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Effect of Design and Process Parameter to Cold Forging
Die Design: A Finite Element Analysis

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Abstract: Cold forging process can be described as the process where a metal is plastically deformed at room temperature with application of huge pressure. The process not only changes the shape but also improves the properties of the forged parts due to grain size refinement. Currently the Computer Aided Engineering (CAE) tools are widely used as a replacement of the empirical trial and error method. The objective of this research is to model the cold forging process using finite element analysis. The study will investigate the stress distribution, load-displacement curve and effect of die geometry and lubrication to the die performance. Due to geometrical considerations and computational limitations, the study only involve of two-dimensional (2D) simplified model of cold forging process using ABAQUS software.

Key words: Cold forging die, die geometry, lubrication, Finite Element Analysis (FEA)

INTRODUCTION

Cold forging has various advantages including little loss of material, improved strength, geometrical precision of components and high production rates (Button and Roque, 2000; McCormack and Monaghan, 2001). There are several methods of studying forming processes which can be categorized as the analytical, numerical and experimental methods. The validation of analytical and numerical methods is carried out based on the experimental result; therefore to save the cost physical modeling is employed. In most cases numerical methods provide more flexibility than physical modeling since they allow for quick changes in the tooling design (Tong et al., 2003).

Many researchers have take the advantages of computer advancement to integrate CAD/CAM in design of optimal tooling (Jolgaf et al., 2003) and some of the others integrate CAD/CAM/CAE/RP in demonstrating forging process (Yang et al., 2002). In metal forming, the research can be divided into three main areas;

- Die Design, several tools and approach have been used such as CAD/CAM system, expert system and mostly FEA methods. Improvement of die design for optimal die life is the main area being studied.

- Process Planning, the research is focus on the development of the most efficient and economic process sequence and planning and it is commonly used expert system and CAD/CAM system as the medium.
- Product Performance, here quality and reliability of the final product. The defect such as die filling and cracking behavior are the area of focus. The approach usually taken are physical experimentation method, either physical modeling or real experiment.

In cold forging higher load is needed in order to complete the process. The higher stress applied, the shorter die life, because most of dies failed due to cracking under cyclic load or fatigue and wear (Falk et al., 2001). So that, to improve die performance, stress should be as lower as possible. Initially there are several method proposed to improve die life:

- Improve surface finish
  - Treatment (Farrahi and Ghadbeigi, 2006; Wagner et al., 2006; Jeong et al., 2001)
  - Shot peening
  - Nitriding
  - Nitrocarburizing
  - Hard roller burnishing

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- Laser beam treating
- Surface texturing
- Process Optimization
  - Forging steps/sequence
  - Preform (Lapovok, 1998)
- Minimize stress concentration (McCormack and Monaghan, 2001)
  - Die design
  - Fillet
  - Corner radii
  - Lubrication
  - Size
- Die material (Le and Chen, 2001; Vasquez *et al.*, 2000)
- Non-destructive test (Koc and Arslan, 2003)
- Pre-stressing element
  - Stress pin (Koc and Arslan, 2003)
  - Variable shrink-fit interference (Vasquez *et al.*,)
  - Split insert design (Vasquez *et al.*, 2000)

In other research, factor such as preform shape is also taking into consideration in order to improve dimensional accuracy of the forged parts (Koc and Arslan, 2003). Choi *et al.* (2006) study the effect of process parameter of round shape product focusing on feed rate and rotation angle for optimal forging pass design. They proposed an optimal process condition based on FEM result. Several other tools also used in determining optimal design and process parameter such as genetic algorithm (Castro *et al.*, 2004), sensitivity analysis (Zhao *et al.*, 2004) and inverse methods (Sousa *et al.*, 2002). Other area is the machining condition of the die such as depth of cut, type of machining tools and surface roughness of the die.

In this research, the die performance will only focus on effect of the die geometry and lubrication to the stress and strain lead determination of die life.

Forging parameter: There are many parameters that can influence the stress level during the cold forging process. The forging parameter can be divide into two, design parameter and process parameter. The former play roles during the die design process i.e., modeling stage and the latter during it use. Design parameter represents the geometrical aspect of the die such as corner radii and fillet. Process parameter is a variable related to the forging process such as process stages, load applied, shape of the die, preform and lubrication. Machining process of the die also consider as process parameter. The effect of some of the parameters have been studied numerical and experimentally. Figure 1 shows the forging parameters division.

