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Simulation and Studying of Conical Gears Forging

¹A.M. Jafarpour, ²A.S. Asl and ³R. Bihamta

¹Department of Mechanic Engineering, Faculty of Engineering,
Sama Organization (Affiliated with Islamic Azad University), Mamagan Branch, Iran

²Department of Mechanic Engineering, Faculty of Engineering,
Peyame Noor University, Tehran, Iran

³Department of Civil Engineering, Aluminum Research Center (REGAL),
Université Laval, Québec, Canada

Abstract: Forging is one of the most important methods for manufacturing the complicated parts. In this study die designing of the conical gears are considered by using of the modern methods. Conical gears are one of the extensively used components in automotive industry. Preferred fibrous structure which can bear highly dynamics loadings and cost effectiveness are the most considerable characteristics of forging process in producing gears. Various flaws like un-filling, overlap and crack can cause defect in the final part quality which most of them are due to inappropriate design of preform dies. In this paper using both numerical and physical methods, three forging steps for producing a conical gear are performed and compared. The results obtained from simulation and the Physical methods show that the accuracy of method is high and acceptable. With these results die designer can have better idea about optimized design.

Key words: Forging preform design, physical modeling, finite element method

INTRODUCTION

Designing the forging dies is one of the most important challenges that the companies should cope with it. Many of the designed forging dies are been scraped every day in the companies because of unsuccessful results. The modern methods have been working by the researchers, since the forging methods developed. These days application of computer in various metal forming processes like forging, rolling, extrusion and others has inevitable role in designing appropriate process tools and defining optimized parameters. And in the literature there are various papers about application of computer in metal forming design; for instance, Altan and Akerman (1973) depicted the principal of application of computer in designing forging dies. In this study, the application of computer limited to the computation of complexity of part, flash dimensions and preform dimensions. Short time after him, Biswas and Knight (1976) presented a more completed program for designing preform and finish forging dies in the circular parts. Also, a striking advancement in the field presented by Oh (1982). In the program presented by Oh (1982), the state of material is considered elasto-plastic for every type of dies presented. In the recent years, some researchers presented a simulation of connecting rod 8 steps rolling and forging with predicting size of

Corresponding Author: Aidin Salimi Asl, Department of Mechanic Engineering,
Faculty of Engineering, Peyame Noor University, Tehran, Iran
Tel: (+98) (411) (5419742) Fax: (+98) (411) (543292)

austenite after performing forming operation (Grass *et al.*, 2005). Ebrahimi and Najafizadeh (2004) developed a new method for evaluation of friction in bulk metal forming. In other forming process like radial forging or swage autofrettage or other process there are various published papers (Hwong *et al.*, 2006). For example, the study published newly on the subject of radial and indentation forging and swage autofrettage (Bihamta *et al.*, 2007a). In this study, due to vast application of conical gears in the automotive industry, three steps of forging of this part is simulated using the FE method and effect of various parameters like friction coefficient, flash thickness, billet size, stress and strain distribution, residual stress distribution in the finished part and required load in are investigated. The FE method has been used by some researchers (Tomove *et al.*, 2004). Also, for better investigation of process and validating the developed FE model, some physical modeling using plasticine material performed and results showed good agreement with each other. The objectives of this study is to help the companies to design a forging die that is not needed to be improved again. It means that by using of this system in forging companies we would not have any scraped and useless forging die. Also, the cost of forging products would be decreased dramatically.

MODELING METHOD

Modeling is one of the most important methods of simulation that has been used in mechanical engineering by many of researchers (Tomov *et al.*, 2004). For modeling and considering the process, a conical gear in Forging Company of Iran Tractor Manufacturing Factory (FC-ITMF) was choosed. It was supposed to probe different parameters (such as material, temperature, lubricant and etc.) that effect the die designing process, before practically conducting, to prevent scraped dies and parts. For developing FE model for investigating three forging steps in production of conical gear part, the commercial MSC. AutoForge™ package is used. Because of complex geometry of dies, especially in preform and finish steps AutoCAD™ software is used for importing the geometry of dies in the FE software. In the Fig. 1, the geometry of as

