COMPUTER SIMULATION BASED DESIGN AND OPTIMISATION OF DIE FORGING OPERATIONS

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ABSTRACT

Industrial case studies of application of computer simulation methodologies for design and optimization procedures are described. Application of inverse modeling to the optimization of perform design is discussed. Finite element simulation which is now being used in the forging industry routinely for analysis and virtual die try outs, has to be extended (a) more down stream operations such as heat treatment & machining and (b) to perform design, and process optimization. The paper discusses the latter application in brief. **DEFORM** (©Scientific Forming Technologies Corporation, Columbus, OH) has been used with appropriate subroutines developed at **ProSIM** as the simulation engine in all the case studies.

INTRODUCTION

ProSIM is a process simulation and modeling research laboratory with focus on metalworking and materials technology operations. Present paper discusses the following case studies. Some of the typical results are shown in the paper.

- Hot profiled extrusion
- Cold blanking – punch design
- Die stress in Cold extrusion
- Rotary swaging of Rods
- Forming of tubes
- Cold forming, blank shape optimization
- Connecting rod perform design

Hot extrusion of profiles

Simulation of hot extrusion of aluminum was carried out. A 300 mm diameter billet of PM-AlFeSi was extruded at 420^{o}C, with the dies preheated to 455^{o}C to obtained contoured profiles. Simulations have been used to design the dies. Figure 1 shows the stress distribution in the workpiece, after the extrusion has reached steady state. Figure 2 shows the temperature distribution is a sectioned profile. The temperature, strain, and strain rate distribution determine the microstructure evolution in the extrusion, which is an important parameter of the study. The preliminary die design is completed and the work on microstructure modeling is on going.

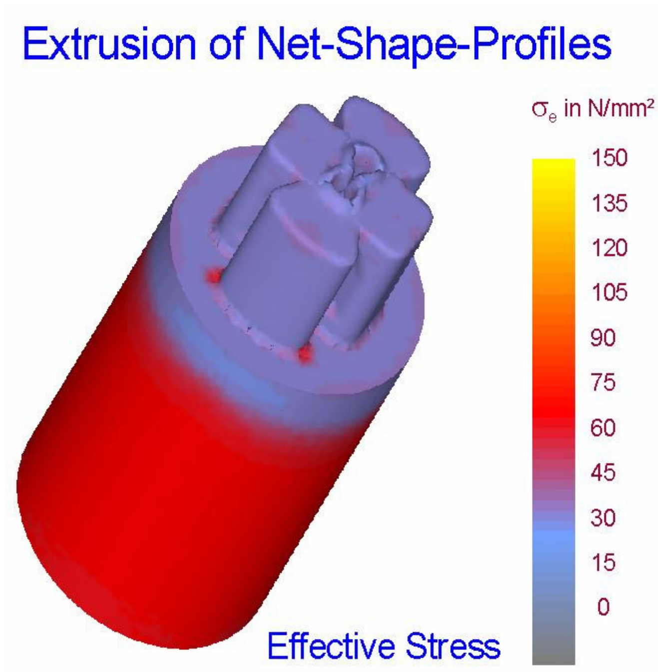

Figure 1. Effective stress distribution in a hot aluminum extrusion

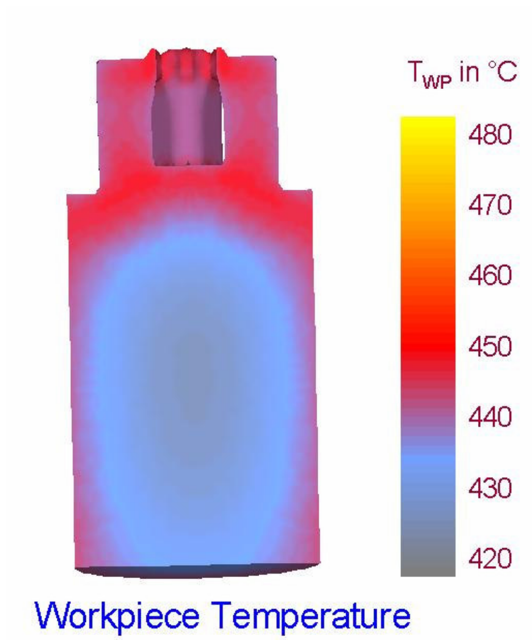

Figure 2. Steady state temperature distribution in hot extrusion.