MODELING

Main objective of this study is to investigate the effect of process and design parameter to die performance. For that reason two parameters i.e., geometrical aspect and lubrication aspect are selected to represent the design and process parameter respectively. The cases are dividing into two, with and without lubrication. As shown in Fig. 2, there are two radiuses involve i.e., R1 and R2 which can be further divided into four sets of model shown in Fig. 3. Details of parameter setting as list in the Table 1. Note that for set 1, the radius for both R1 and R2 are zero denoted that it is a sharp edge.
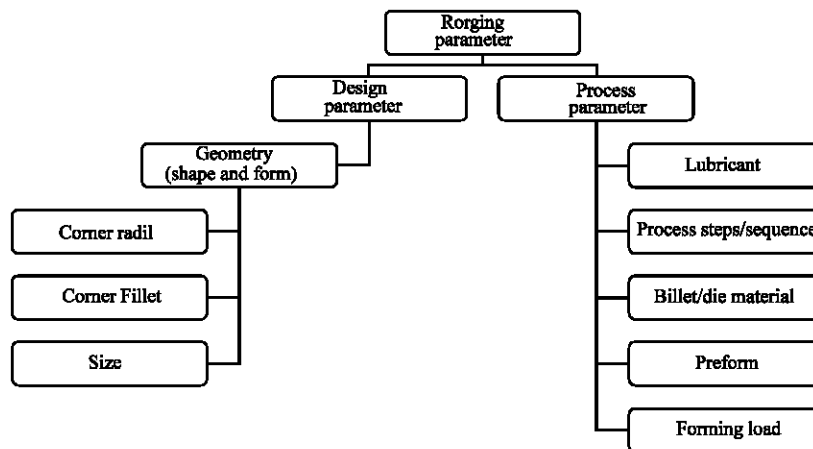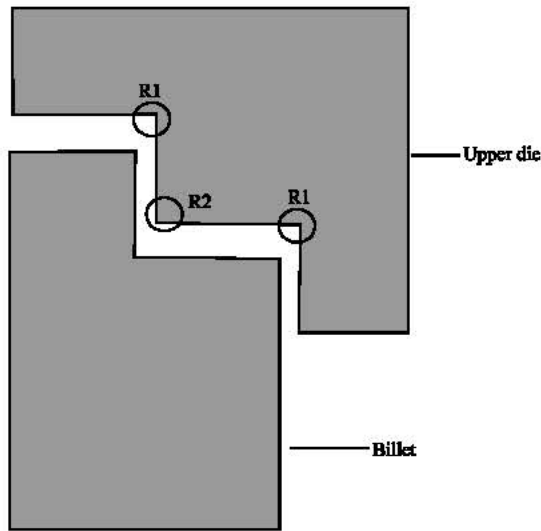

Fig. 1: Forging parameters
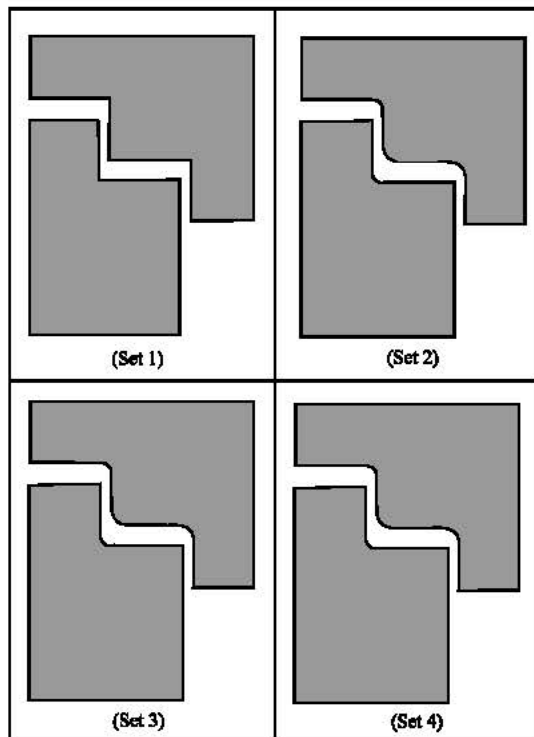
Fig. 2: CAD model of the upper die and billet

Fig. 4: Meshed model of the die and billet

Table 2: Material property of die and billet

Part	Property	
Die	Material	Tool Steel
	Modulus of Elasticity, E	193 GPa
	Poisson Ratio	0.30
	Density	7.83×10^3
Billet	Material	Copper
	Modulus of Elasticity, E	110 GPa
	Poisson Ratio	0.34
	Density	8.954×10^3

The model developed is a quarter of the model as a case study. The meshed model is shown in Fig. 4. The bottom line of the billet is fix in the x and y direction, whereas the axisymmetry side of the billet is fix in the x direction only. In order to avoid die sliding to the right, it has been fixed in the x direction. Load is applied form the top (y direction). Number of elements should be control not to exceeding 1000 element due to the software used is student version.