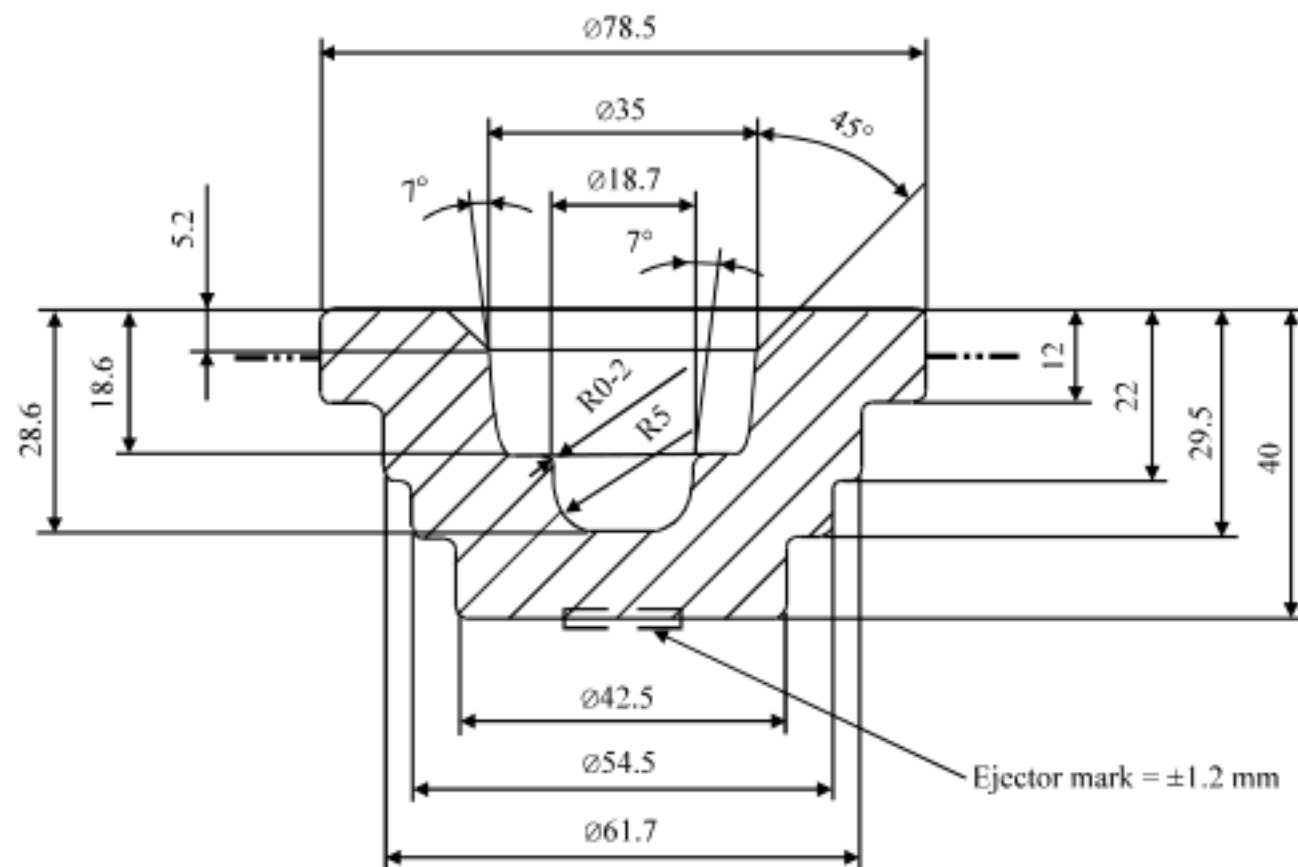


Fig. 1: As forged conical gear

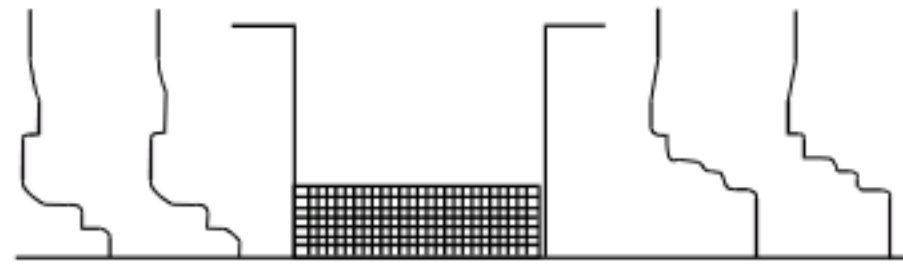


Fig. 2: Three steps of forging with billet (Step 1: Scale break, Step 2: Preform, Step 3: Finish)

forged part and in the Fig. 2, the three steps of forging with its billet in the axisymmetric state is presented the friction factor using the following formula:

$$m = \frac{(R/H)^b}{(4/\sqrt{3}) - (2b/3\sqrt{3})}$$

Where:

R = Average radius of cylinder after deformation

H = Cylinder height after deformation

b = Buckling parameter has been developed by Ebrahimi and Najafizadeh (2004)

m = Friction coefficient

EXPERIMENTAL PROCEDURE

For better investigation of process from the view point of material flow and strain distribution, physical modeling method was utilized. Physical method developed in 1994 for the first time (Kim *et al.*, 1994). In their research they found that using plasticine, simulate the material current with a very accurate agreement. The experiments were conducted in number 1 workshop of forging company of ITMF in Tabriz City during 2007 and 2008. This method is conducted to compare the results with the simulation conclusions. In this method, using plasticine as a work piece material and Polyethylene as a die material, the process requires very low load for performing it in a way that the CNC milling machine was used as a press for performing process. In physical modeling method billet are made from layers of plasticine with various colors, so the change in their thickness would be a determining factor for strain change in various regions of final part. On the other hand, it shows the strain distribution and possible over lap defect well. Using Polyethylene as a die material has a problem of sticking material to it in comparison with Plexiglas, so for getting ride from this problem, the dies were machined with high speed machining speeds to have better surface finish. Also, for investigating the filling or un-filling the die, some measuring instrument like R-measuring gage and collies are used. Schematic drawing of dies are shown in the Fig. 3. Lubrication of dies is essential factor in extracting defect free part from dies. So, the best lubricant in the case of plasticine material was Soap+Water emulsion. Another important factor in performing this experiment is press. As shown in Fig. 4 the CNC milling machine is used as a device for forming the parts. So the feed rate of the machine set to the speed equal to the press used in the simulation. The obtained result showed good agreement with numerical result and presented in the results section. The situation parameters used in this study have been shown in Table 1.

