

Basic Numerical Simulation of the Forging Process

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ABSTRACT

The principal objective of this paper is to provide a short overview of recent research in the numerical simulation of forging, with an emphasis on applications rather than the mathematical formulations which are well documented elsewhere. The paper addresses a number of specific topics, including Process Modelling, Tool and Die Design, Interface Phenomena, Material Phenomena and Computational Aspects. The paper also looks at recent developments in re-meshing and its importance in realistic forging modelling. While many features of the forging process have been covered there are still a number, such as inter-stage heat treatment and post process thermal behavior that have received little attention. A holistic approach to forging modelling is still awaited in which all features of the process together with the influence of aspects such as press behavior are considered.

Key Words – Forging, Tool and Die Design, Inter stage heat treatment.

1. Introduction

While forging may be one of the most ancient of metal working techniques, it remains today one of the most important manufacturing processes embracing primary processes such as the reduction in size of large cast ingots (>1 m diameter), to the net-shape microforming of electronic components (<1 mm). Such a diverse range of scale may at first sight present a forbidding range of differing requirements for numerical simulation, but this is not necessarily true. There will of course be certain size-dependent questions that must be considered, such as ‘how many elements should be used for modelling a billet

1 m diameter by 4 m long’, or ‘is grain orientation important at the microscale’, but the vast majority of forging processes can be modelled using a single large-strain plasticity code. Special problems, such as anisotropy or grain growth, will naturally require particular techniques but the over-riding requirement is, for researchers, to ensure that the code is as complete and robust as possible, and for industrialists, to ensure that the code is easy to use and provides a realistic model of the real process. Of course these are complementary requirements, but the motivation for their satisfaction may be different. Numerical simulation techniques can, in principle, address questions such as ‘how many forming stages are required for a particular product’, ‘can a product be made using net-shape forging to avoid post-forging processes’, ‘will the forging tools withstand the cyclic loading inevitable in high volume hot forging’, ‘will the final product have the required grain structure and mechanical properties’ and so on.

The principal objective of the first part of this paper is to provide a very brief summary of current research into the development and application of numerical simulation techniques in forging modelling, in order to guide researchers on who is active in specific areas of this topic. The second part of this paper gives a slightly more detailed overview of developments in an area essential for the successful modelling of realistic forging processes, that is re-meshing techniques for both 2D and 3D geometries. Some of the earlier contributions to this work are also cited and examples of how some of these techniques could be used are given. The phrase ‘simulation of the forging process’, may imply modelling solely of the deformation process, but if this narrow definition were adopted it would exclude many other important facets of the production process. These include billet preparation, pre-process heating, inter-stage annealing or cooling, post-process thermal behaviour, elastic unloading and recovery, die stresses, deformation and wear, lubrication phenomena and behaviour of the forging press. The complete simulation should include all these features. While this complete model may await improvements in computer speed and capacity, each of the individual elements has already been the subject of some research and all that remains is the motivation and means to bring them together.

2.LITERATURE REVIEW

An good literature review is done to understand the present practices and theories for prediction and validation of die Life in hot forging dies. In the modern world many of scientists, researchers and forgers tried to find out actual die life

prediction model. Many of them considered basic models of material failure and produce their own model based on it. Mr. Lejla Lavtar et al. [2] worked on analysis of the main types of damage on industrial upper and lower, Hot-forging dies for hot forging of car steering mechanisms. The dies were previously gas nitrided at various conditions and exhibit various microstructures after nitriding. They failed after a different number of forging strokes. Measurements of micro hardness depth profiles and examinations of nitrided layers with an optical microscope were conducted. The design of die shape in sequential forging steps has a predominant role for a prolonged die life in comparison to the quality of nitrided die cavity surface. Another team of researchers S. Jhavar et al., [3] concentrated on the life of industrial dies and molds. They have focused on the how the life of die can be efficaciously increased by timely repair of damaged surfaces. As per this study the degree and severity of damages of these vital production tools depend on the service conditions and requisite precision in shape and size of dies and molds. This study comprehensively depicts the global scenario of the dies and mold industries, various materials used for manufacturing of dies and molds, their modes of failures under different duty conditions and various repairing options. As per his study, the major causes of failures during operations are due to high thermal shocks, mechanical strain, cyclic loading and corrosion resulting in heat checking, wear, plastic deformation and fatigue. Other cause failures are due to faulty design, defective material, mishandling and force majeure due to accidental conditions. Mr. Changhyok Choi et al., [4] studied in field of In warm forging, according to his study, die life is affected by abrasive wear and plastic deformation and may be shortened considerably due to thermal softening of the die surface caused by forging temperature and pressure. In this study, a methodology is developed for estimating abrasive die wear and plastic deformation in a warm forging operation, using a tempering parameter.

