Journal for Technology of Plasticity, Vol. 33 (2008), Number 1-2

SOME ASPECTS OF FORGING MODELING

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ABSTRACT

This paper written in part with a European perspective describes recent research by the author and co-workers in the area of metalforming processes and highlights some areas for future research. Forging simulation is initially discussed against a background of the commercial case for its use. From early research developing the Upper Bound Elemental Technique (UBET) methods of designing preforms are discussed that include a reverse simulation technique based on a Tetrahedral Elemental Upper Bound Analysis (TEUBA). Interface properties can be quite critical in metalforming but yet the data that is integrated with commercial simulation software is not quality assured. Some research on modeling of friction and heat transfer to overcome this problem is described.

Key words: *Forging modeling, UBET, TEUBA*

1. INTRODUCTION

A major contribution to the wealth and competitiveness of the EU can be made through its manufacturing industry and a core aspect of that industry is the production of metallic parts by casting and forming processes. Whereas casting involves solidification of molten metal into a mould defining the shape required, in contrast forming processes takes a piece of stock material and deforms it plastically i.e. in the solid phase using profiled dies to produce the required shape. In many cases the process requires several sets of dies to achieve the overall shape transformation.

The fundamental conservation of material resources inherent in forming processes makes them particularly attractive for environmental reasons when compared with machining and casting processes. Within the range of forming processes, forgings are to a limited extent competitive with castings as an efficient means of producing shapes. However only forgings, exploiting their inherent aligned fibre structure, can provide the necessary mechanical properties and assurance of product integrity necessary for many components. These processes will therefore continue to be required as long as the motor and aerospace industries exist. Similarly for resilient sheet components such as car and airframe panels only forming processes are acceptable

In the user industries of formed products the main development thrusts, which are required, are:

- Improved engine and vehicle efficiencies
- Reduced pollution from products
- Improved manufacturing efficiency and conservation of resources

In terms of formed parts this can be achieved by:

- Improved strength to weight ratios components
- Improved consistency of product supply
- Flexible delivery of parts
- The production of nearer to net shape parts
- Reduction in material wastage

For the parts supply industry some of the implication of this are concerned with how to acquire and use:

- Improved efficiency by introducing flexible batch size production
- Reduced lead times from design to product and avoidance of trial & error methods
- Improved net shaping technology
- Reduced reliance on manual and experiential skills

To meet this demand the following is required:

- Improvement and take up of knowledge based systems for the tool and process design
- Improvement and take up of modelling/simulation techniques
- Better predictability product structure and properties
- Enhanced adoption of concurrent engineering methodologies

The forming industry is largely comprised of SMEs and is operating in a global market with strong competition from the Far East where lower labour costs enable a good competitive edge to be gained. European manufacturers must therefore compete on a technological basis as outlined above.
An account of some of the research conducted by the author and co-workers in recent years now follows. This highlights some of the problems and possible solutions.

2. FORGING SIMULATION TOOLS AND PERFORM DESIGN.

A range of simulation packages is now available commercially. By and large they are accurate and impressive in the detail that they can predict. There are many examples where the simulation has enabled flow defects in the form of die under fill and folds to be avoided by using simulation thus avoiding the need for costly trial and error methods to prove the process. A very sound financial case can be made for the investment in the software on this basis alone. In the aerospace industry supply companies where the requirements are sometimes more sophisticated, for example the prediction of microstructures, the case is even more readily made.
The early days of forming process modelling were set against a backdrop of only limited application of computers in the forming industry. There was a distinct feeling that the introduction of any computer-based methods would remove someone's job rather than enable the product to be made more cheaply. The author and several co-workers were at this time researching upper bound based methods for forming analysis and had been able to computerise an elemental approach proposed by Kudo(1). This Upper Bound Elemental Technique (UBET) (2) was somewhat easier to use than the Finite Element based methods that were being researched at that time and was thus

more readily accepted by the industry. Fig 1 shows the rather crude basis on which the workpiece was subdivided into elements. The technique was however limited to 2D applications and whilst being extremely fast and easy to use compared with the Finite Element methods available, this advantage was being eroded rapidly. But, with UBET it had been possible to develop a unique reversing technique that started with the finished shape of a forging and established the ideal shape of any intermediate or preform stages that might be required (3). This advantage still remains. Also the processing speed advantage has been maintained by developing a 3D version of the method that also incorporates the reversing concept for preform design.