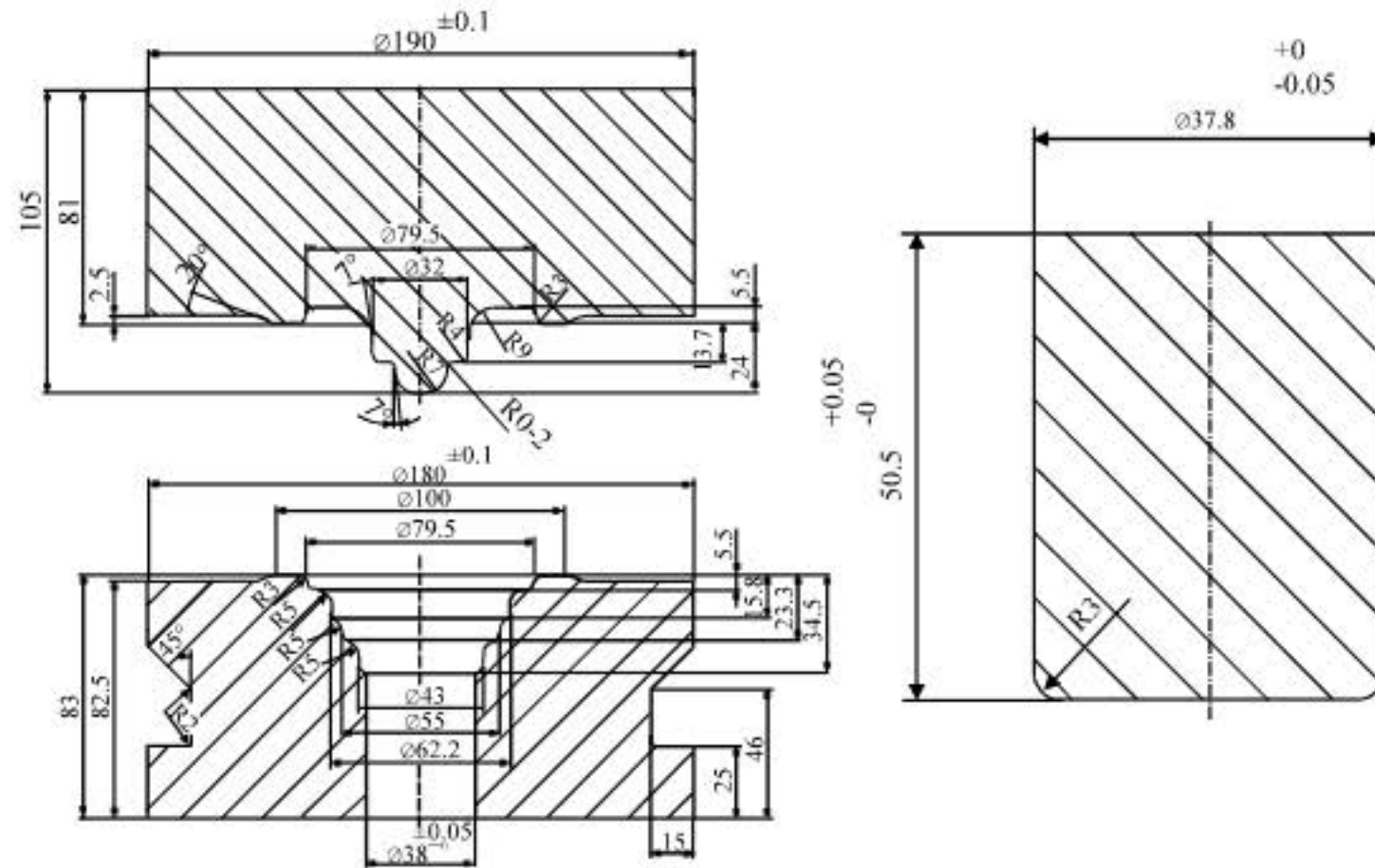


Fig. 3: Schematic view of dies used in the physical modeling



Fig. 4: Arrangement of tooling for performing physical modeling

Table 1: Input parameters used in the numerical simulation

Parameters	Value	Unit
Environment temperature	24	°C
Top scale break die temperature	130	°C
Bottom scale break die temperature	100	°C
Top preform die temperature	210	°C
Bottom preform die temperature	180	°C
Top finish die temperature	220	°C
Bottom finish die temperature	200	°C
Heat transfer coefficient (work piece-tool)	1.5×10^4	W/m ² k
Heat transfer coefficient (work piece-environment)	150	W/m ² k
Friction factor	0.4	-

RESULTS AND DISCUSSION

Figure 5a and b compare numerical results and section of produced part by physical modeling method. In the region pointed with letter A, the amounts of strains are very low and this region has a very low change in its layer thickness. Regions B and C has very high amount of change in their layers thickness which is a witness of having very high amount of strain in these regions. The developed physical modeling is also used in quantitative manner i.e., with measuring the changes in the amount of layers thickness variation and dividing it to the original layer thickness the amount of equivalent strain in that point is calculated; as an example, these amounts are written beside the part and can be compared with the gained strained from numerical method. This comparison shows acceptable correspondence with both methods. Figure 6 shows variation of loads in various steps of