Cold Blanking – Punch Design.

The case in question is a combined extrusion process involving piercing, blanking and extrusion. The punch life was very low. The initial focus was on the punch stress and punch material selection. After careful analysis, it was found that the punch material, production and heat treatment were not posing any problem. After comprehensive simulation studies, it was found that the punch was deflecting by a very small magnitude, (as shown in figure 3), which would foul with the die, (as shown in figure 4) and break by chipping. Interference of the shrink rings and the shrink ring design were changed to ensure proper production.

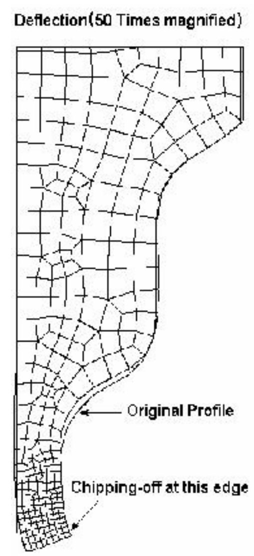

Figure 3. Deflection of blanking punch (magnified 50 times)

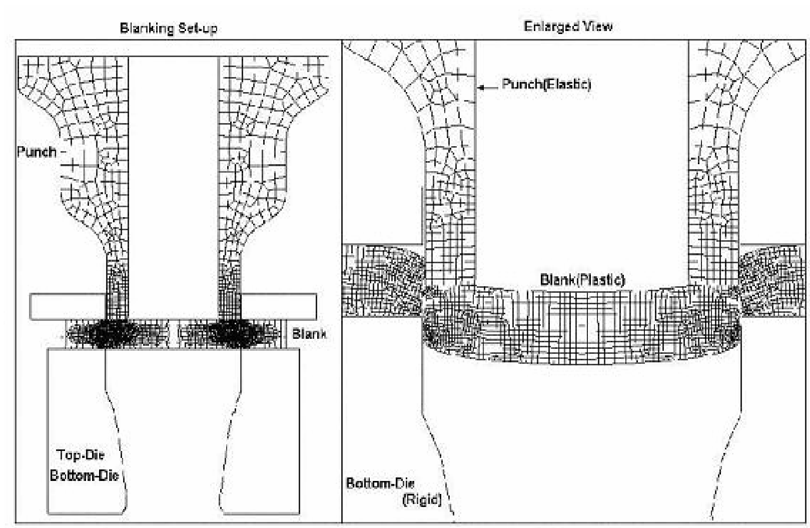

Figure 4. Die-Punch assembly for the combined extrusion process

Die Stress in Cold Extrusion

An automotive Inlet valve is produced by cold extrusion. In the original design used, the dies were failing. The die stress analysis has revealed that the peak stresses were unsafe (high tensile stresses) as seen in figure 5a. The die-punch design was modified which brought down the stress level as shown in figure 5b, which enhanced the die life.

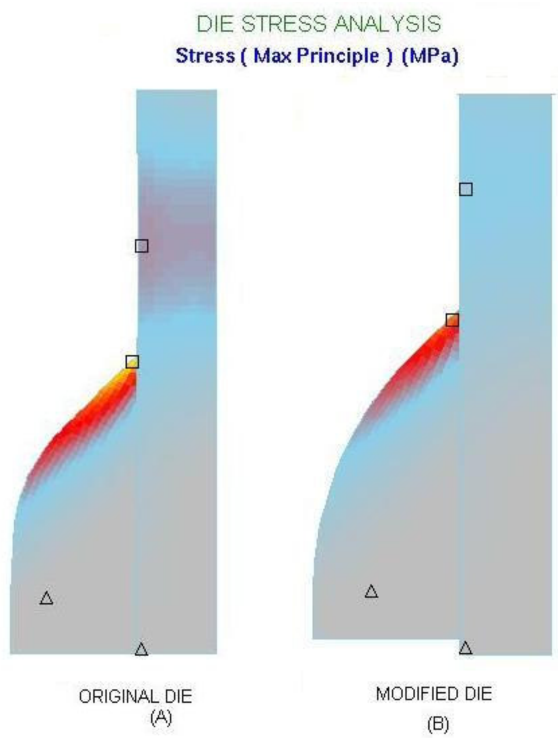

Figure 5. Maximum principal stress in the die and shrink shell. (a) high tensile region (yellow) in original design, and (b) modified design with reduced stresses.