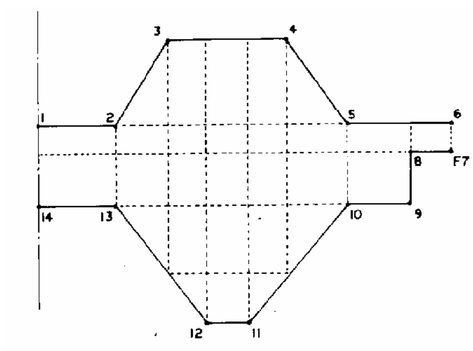
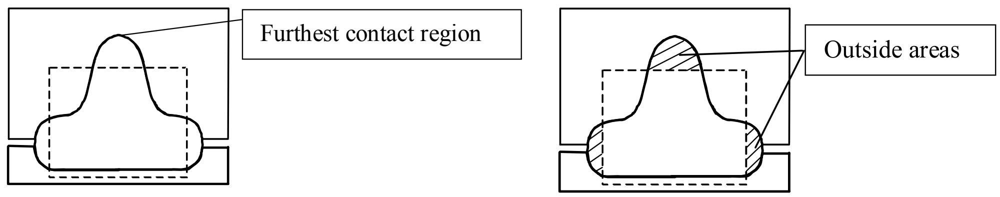


Figure 1 - UBET elemental subdivision

The method used is based on the measure of the material distribution to set a rectangular target shape for plane strain forging problems. The material distribution of the workpiece varies during the forging process. In most cases, the initial shape of the workpiece needs to be a simple geometry, such as a rectangular or circular section for two dimensional plane strain applications. The reverse simulation should be able to find a deformation path, which always leads towards a simple distribution, from the finished product geometry to an initial billet. In order to satisfy this requirement, it is necessary to set a target shape with a simple material distribution to determine the boundary conditions for the reverse simulation. A rectangular section is supposed to be the billet section, i.e. the target shape, in this research for plane strain applications. The second moment of area is used for this purpose to set a rectangular target shape with the closest distribution to the workpiece in plane strain cases. The target shape is then used to identify a contact region, i.e. a node in a finite element model, which will be released from a die surface and thus the boundary conditions can be established. Fig. 2 shows a rectangular target shape identifies the furthest contact region and is used to calculate the complexity. The reversed shape is then compared with the shape resulting from no-node-released boundary conditions. because the time to release the node is unknown. The simpler one of these two reversed shapes is selected. The procedure is repeated until all contact nodes are released. If the shape so determined is very close to a rectangle, the billet size can readily be established. However, the reversed shape may be still complex. In this case, a preform is needed and the determined shape is taken as the finished product to run another reverse simulation until a simple shape close to a rectangle is found. More details of this procedure can be found in reference (4). An application is illustrated in Fig 3. It is based on a tetrahedral element formulation.



(a) Rectangular target shape

(b) Complexity calculated by outside areas

Figure 2 - Rectangular target shape used to identify the furthest contact region and to calculate complexity of shape