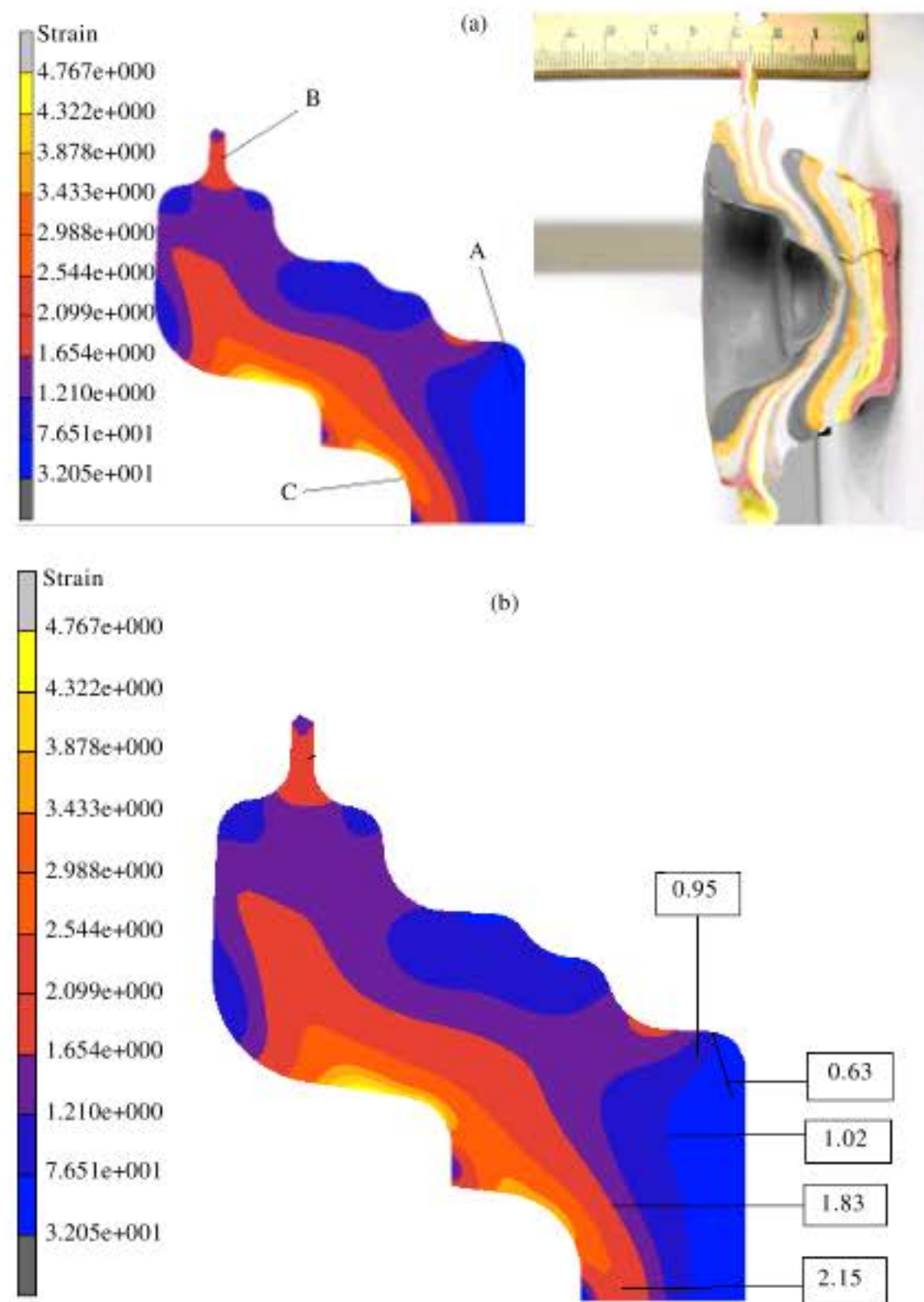


Fig. 5: Comparison between numerical and physical modeling results, (a) qualitative comparison between section of produced part and numerically simulated part and (b) numerically and physically obtained equivalent plastic strain

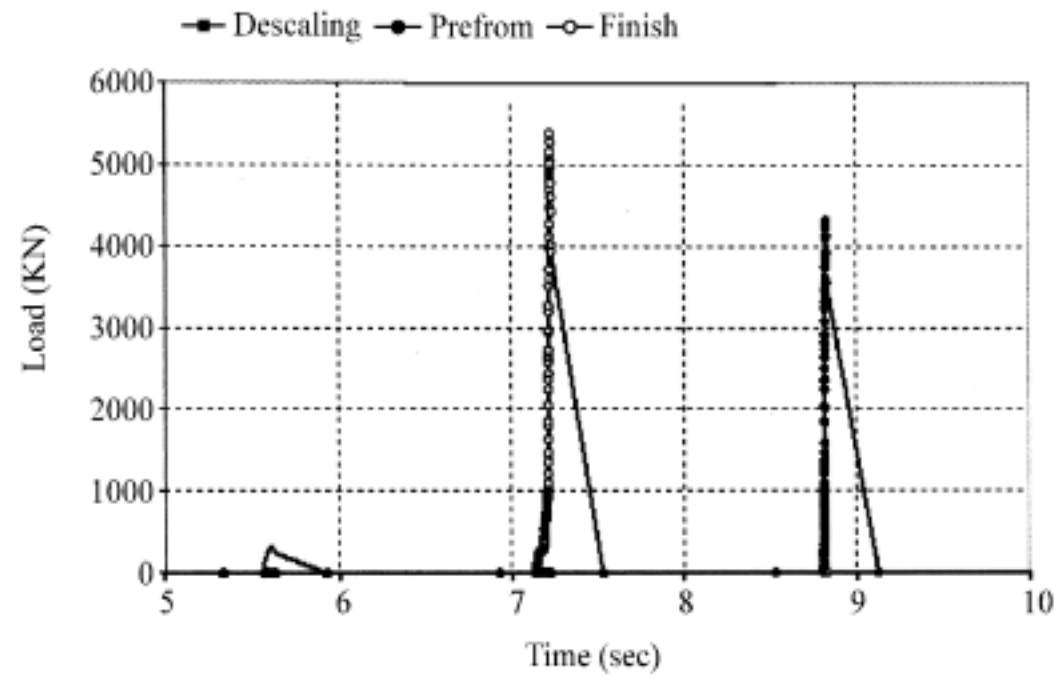


Fig. 6: Loads in various steps of forming

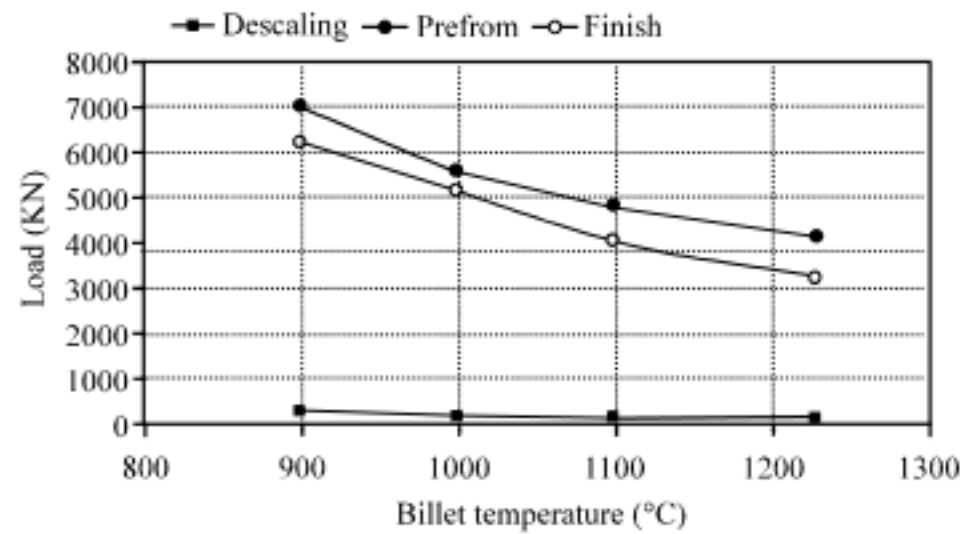


Fig. 7: Effect of temperature on the forging loads

forming process in the following conditions: Friction Coefficient: 0.4, material: 20 MnCr 5 and scale break distance: 50 mm. The maximum amount of loads in scale break, perform and finish steps are: 29.1, 537 and 431 Tons, respectively. It seems that main reason for having maximum amount of load in preform step is having larger amount of deformation in comparison with other steps and having lower amount of flash thickness in comparison with finish step. The results obtained from the simulation method have a close agreement with of the physical. The accuracy is more acceptable than earlier study by other methods (Bihanta *et al.*, 2007b).