The properties for the die and billet are listed in the Table 2. The die is meshed using triangular meshing, whereas the billet is meshed using quadratic meshing, this is because the die is the key of this study.

RESULT AND DISCUSSION

The forging process involve two contacted surfaces i.e., die and billet at different strength, one of the surface will deform to follow the other stronger surface. Here several parameter need to be taken into consideration especially the geometry of the die and lubrication. Theoretically these two parameters are related to each other as suggested in the general friction model used by

Fig. 3: Four sets of die geometry

Table 1: Four sets of model used in the simulation

Set	Radius 1, R1 (mm)	Radius 2, R2 (mm)
1	0	0
2	2	4
3	4	6
4	6	12

Omer (2004). In the model, the lower contacted area, the lower stress induced. By using the developed model, a study of closed-die forging is studied. The analysis is using the available software named ABAQUS.

Figure 5 to 7 shows the contour of the effective Von Misses stress at different friction coefficient of the die. Only result for the set 4 is used. The results are at 30% deformation of the billet due to the highest stress occurs throughout the process. For each of the cases, the highest stress is found to occur at right bottom area of the die, where there is a contact between die and billet. This is due to the plastic deformation and the sliding of the billet on the die surface. To study the effect of friction, coefficient of friction used for each of the models is 0.05, 0.1 and 0.15. The focus of the study is to see the maximum stress occurs, mainly tool stress. The result indicates that, by increasing the coefficient, the maximum stress is reduced.
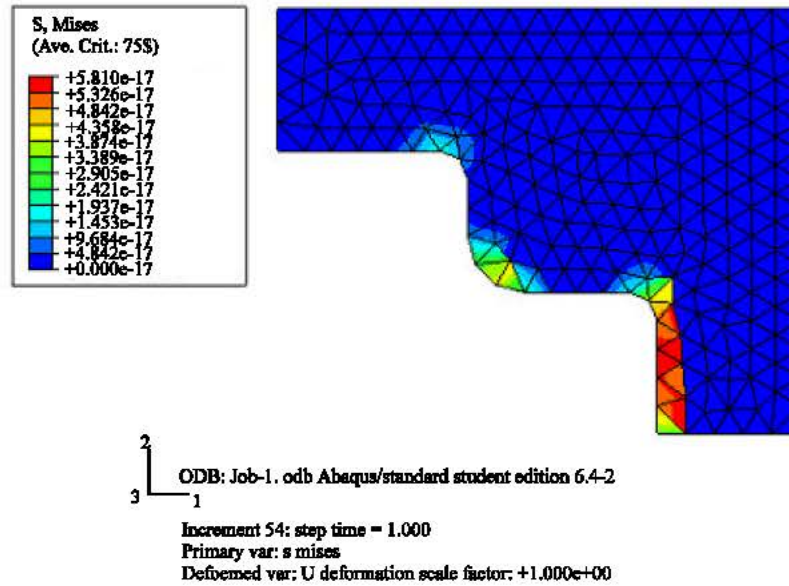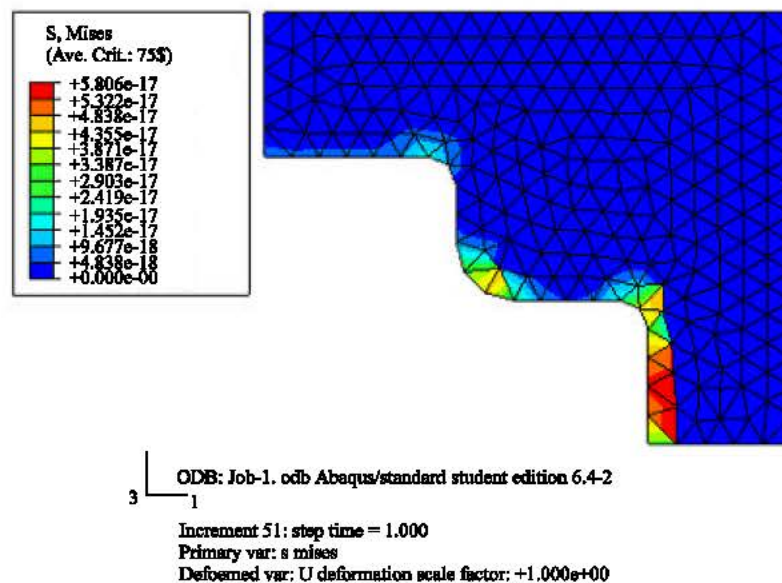
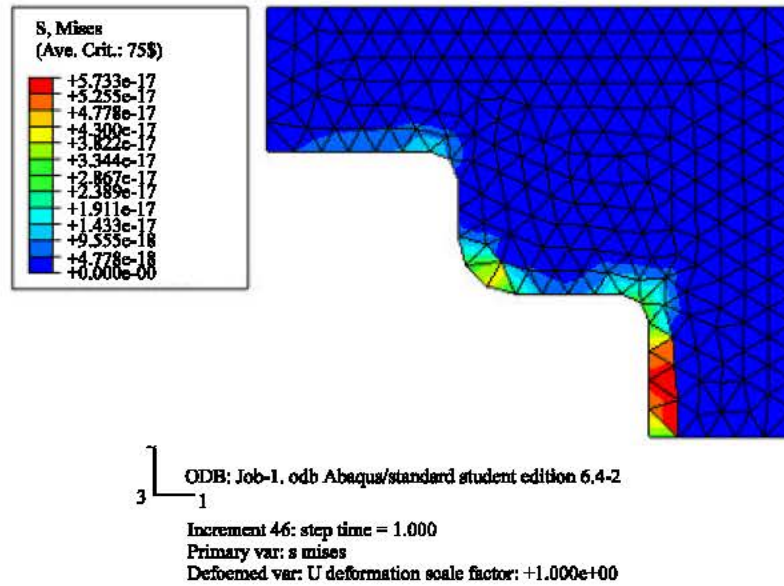Fig. 5: Set 4, friction = 0.05