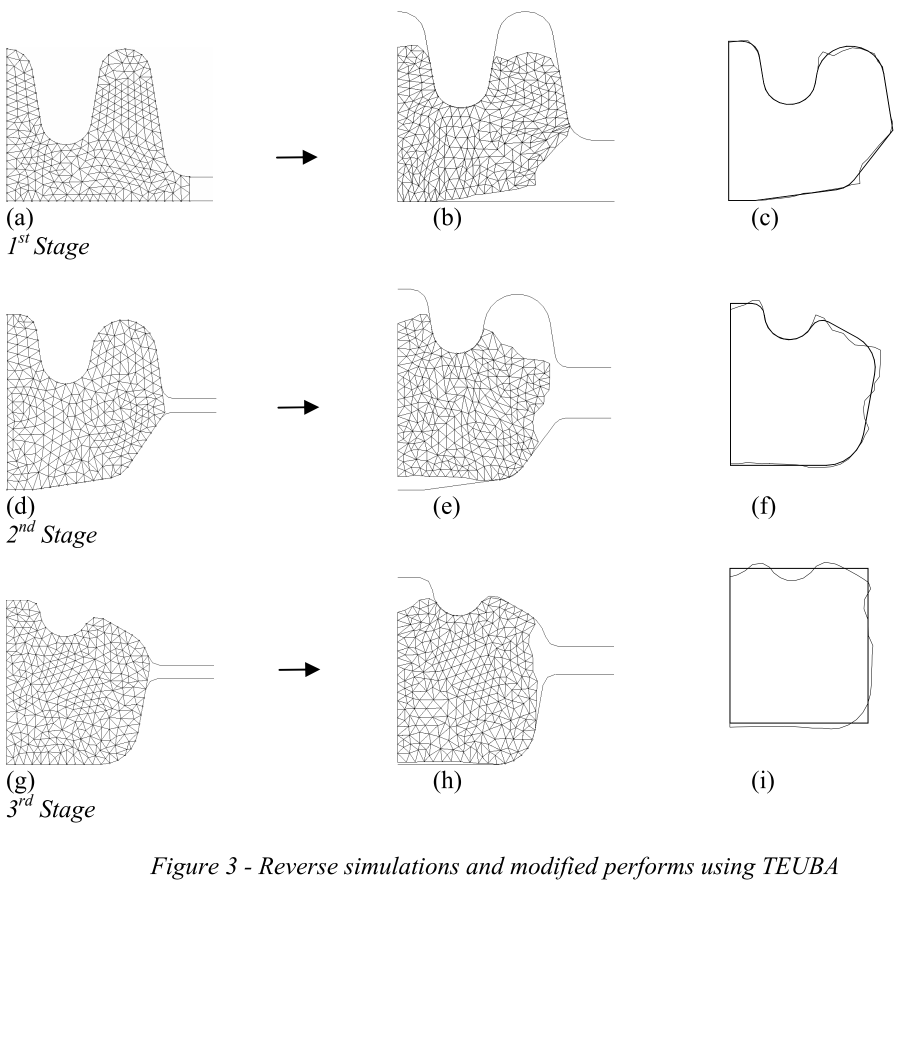


Figure 3 - Reverse simulations and modified performs using TEUBA

3. CERAMIC TOOLS.

As the demands made upon hot and warm forging and extrusion tooling to perform to new levels of productivity continues to grow, the challenge to engineers, and material scientists alike calls for a new approach. Until now, hot working tool steels have been the only cost effective die material option. Recently, the use of ceramic materials as functional materials has increased rapidly in a wide field of industry, since they have many excellent technical properties such as high hardness, high corrosive resistance, high elastic modulus, etc.

The use of ceramic inserts in steel forging tools offers significant technical and economic advantages over other materials of manufacture. This arises largely due to the very high wear resistance of certain ceramic materials. These potential benefits can however only be realised by optimal design of the tools so that the ceramic inserts are not subjected to stresses which lead to their premature failure. This is now possible since reliable information on the loading conditions in forging tools can now be obtained from process simulation. In some cases die stress calculations can be coupled with the plastic flow analysis. Currently this approach can lead to excessive computing times and has not therefore been adopted in the work described here.