Effect of Temperature on Loads

For investigating effect of temperature on required forging load, different simulations in various temperatures are performed. As it is clear in the Fig. 7, with decreasing temperature from 1230 to 900°C, the required load increased severely. For instance loads in the scale break step increased from 32 to 50.1 tons and for the preform and finish steps from 435 to 721 and 344 to 639 tons, respectively. These data shows that choosing temperature in the determined range (900-1260°C) and possibly in the upper ranges are necessary in reducing required loads. On the other hand, forging dies are preheating in the recommended temperatures (150-260°C) and preferably in the upper level of it. It is worth to mention that choosing billet temperature in its upper level has two reverse effects: first effect is that if the temperature increases the oxide layers thickness increase severely on the other hand, if

removing the oxides with higher amount of thickness is easier than the thin layers which has more adhesion to billet. But, thicker layers cause more material waste in the production. So, every producer should choose the optimum condition depending on its facilities.

Effect of Lubrication (Friction Coefficient) on Required Load

In Fig. 8 variation of required load for forging conical gears in various friction coefficients (0.3 up to 0.6) is presented. It is clear that the scale break section has minimum variation in amount of forces (31.5 to 32.2 tons), but in the preform and finish steps there are tremendous changes in the maximum required loads, in a way, loads increased from 460 to 622 tons and from 392 to 480 tons in the preform and finish steps, respectively. One of the interesting points about variation of forces is more sensitivity of preform step to the lubrication than other steps which shows necessity of paying more attention for the lubrication of this step.

Effect of Flash Thickness on the Loads

Figure 9 shows required forging load in various flash thicknesses. It is clear that decreasing flash thickness from 3.1 to 2 mm causes increasing in preform step loads from 389 to 537 tons. It seems that main reason for this fact is ease of escape of material from inside of die outwards. This phenomenon happens in the finish step too, in a way loads for the finish step increase from 307 to 432 tons. Another important fact detected from Fig 9 the higher sensitivity of the preform step to flash thickness variation than finish step. Therefore, preform dies should be manufactured accurately specially their flash regions. Because, in some cases it is possible that some inaccuracies in this region fabrication causes over loading of the press in the production step.

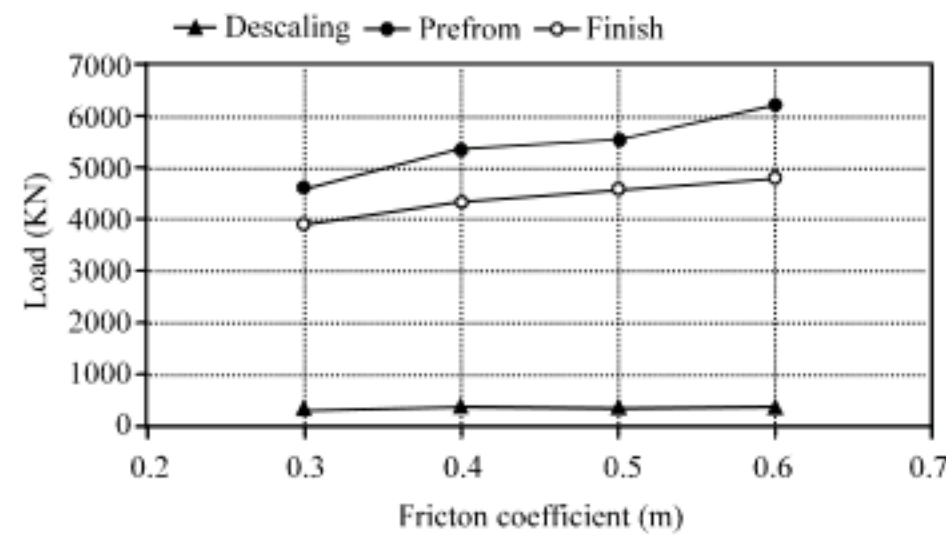


Fig. 8: Variation of Forging loads in various lubrication condition (friction coefficients)

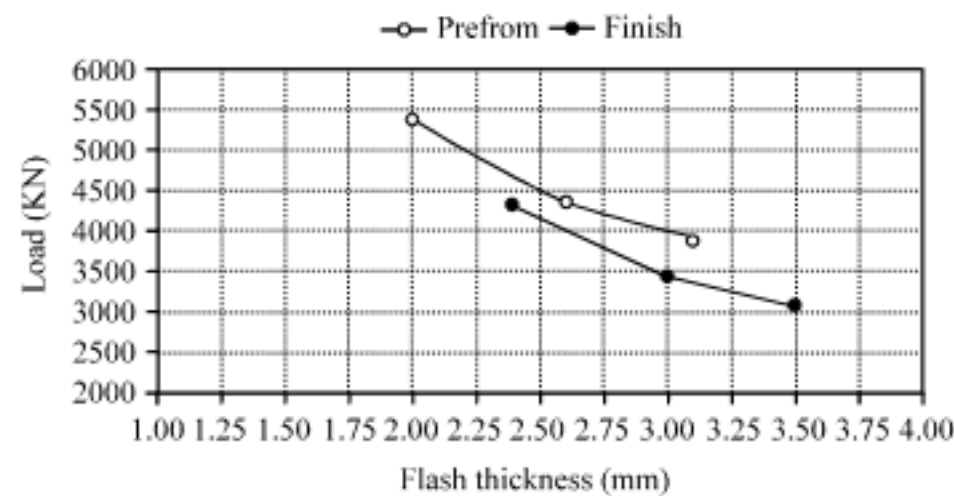


Fig. 9: Effect of flash thickness on the preform and finish step forging loads

Temperature Distribution in Various Forming Steps

In Fig. 10a and b, distribution of temperature for scale break step when billet has less contact time (distance = 70 mm) and when it has higher contact time (distance = 50 mm) is presented. As shown in Fig. 10a and b very thin layer of billet in the outer area has a temperature decrease which is about 80°C for the distance 70 mm and 200°C for distance 50 mm.