Fig. 6: Set 4, friction = 0.1

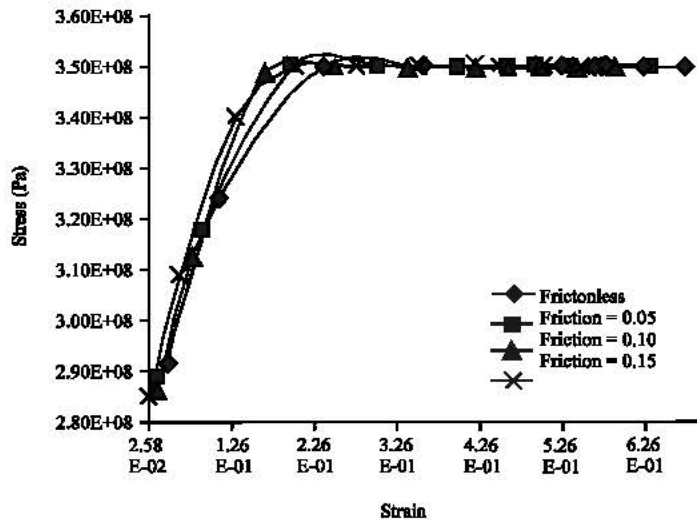Fig. 7: Set 4, friction = 0.15

Fig. 8: Stress-strain curve for set 1

The stress-strain curve for set 1 is shown in Fig. 8. It is shown that for there is no tremendous effect due to the friction coefficient changes. Even though this is not the final stage of the forging process, the result can still be used for reference.

After that the maximum stress at different displacement is plotted as shown in Fig. 9 (a-d). The stress begins after 11 mm because it is an initial location of the die or the gap between billet and die.