Rotary Swaging of Rods

Rotary swaging is a complex operation. Designers are concerned about the reduction ratios to be given in each stroke and the amount of straining and the depth of strain hardening. In the rotary forging operation, there is a metal flow in both forward and backward directions. It is important in simulation to characterize the extent of metal flow in these directions. The stiffness of the machine tool arm, the die/billet geometric configuration determine this flow tendency. Figure 6 shows the metal flow tendencies in the rotary swaging of rods, simulated as simple 2D axi-symmetric cases. Figure 7 and 8 show the strain and effective stress during a two-stage rotary swaging operation.

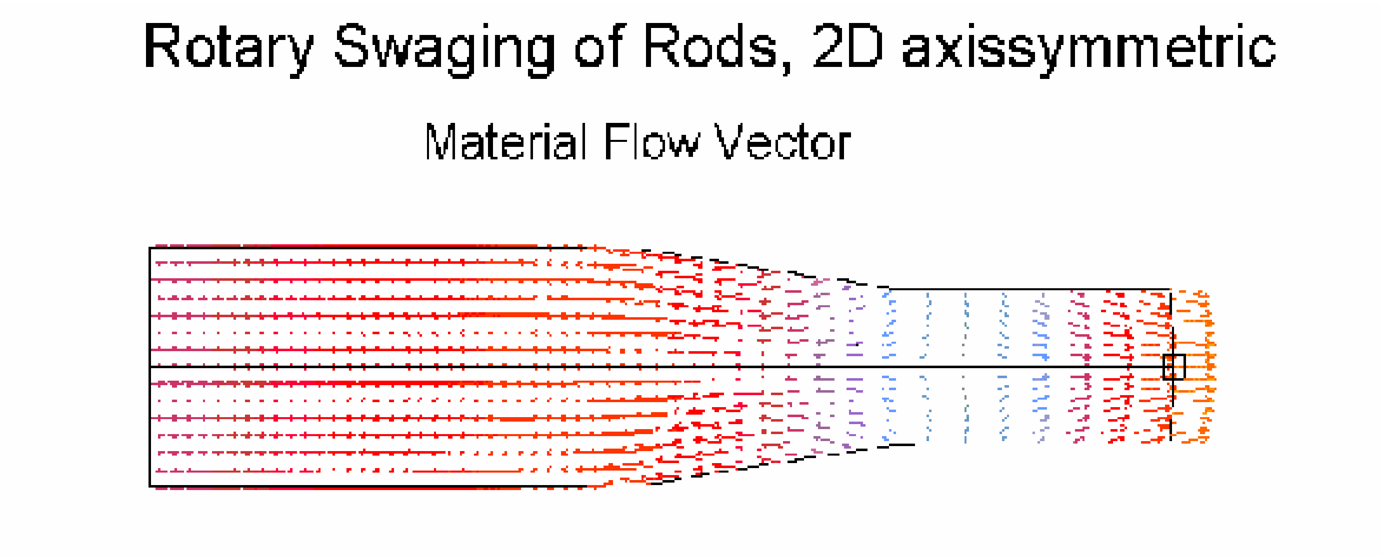

Figure 6. Metal flow direction in rotary forging simulated using 2D Axisymmetric simulations to get a first cut feel.