Preform Step

Figure 11a-c, shows part temperature distribution for preform step in various times during this step. The region of work piece which has more contact with die has lower temperature while the inner regions have higher temperatures. The temperature reduction continues up to end of step and in the end of the step some regions has 800° temperature and the overall temperature of part decreased at least 100°C in all regions.

Finish Step

In Fig. 12a-c, distribution of part temperature for various times of finish step is presented. As it was expected part temperature is minimum in this step. Interesting point about this figure is the increasing of temperature in some regions which has higher amount of deformation. This fact is ascertained by Altan *et al.* (1983).

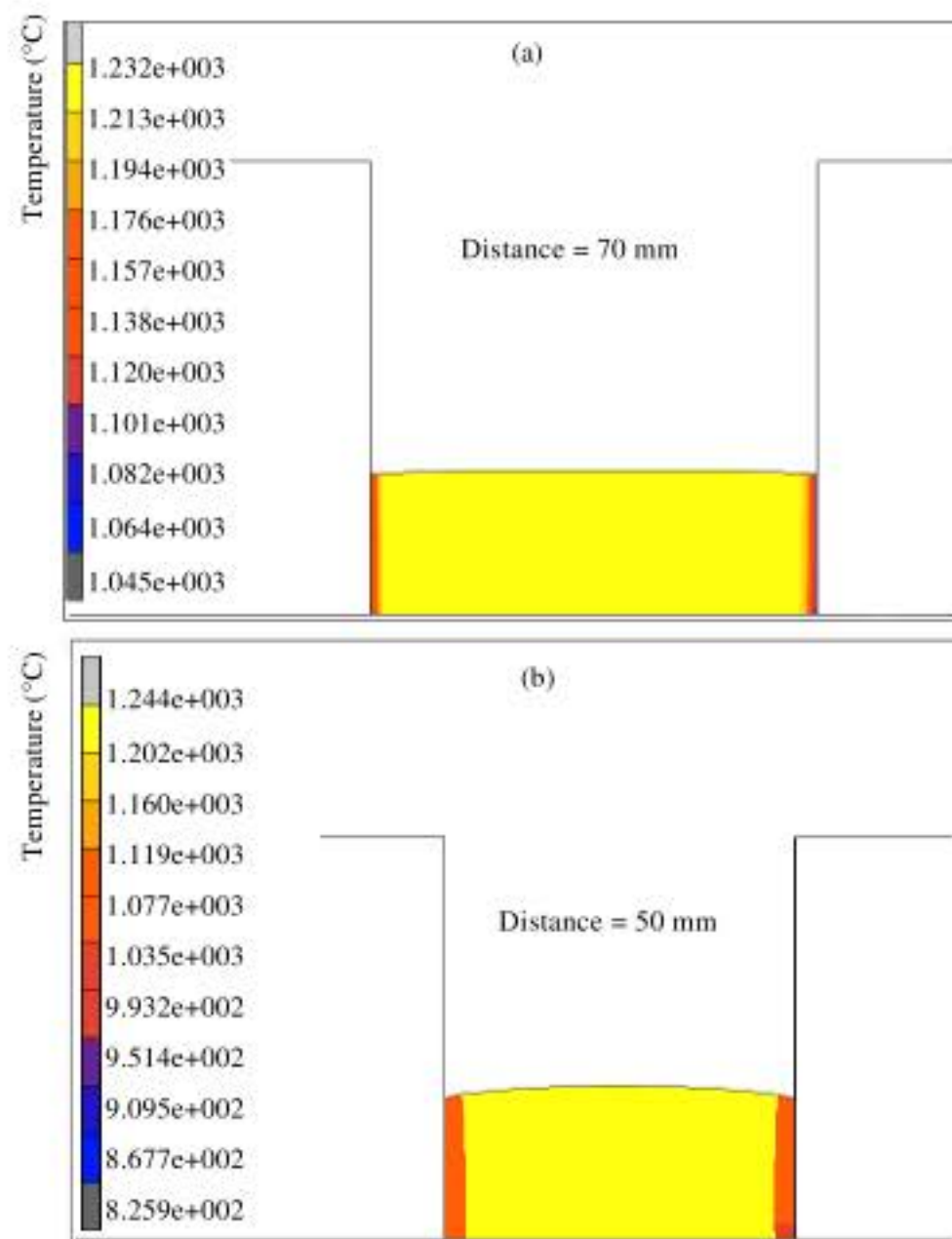


Fig. 10: Distribution of temperature for the scale break step, (a) distance = 70 mm and (b) distance = 50