Kwon and Bramley (5) have established a method where the data on the loading of the tools is determined from a commercial forging simulation package as the contact stress distribution on the die-workpiece interface and as temperature distributions in the die. This data is then processed as load input data for a finite element die-stress analysis. Process simulation and stress analysis are thus combined during the design, and a data exchange program has been developed that enables optimal design of the dies taking into account the elastic deflections generated in shrink fitting the die inserts and those caused by the stresses generated in the forging process. The stress analysis of the dies is carried out to determine the stress conditions on the ceramic insert by considering contact and interference effects under both mechanical and thermal loads. An example is given of the application of this methodology and subsequent experiment trials for the optimal design of Zirconia and Silicon Nitride inserts in a simple forging configuration as shown in Figs 4 & 5

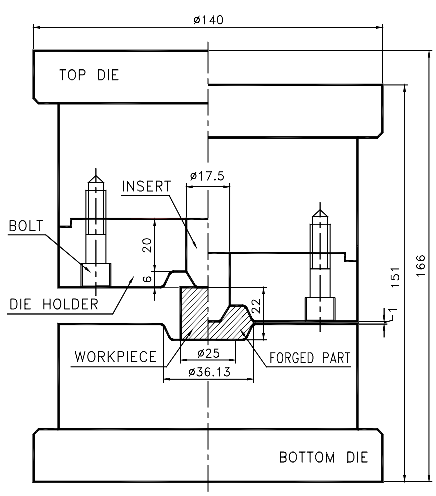


Fig 4 Forging tool set with ceramic insert

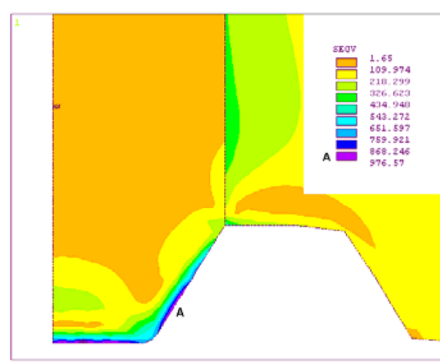


Fig 5. Die stress contours in the region of the insert

4. FRICTION MODELLING

For the simulation of metal forming processes, input data relating to the tool-workpiece interface is necessary. This can be crucial in terms of predicting metal flow and loads and in the case of microforming applications this input data becomes very much more critical and traditional methods are not realistic. It was therefore proposed to develop an approach that seeks to describe friction by modelling the geometric surface roughness of the tool (6). This finite element based model has been validated experimentally in terms of loads and metal forming using the ring test and actual surface measurements to obtain the equations (1) and (2) that related to the m-values to the surface profile.

$$m = 90.439\left(\frac{a}{t}\right)^3 - 59.321\left(\frac{a}{t}\right)^2 + 14.642\left(\frac{a}{t}\right) - 0.4921 \tag{1}$$

$$\frac{a}{t} = 1.6193m^5 - 4.3152m^4 + 4.7504m^3 - 2.3098m^2 + 0.6075m + 0.0028 \tag{2}$$

In principle the techniques requires the tool surface profile to be measured using normal metrology equipment. This gives an equivalent sinusoidal profile that is used in the simulation. In this way an ideal flat surface with an m-value is converted into a sinusoidal profile. This concept is shown in Fig 6.

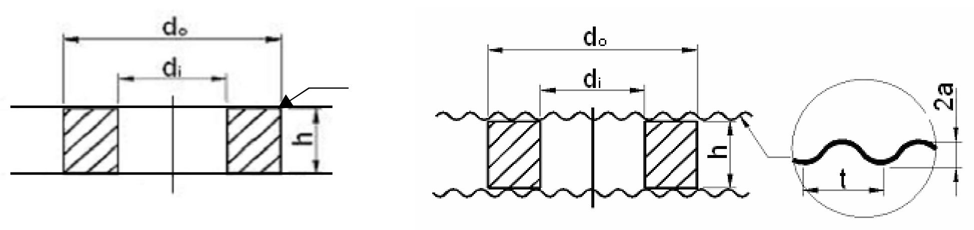


Figure 6 - Geometric model of the tool surface using a profiled surface

These equations were used to model the load displacement trace in ring upsetting and the results shown in Fig 7 demonstrate good correlation. It can potentially enable more accurate and also more flexible modelling of friction where the friction condition varies across the tool surfaces. Some preliminary investigations into applying the procedure to accommodate the behaviour of a lubricant are depicted in Figs 8. Here the lubricant film is modelled as a third material on the interface between the tool and the workpiece. Fig 9 shows some preliminary results indicating the way in which the lubricant can be trapped in the contours of the tool surface.