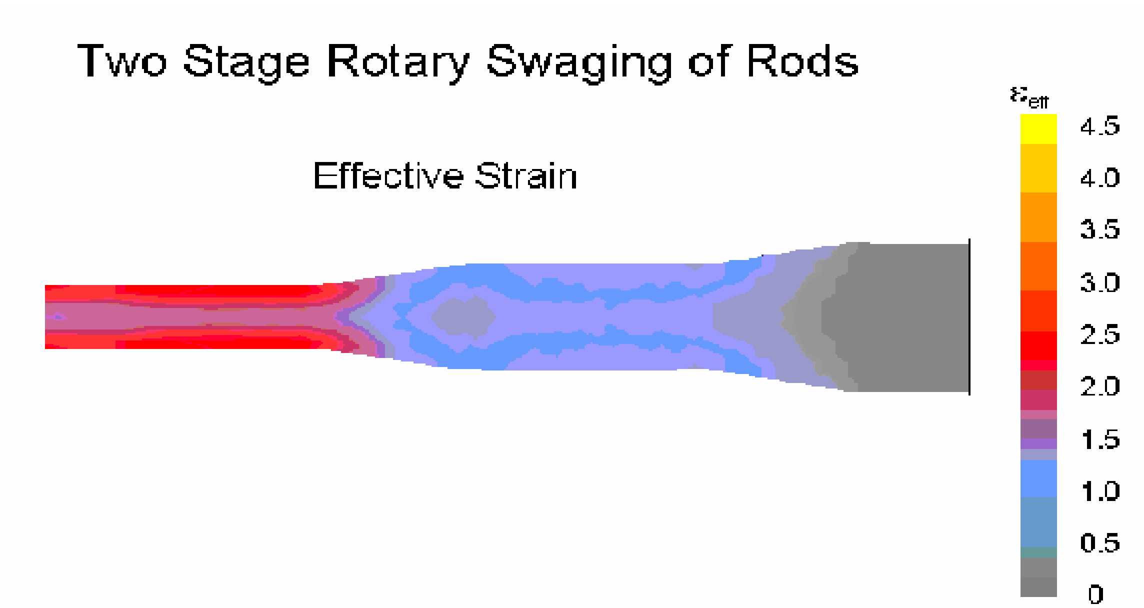

Figure 7. Effective strain distribution in two stage rotary swaging operation of a rod.

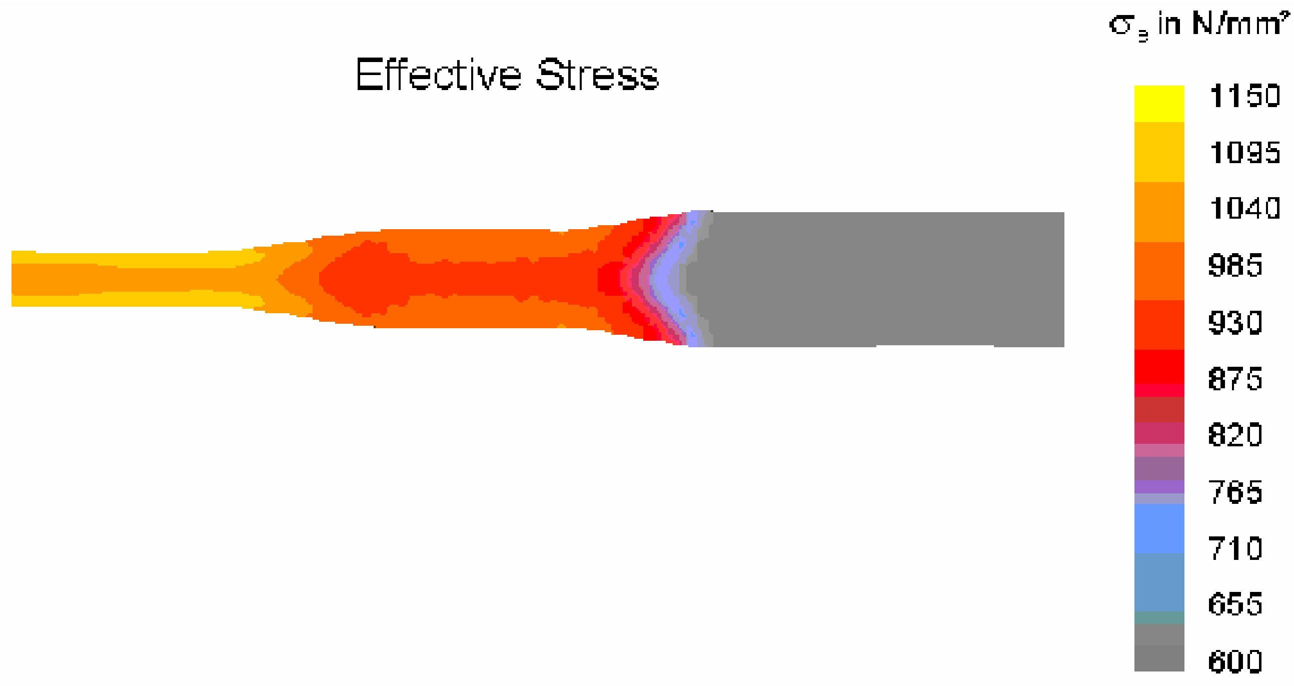

Figure 8. Effective stress distribution in two stage rotary swaging of rod.