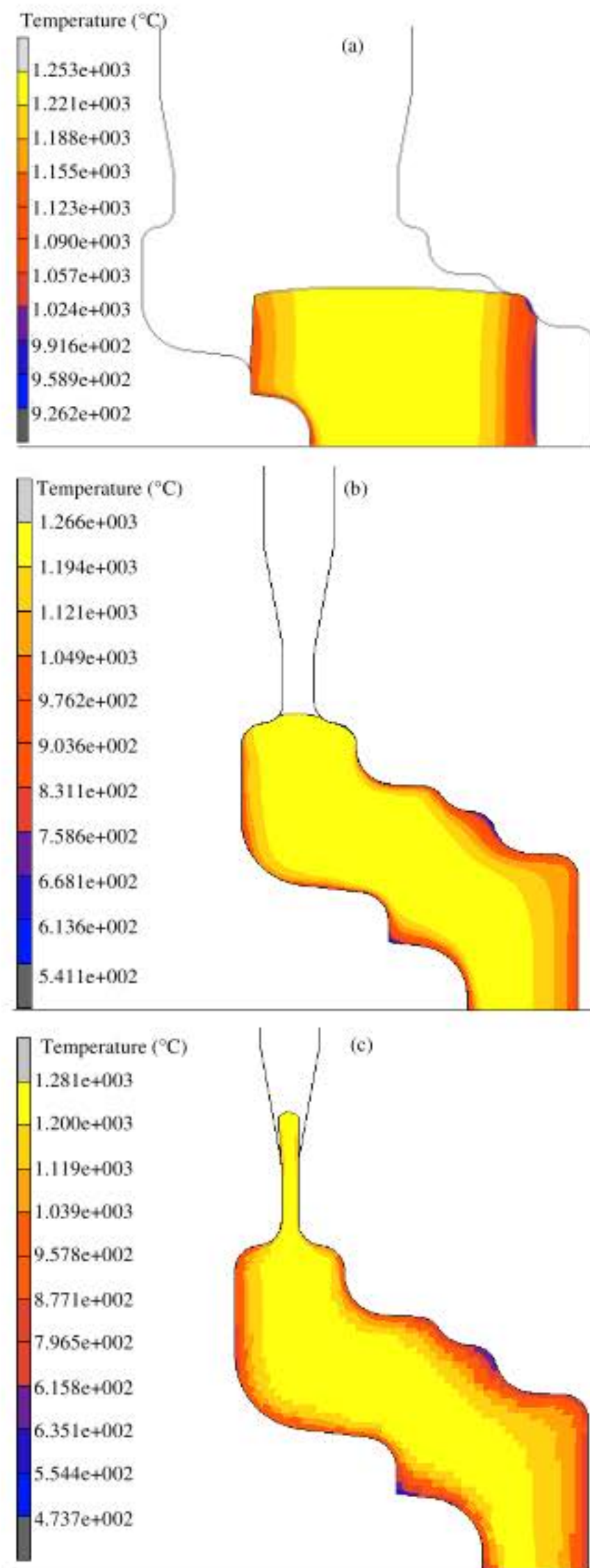


Fig. 11: (a) Distribution of temperature in preform steps (b) Distribution of temperature in preform steps and (c) Distribution of temperature in preform steps

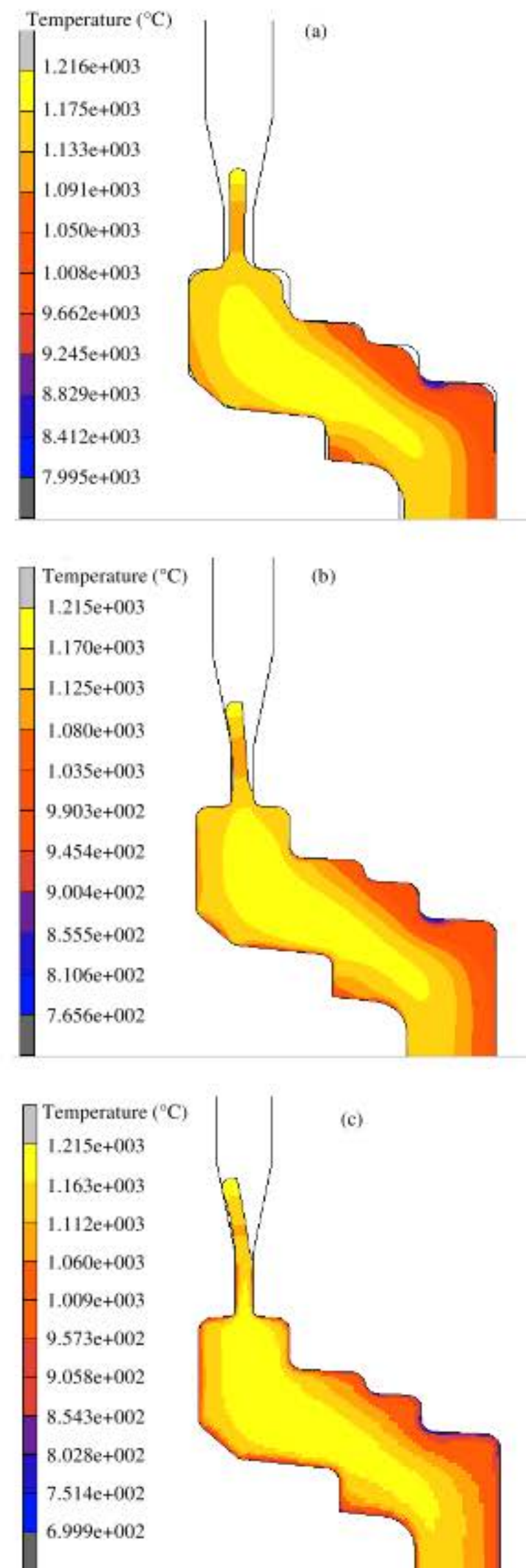


Fig. 12: (a) Distribution of billet temperature in finish steps, (b) Distribution of billet temperature in finish steps and (c) Distribution of billet temperature in finish steps

Strain Distribution

Figure 13 shows distribution of the equivalent strain at the end of preform step. The figure shows that amount of strain in the lower region of the upper die is maximum (2.8) while the average strain of the other regions is about 0.9. As a matter of fact in the work shop observations, these regions of the die in real production have more wears. This is true about the corresponding point in the finish step which has a strain of 3.1 in the lower point of the die and the average strain of 1.1 in other points. Also Fig. 14 shows distribution of the equivalent strain at the end of finish step.

Residual Stress in Final Produced Part

Figure 15 is contour of residual stress in the final produced part. It seems that due to more non-homogeneity in outer surface of the part, these regions have higher amount of