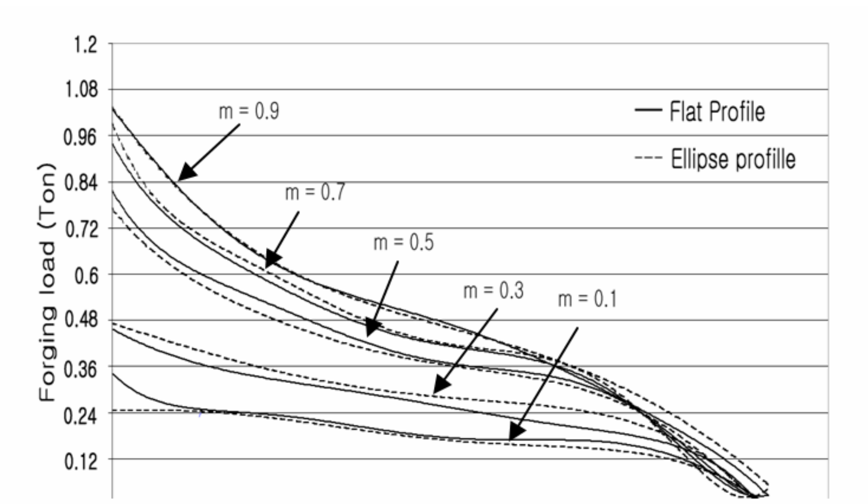


Figure 7 - Comparison of forging loads with conventional friction and a sinusoidal profiles die