Forming of Tubes
Tube forming operations are especially difficult to design. To get the net shape / precision products is often difficult on the shop floor. The elasto-plastic simulations have to be used to predict the defects such as ovality. Figure 9 shows the effective stress distribution in the tube forming where the thickness of the tube is reduced by swaging with a mandrel. Figure 10 shows the effective strain in the tube during swaging

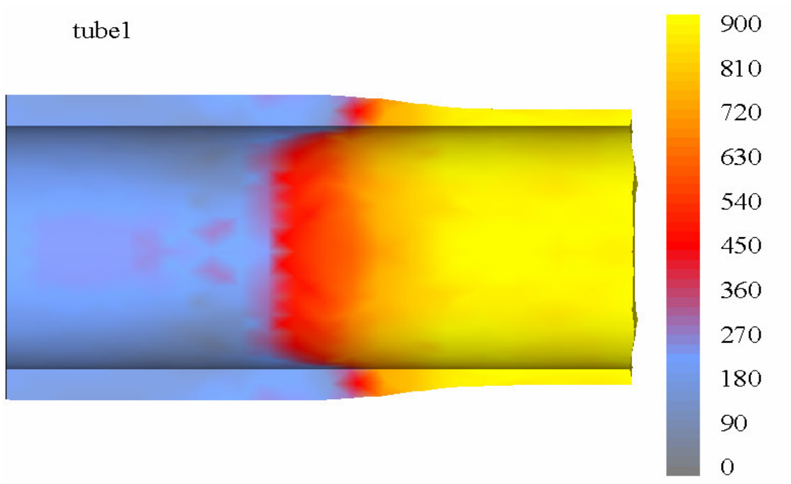

Figure 9. Effective stress distribution in the tube during swaging.

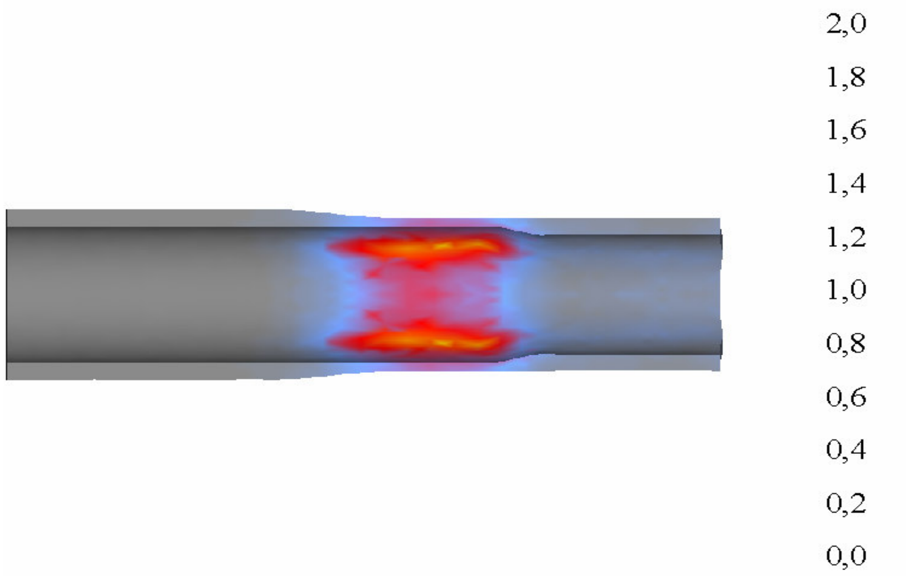

Figure 10. Effective strain distribution in the tube during swaging.

Figure 11 shows the schematic of the mandrel and tube used for simulation.