The result indicates that the maximum stress is at distance 16 mm for almost all of the cases for set 2 to 4 and the value is 350 MPa but for the set 1, it reached earlier i.e., at 14 mm distance. As conclusion, from these series of analysis shown that modifications of the corner radii have little effect. The result may be different at the end of the forging process as the project only analyze at the middle of the process.
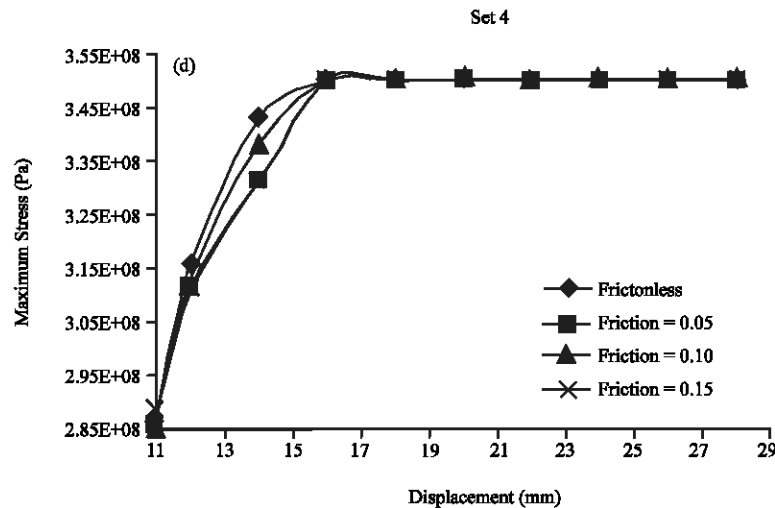
Set 1

Set 2

Set 3

Set 4
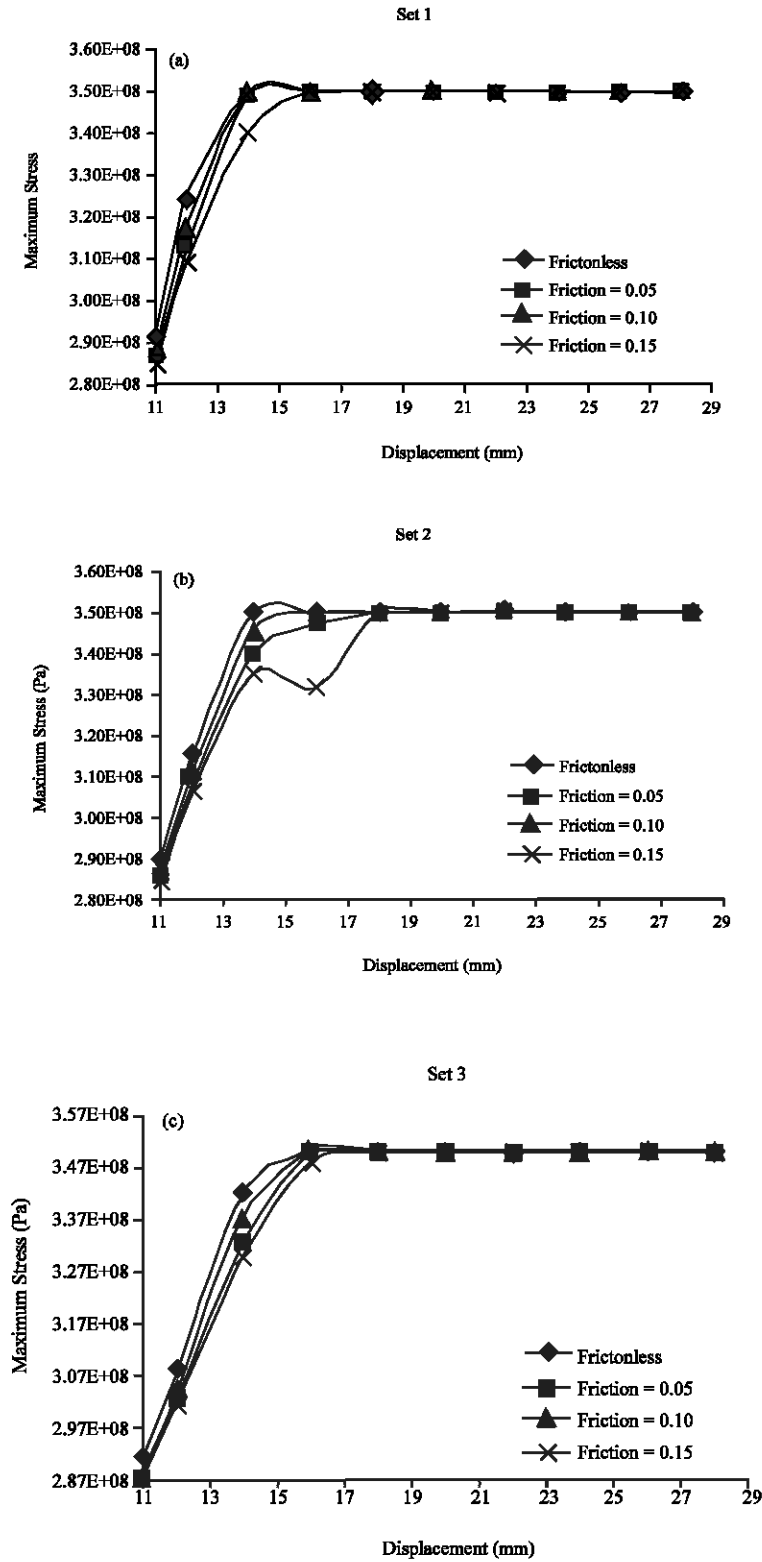
Fig. 9: The effect of friction coefficient to maximum stress for all sets