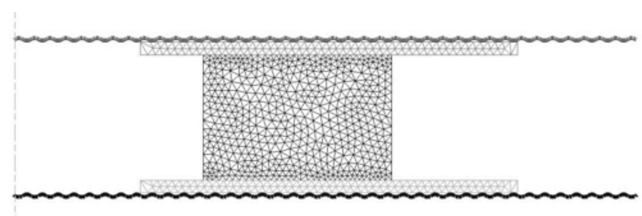


Figure 8 - Modelling lubrication

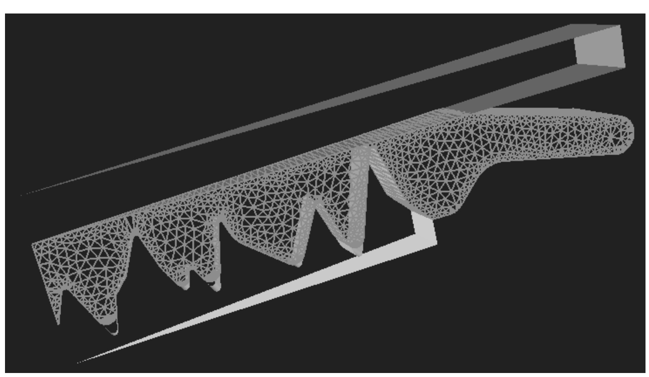


Figure 9 - Lubricant behaviour in forming

5. HEAT TRANSFER MODELLING

Heat transfer has significant effects on the forging process, especially in hot forging. This phenomenon causes non-uniform temperature distributions in the workpiece that can affect the quality of forged components. Heat loss from the workpiece causes its temperature to fall and thus increase the resistance to plastic flow. This effect increases the power required to perform the operation. The temperature increase in the die softens the surface layers making them more susceptible to wear. Thermal fatigue cracking on the die surface is also related to the temperature gradients occurring in the surface layers. Heat transfer at the workpiece-die interface is complicated. The influencing factors include the surface finish of die and workpiece, pressure and the film thickness of lubricant. The generation of heat resulting from the plastic deformation and friction effects at the workpiece-die interface further complicate the situation.
Numerical simulation of forging process is able to predict temperature change and other information such as forging load and stress and strain distribution. But, to ensure the simulation is viable for improving the forging quality or reducing the cost and lead-time, there is a need to obtain accurate the heat transfer coefficient for the simulation.
Some earlier research by Kellow, Bramley and (7) describes the construction of a robust surface thermal couple used to measure temperatures at the workpiece-die interface. This is shown in Fig 10. The thermocouple junction is formed by the slivers of die material that become spread across the insulation during grinding; the junction is maintained by the further sliding action when in use.

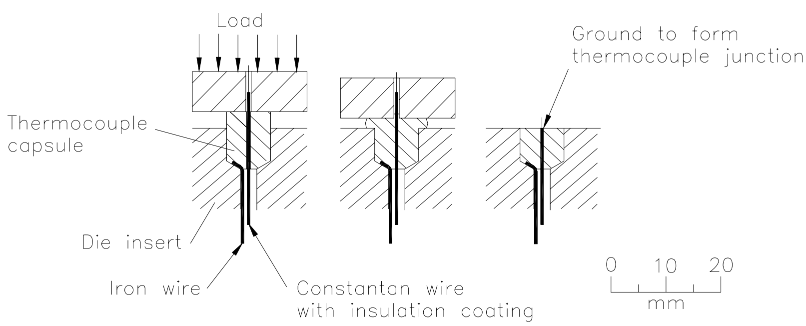


Figure 10 - The manufacture of the surface thermocouple

This was further developed more recently and coupled with FE simulations and the least square method by means of a reverse algorithm (8) to determine the heat transfer coefficient at the contact interface for the forging process. A flow chart of the procedure is shown in Fig 11. Some results are shown in Fig 12 and 13 and it can be seen that the value of the heat transfer coefficient changes quite significantly during the forging stage.

