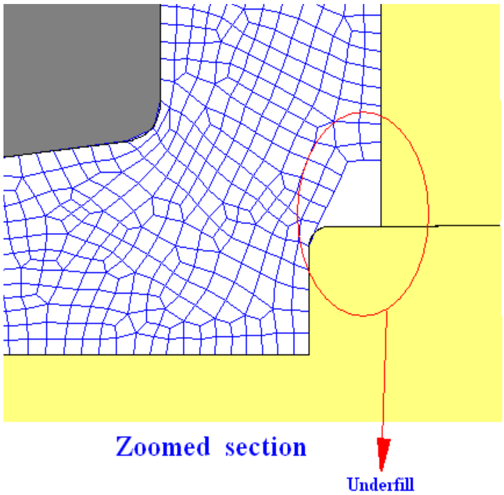


Figure 4b Underfill predicted by simulation

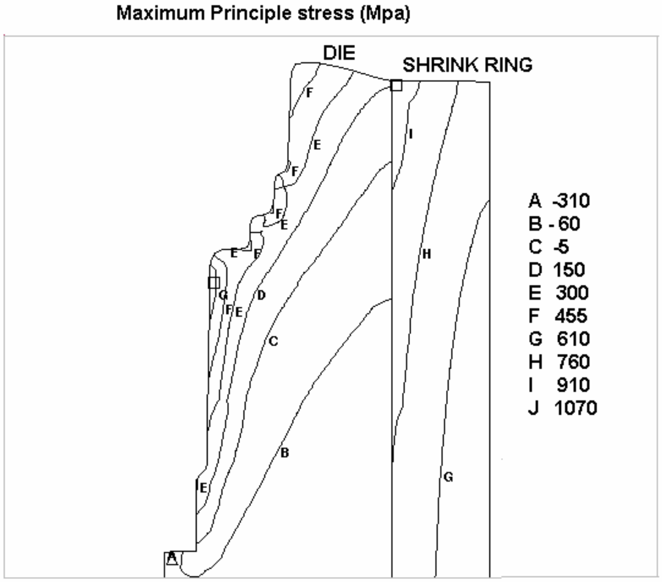


Figure 5 Stress in the die and shrink ring in cold extrusion

Die Deflection (elastic)

Die deflections are known to deviate the net shape of the product and the same has to be compensated. In forging of parts with no taper, where die draft cannot be used, this will be more critical. Figure

7 shows the punch deflection in a cold drawing operation, where the maximum deflection was about 6 microns, but still causing premature punch failure.

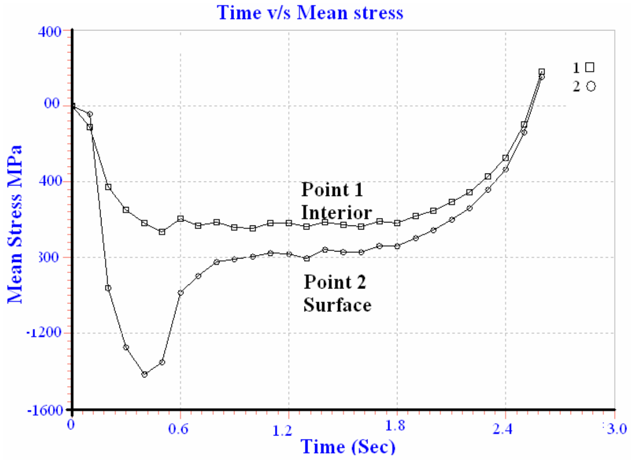


Figure 6a Mean stress at die locations as a function of die travel

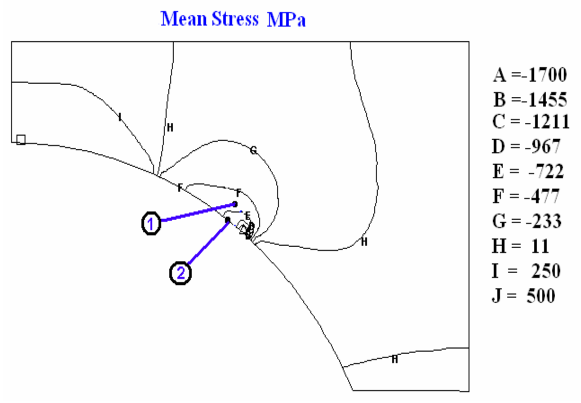


Figure 6b Mean Stress contours in the die at an intermediate stage of forging.

Preform Shape Optimisation

Preform shape has to be optimized to ensure proper die filling and to minimse the billet stock (to reduce the scrap and increase the yield). *ProSIM has developed expertise in applying inverse modeling as tool for perform shape optimization.*

Figure 8a shows the forged component (at the end of simulation) with a large flash area. Out of this area, the zones which can be minimized for yield improvement have been marked as seen in figure 8a, for inverse modeling point tracking.