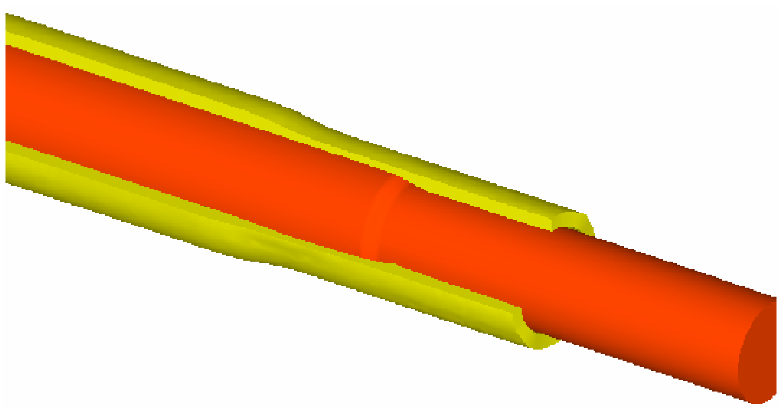

Figure 11. Mandrel and Tube Assembly Schematic.

Cold forming – Blank optimization:

A cold forming of blank is taken as a demonstrator for application of inverse modeling technique to blank shape (preform design) optimization. Figure 12 shows a symmetric section of the final component. This component has been forged by a non-optimal blank, which is resulting in unwanted flash. We have used the point tracking facility in DEFORM to carry out the inverse modeling. The possible periphery of the component with minimum allowable flash is marked for reverse point tracking (as has been marked in figure 12a). By running the reverse (i.e., from end to start) point tracking in DEFORM, we get the possible initial locations of the points selected (in figure 12b). The envelop of initial points is now taken as the outer periphery of the blank. Simulations are run for the modified blank geometry, and the issues such as metal flow, defect formation, under filling are checked. The initial blank design is modified wherever needed. Out of this shape, a suitable optimum blank has to be chosen to take care of issues such as easy manufacturability, handling and so on. Figure 13 shows the flash formation for two different blanks. Yield improvement in this particular case was of the order of 18%.

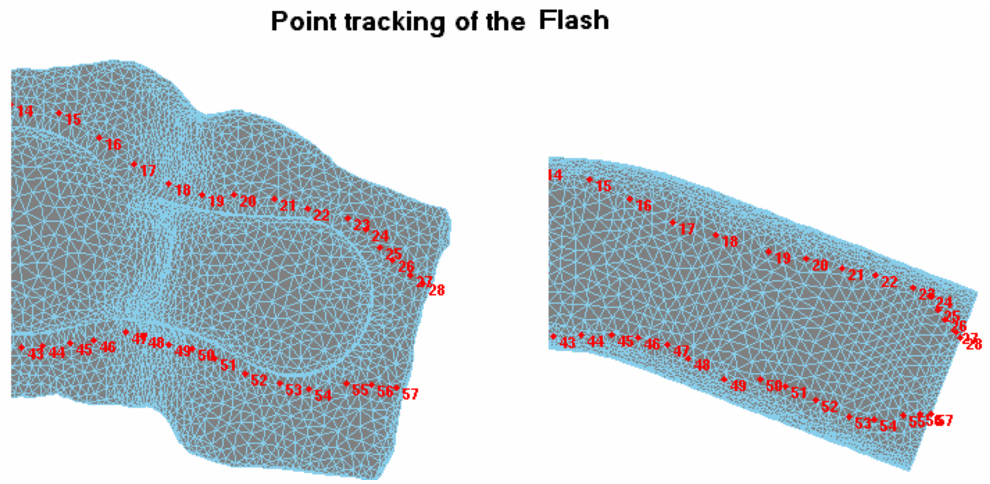

Figure 12 Cold Forming Blank (preform) optimization to minimize the flash. (a) Simulation of forging with original blank, showing the marked points for tracking. (b) Marked (in red) points indicated the possible optimum blank shape superimposed on the original blank shape.

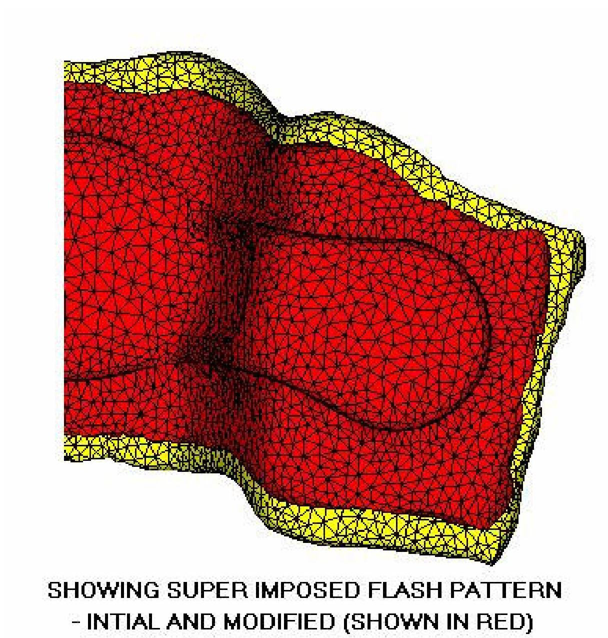

Figure 13. Comparison of flash lengths after forging with optimized blank and the original (un-optimised) blank.