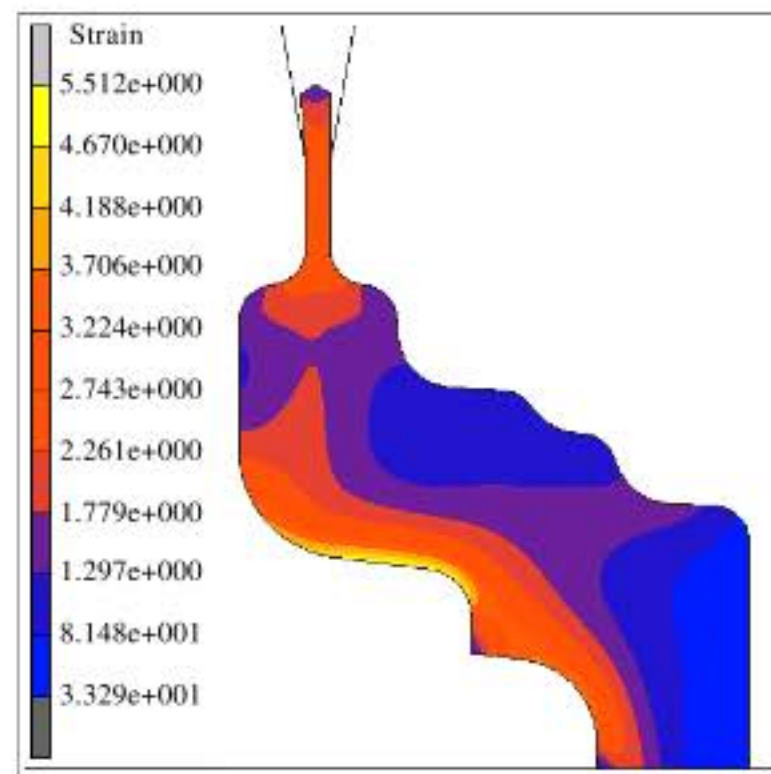


Fig. 13: Distribution of strain in the end of preform step

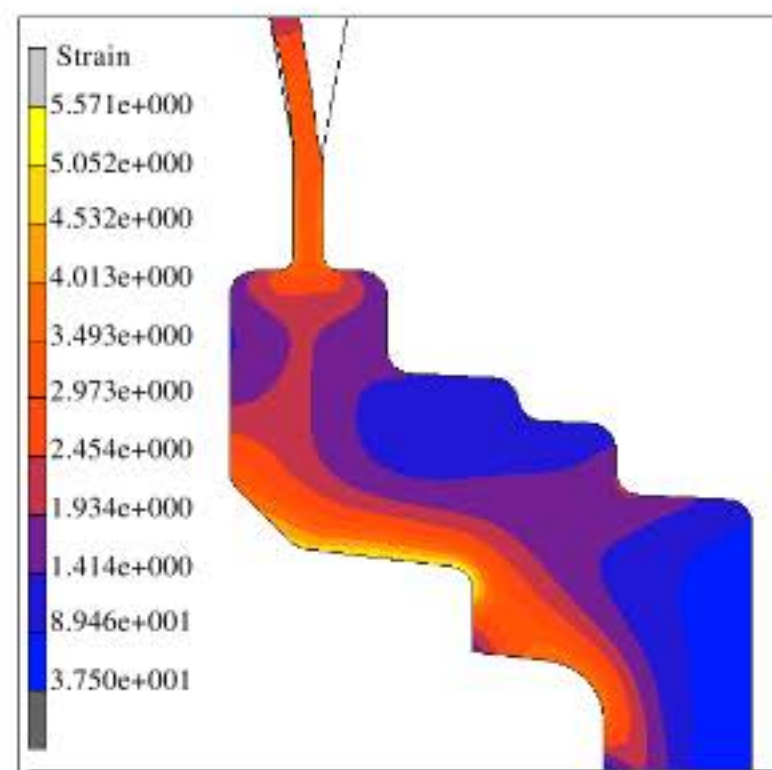


Fig. 14: Distribution of strain in the end of finish step

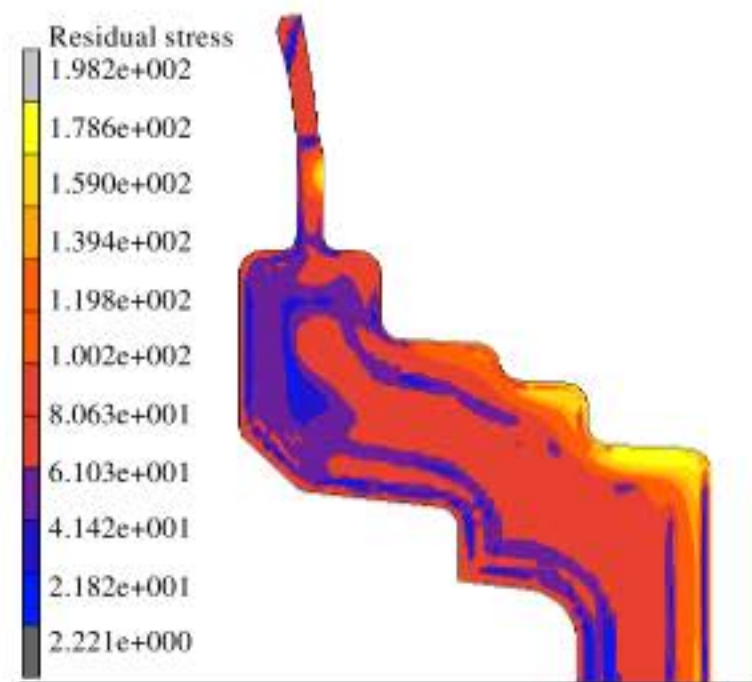


Fig. 15: Distribution of residual stress in the final produced part

residual stress than other regions. One of the important points which should be checked in each numerical study of the residual stress is the maximum amount of equivalent stress which should be lower than maximum amount of plastic strain given in the stress-strain curve of material which that is true about this case (Bihamta *et al.*, 2007a). The amount of the residual stress in the final part dictates necessity of stress relieving operation in this Par.

CONCLUSIONS

In this study effect of various parameters in forging of conical gear is investigated using FE method. Also, for reverification of numerical result and better investigation of process, some physical modeling using plasticine paste in the dies manufactured from polythene are performed and result of both methods has good agreement with each other. The most important result can be summarized as follows: (1) Distribution of strain in various regions of part during deformation and some points which has peak strains, ascertains the necessity of some treatments like welding and/or plasma nitrating on the dies, (2) Friction and lubrication has very important effect on the required loads for forging in a way in some cases causes 30% increase in required loads, (3) Decreasing flash thickness has very important effect on the required loads for forging and if it would be taken very thick, it will cause increase in waste material as a flash thickness and possible unfilling of the die, (4) Distribution of residual stress especially in the regions near to the gears dictates the necessity of stress relieving operation on the final produced part and (5) Physical modeling is an acceptable and fairly inexpensive method for evaluating flow of material in various forming process like forging

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