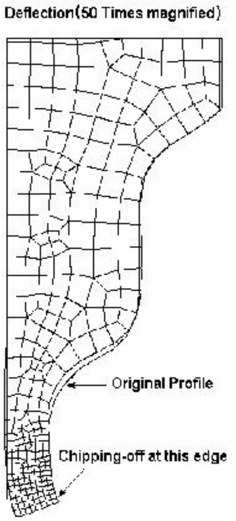


Figure 7 Punch deflection superimposed over original profile.

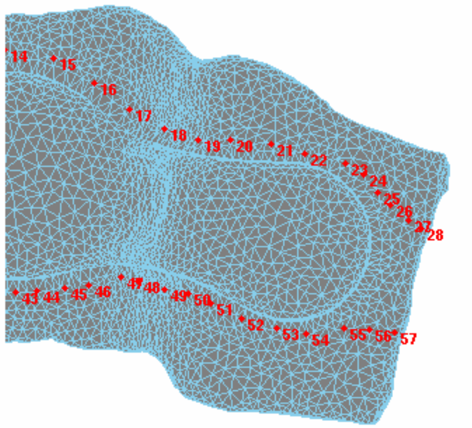


Figure 8a Forging with flash by conventional design. Points marked for inverse model point tracking.

By inverse modeling, from these points, we can get the initial location of these points, which form the initial perform shape for optimized configuration as seen in 8b. Figure 8c shows the forgings with the initial and the optimized performs superimposed. The modified preform has shown a scrap reduction of about 12%. In the actual process, by using inverse modeling procedure, scrap reduction of 26% was achieved compared to conventional perform design.

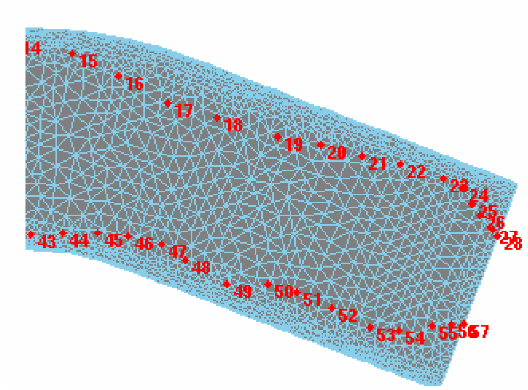


Figure 8b Preform shape obtained by point tracking and inverse modeling

Figure 9 shows the connecting rod perform optimization. In this case, by optimizing the preform shape a yield improvement of 13% was achieved.

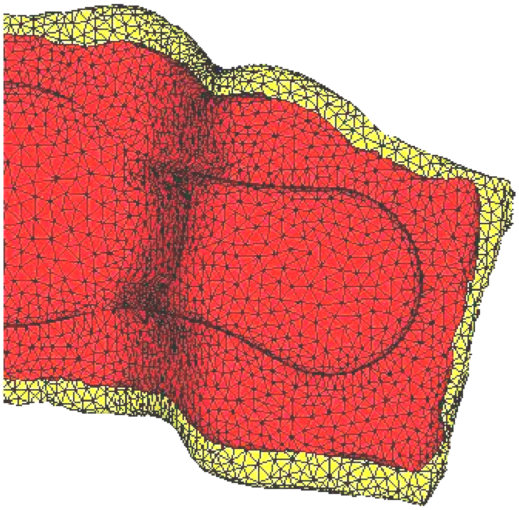


Figure 8c. Flash pattern from initial and optimized preform superimposed.

However, apart from the perform shape, a change of cross section of the billet stock, and the method of production of preform was also to be changed to obtain desired effects.

CONCLUSIONS:

Process modeling of forging can help in the accelerated and accurate development of precision forging. Successful application of process modeling requires a comprehensive interdisciplinary understanding of the numerical schemes, forging process, die design procedures, forging equipment and metallurgy. ProSIM has developed a center for excellence in forging.

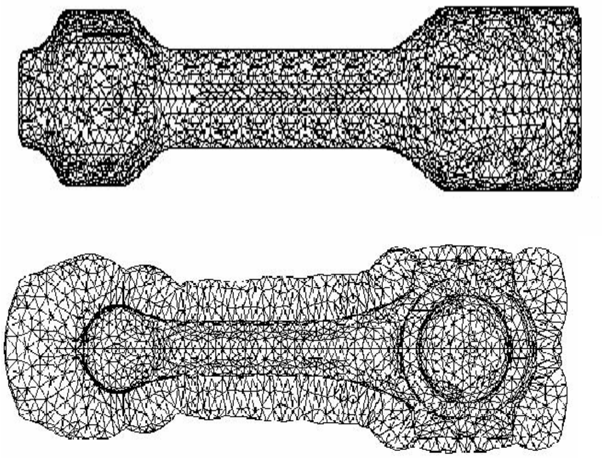


Figure 9 Connecting rod preform optimization