Preform Design of Connecting Rod.

Similar inverse modeling technique is applied to the preform re-design of hot forging of connecting rod. Figure 14 shows the preform (produced by rolling of rounds). The connecting rod produced by the preform is shown in figure 15. Here the yield improvement is about 13 %. By using the inverse modeling it was found that the preforms produced from flat bars, used earlier were not optimum.

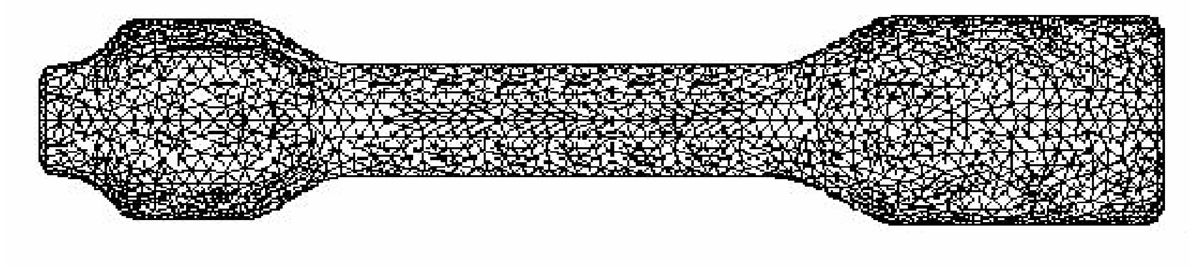

Figure 14. Optimised Preform rolled out of round billets.

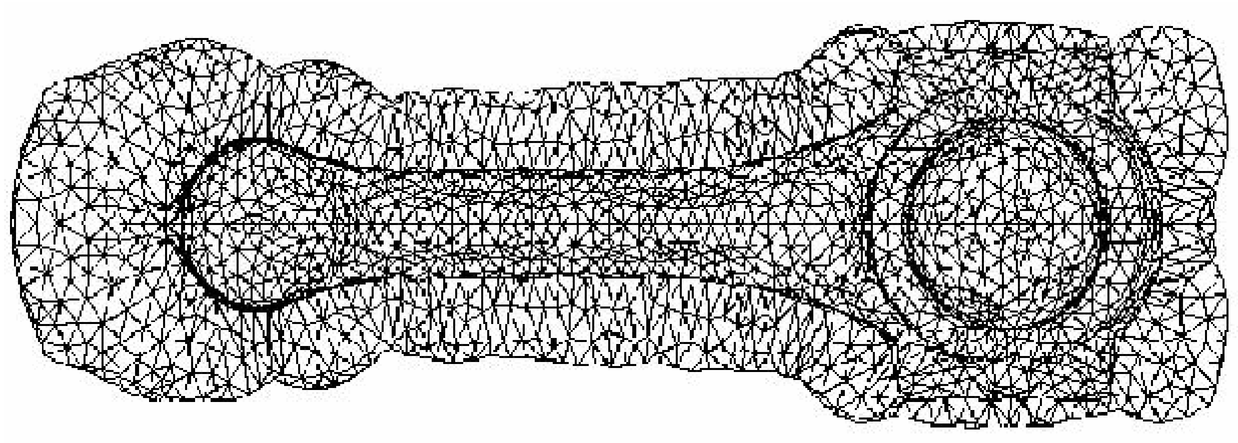

Figure 15. Flash after the hot forging of connecting rod

CONCLUSIONS

Some case studies of application of computer simulation to industrial metal forming operations have been demonstrated. Finite element simulations, when applied with care and due considerations of plant parameters can be used for process design and process re-engineering as well as the optimization of existing processes. While the usage of simulations packages is increasing as a virtual die try out tool, there is more education required (especially for the small and medium enterprises) to make use of the advanced capabilities of the simulation tools.