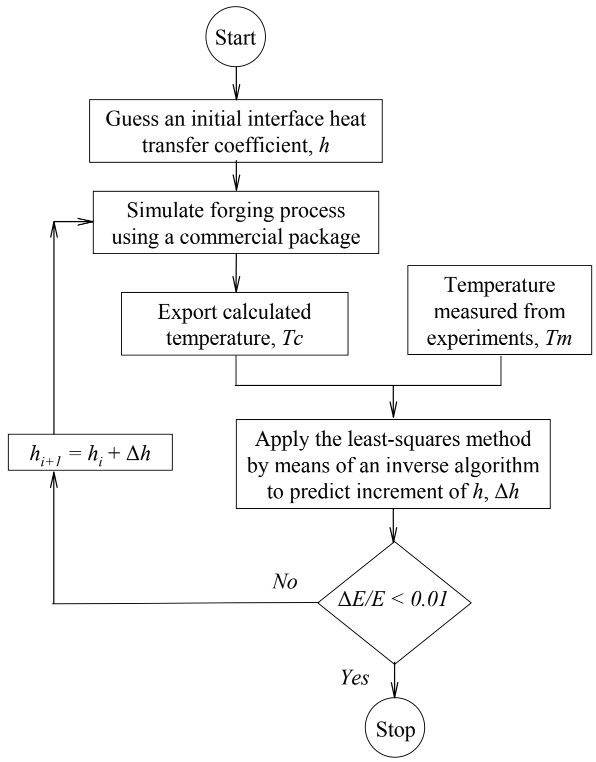


Figure 11 - Flow chart for the heat transfer coefficient determination

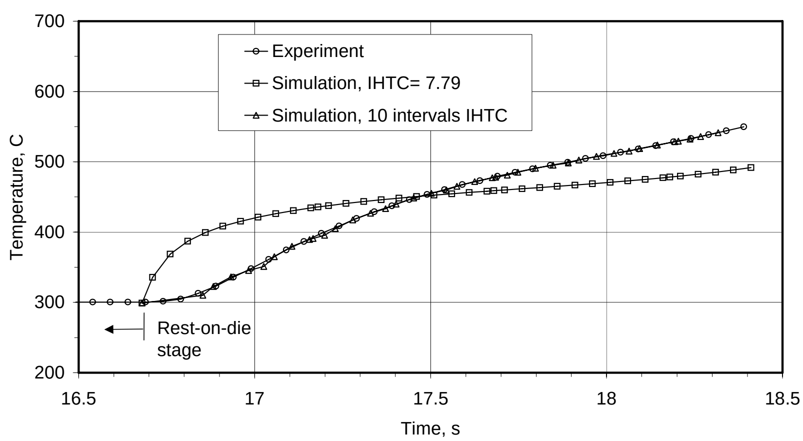


Figure 12 - Temperature comparison at the forging stage

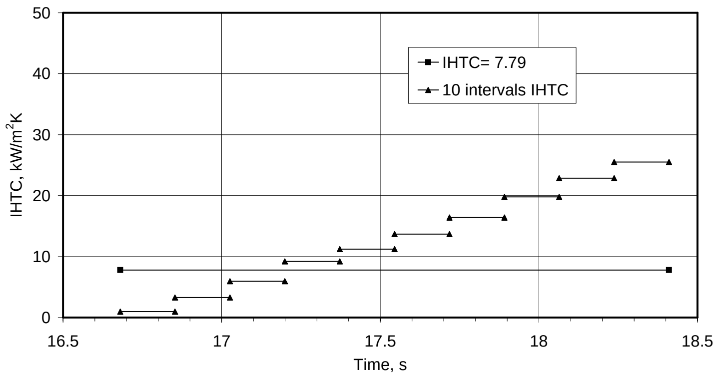


Figure 13 - Interface heat transfer coefficients at the forging stage

6. CONCLUSIONS

Forging simulation has become a very important tool in the industry but, as with all modelling technologies, the outcomes are only as good as the input data. This paper has shown how simulation can be used to design forging tools accurately such that very sensitive ceramic tool materials that have greatly enhanced wear resistance can be used effectively. A new method for the determination of heat transfer coefficients has been described. This needs to be taken forward to investigate how the coefficient might vary in different parts of the tooling and perhaps to establish more information about the heat transfer in other forming processes. Commercial software still cannot be used as a direct method for perform design; it can only reproduce a trial and error approach. A more direct reverse-modelling technique has been described. It has also been demonstrated that perhaps a new method

7. ACKNOWLEDGMENTS

The work described in this paper was carried out in collaboration with co-workers at the University of Bath and the author gratefully acknowledged the following: Dr F H Osman, Dr D J Mynors, Dr C C Chang, Mr H Jeon, Dr M I Ghobrail and Dr H H Kwon.

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NEKI ASPEKTI MODELIRANJA PROCESA KOVANJA

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REZIME

U radu je prikazan jedan broj istraživanja autora u oblasti tehnologije plastičnog deformisanja kao i oblasti budućih istraživačkih aktivnosti. Razmatran je problem simulacije procesa kovanja sa stanovišta komercijalnog korišćenja softverskih paketa. U prvom delu rada detaljno je prikazana UBET metoda (Upper Bound Elemental Technique) koja je u početku svoje primene korišćena za definisanje polufabrikata kod zapreminske obrade aksijalno-simetričnih obradaka. Tehnika povratne (reverse) simulacije koja je kasnije razvijena na bazi tetraedarskog UBET-a (TEUBA) je takođe elaborirana, a na nekoliko primera su proanalizirane mogućnosti i ograničenja ovog postupka.

Na kraju modeliranje „međugraničnih“ karakteristika (trenje, prenos toplote...) je takođe obrađeno i ilustrovano na konkretnom primeru.

Ključne reči: *Modeliranje procesa kovanja, UBET, TEUBA*