CONCLUSION

The objective of this study is to investigate the effect of design and process parameter to forging die performance. From the numerical result it can be concluded that;

*   The result indicates that for sharp corner, the maximum there is achieved earlier that corner with radii.
*   This is shown that by implementing corner with radius, stress induced can be reduced.
*   In the other hand, for the case of friction effect, the result indicate that, the effect can be seen if the coefficient of friction used is 0.15 or more.

REFERENCES

Button, S.T. and C.M.O.L. Roque, 2000. Application of the Finite Element Method In Cold Forging Processes, Revista Brasileira de Ciências Mecânicas, 22: 189 - 202.

Castro, C.F., C.A.C. António and L.C. Sousa, 2004. Optimization of shape and process parameters in metal forging using genetic algorithms. J. Materials Processing Technol., 146: 356-364.

Choi, S.K., M.S. Chun, C.J. Van Tyne and Y.H. Moon, 2006. Optimization of open die forging of round shapes using FEM analysis, J. Materials Processing Technol., 172: 88-95.

Falk, B., U. Engel and M. Geiger, 2001. Fundamental aspects for the evaluation of the fatigue behaviour of cold forging tools. J. Materials Processing Technol., 119: 158-164.

Farrahi, G.H. and H. Ghadbeigi, 2006. An investigation into the effect of various surface treatments on fatigue life of a tool steel. J. Materials Processing Technol., 174: 318-324.

Jeong, D.J., D.J. Kim, J.H. Kim, B.M. Kim and T.A. Dean, 2001. Effects of surface treatments and lubricants for warm forging die life. J. Materials Processing Technol., 113: 544-550.

Jolgaf, M., Hamouda, A.M.S.S. Sulaiman and M.M. Hamdan, 2003. Development of a CAD/CAM system for the closed-die forging process. J. Material Processing Technol., 138: 436-442.

Koç, M. and M.A. Arslan, 2003. Design and finite element analysis of innovative tooling elements (stress pins) to prolong die life and improve dimensional tolerances in precision forming processes. J. Materials Processing Technol., 142: 773-785.

Lapovok, R., 1998. Improvement of die life by minimisation of damage accumulation and optimisation of preform design. J. Materials Processing Technol., 80-81: 608-612.

McCormack, C. and J. Monaghan, 2001. A finite element analysis of cold-forging dies using two- and three-dimensional models. J. Materials Processing Technol., 118: 286-292.

Omer, N.C., 2004. Friction analysis in cold forging. Master Thesis, Middle East Technical University.

Sousa, L.C.C.F. Castro, C.A.C. António and A.D. Santos, 2002. Inverse methods in design of industrial forging processes. J. Materials Processing Technol., 128: 266-273.

Tong, K.K., Goh, C.S. Fu, M.W.T. Muramatsu and M.S. Yong, 2003. Predictive Methods and Improvements in Die Life for Cold Forging. Technical Reports, STR/03/005/FT.

Vasquez, V., D. Hannan and T. Altan, 2000. Tool life in cold forging-an example of design improvement to increase service life. J. Material Processing Technol., 98: 90-96.

Wagner, K., A. Putz and U. Engel, 2006. Improvement of tool life in cold forging by locally optimized surfaces. J. Materials Processing Technol., 177: 206-209.

Yang, D.Y., D.G. Ahn, C.H. Lee, C.H. Park and T.J. Kim, 2002. Integration of CAD/CAM/CAE/RP for the development of metal forming process. J. Materials Processing Technol., 125-126: 26-34.

Yi-Che Lee and Fuh-Kuo Chen, 2001. Fatigue life of cold-forging dies with various values of hardness. J. Materials Processing Technol., 113: 539-543.

Zhao, G., X. Ma, X. Zhao and R.V. Grandhi, 2004. Studies on optimization of metal forming processes using sensitivity analysis methods. J. Materials Processing Technol., 147: 217-228.