Siamak Abachi et al., [1] worked with hot forging die wear with finite volume method. The wear analysis of a closed hot forging die use the final stage of a component has been realized. The simulation of forging process was carried out by commercially available software based on finite volume method and the depth of wear was evaluated with a constant wear coefficient. By comparing the numerical results with the measurement taken from the worn die, the wear coefficient has been evaluated for different points of the die surface and finally a value of wear coefficient is suggested.

From above literature survey it is clear that some attempts are made regarding prediction of die life in case of hot forging dies. But a comprehensive theory in relation with these factors is still to be formulated. This work is done with keeping the same as work objective.

3.MATERIAL & METHODS

During the hot forging process, the temperature of a die increases due to the contact between the dies and the hot deforming material. The rate of temperature rise can be attributed to several factors, such as the initial temperature of dies and billet, the contact time and pressure, the die material and surface treatment conditions. The thermal softening induced by this temperature rise gradually reduces die hardness, and finally leads to the plastic deformation of a die [8]. The longer contact time at the elevated temperature gives rise to a decrease of the surface hardness of a die. In order to consider the thermal softening effect in estimating die service life against plastic deformation, it is required to introduce the tempering parameter, M, as shown in Eq.(1), which represents the effect of die hardness change on the contact temperature and time successive forging cycles [8]:

$$M = T X(C + \log_{10} t) X 10^{-3} \dots \dots \dots (1)$$

Where T is the tempering temperature (K), C is the material constant which has about 20 for carbon steel, t is the tempering time. Also, from starting to deform until ejecting the forged part, the temperatures of die surface change during one forging cycle, so the introduction of equivalent temperature is required. The equivalent temperature, T_{eq}, can be approximately expressed as shown in Eq. (2)

$$T_{eq} = \frac{2 T_{max} + T_{min}}{3} \dots \dots \dots (2)$$

Where T_{max}, and T_{min} are the highest and lowest temperatures during one forging cycle, respectively. To estimate die service life for the plastic deformation of a die induced by thermal softening, the tempering time, t, at Eq. (1) is replaced with hardness holding time t_h, where t_h is the time which takes until initial die hardness gradually reduces to reach the critical hardness by thermal softening, as shown in Eq. (3):

$$t_h = \exp \left(\frac{M_{yield} X 1000}{T_{eq}} - C \right) \dots \dots \dots (3)$$

Where M_{yield} is the M value when initial die hardness is equals to the corresponding hardness of the yield strength of the die. When the material is a perfect plastic, the hardness (HrC) of material is about three times of the yield strength

of material [6]. The main tempering curves of this hot work die material, H13, obtained from thermal softening experiments are shown in Fig. 1.

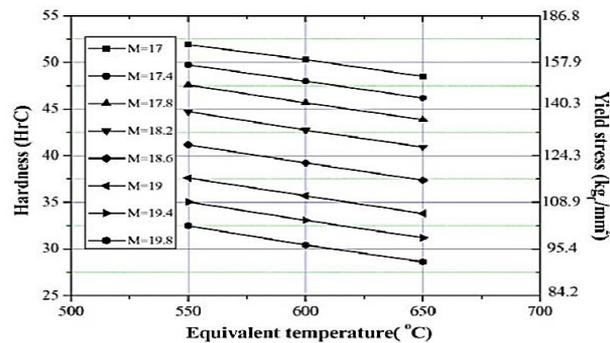


Figure.1: Main Tempering curve for H13 [6]

An actual working finishing die was quenched at 1030°C and then it had the first tempering for 3h at 550°C and the second tempering for 3.5 h at 600°C. Die surface was treated as ion-nitriding process for 14h at 520°C Therefore, for hardness holding time for estimating the die service life considers the first and second tempering time, which can be derived as follows:

$$T_{eq} = \frac{2T_{max} + T_{min}}{3}$$

$$M = T \times (C + \log_{10}t) \times 10^{-3}$$

$$t_h = \exp\left(\frac{M_{yield} \times 1000}{T_{eq}} - C\right)$$

$$M_{yield} = T_{eq}\{c + \log(t_h + t_1 + t_2)\} \times 10^{-3}$$

$$t_h = \exp\left(\frac{M_{yield} \times 1000}{T_{eq}} - C\right) - t_1 - t_2$$

$$\text{Where, } t_1 = 100 \exp\left\{\frac{T_1}{T_{eq}} \times (C + \log t_h) - C\right\}$$

$$t_2 = 100 \exp\left\{\frac{T_2}{T_{eq}} \times (C + \log t_h) - C\right\}$$

Where T_1 , T_2 are the first and second tempering temperatures, t_1 , and t_2 is the hardness holding times at the first and the second M_{yield} values for T_{eq} , respectively. In order to calculate the hardness holding time, effective stresses and equivalent temperatures can be obtained from rigid-plastic finite element analysis. M_{yield} value can be determined from the main tempering curve. t_1 and t_2 are substituted into Eq. (4) to obtain the hardness holding time. Finally, the die service life of the finishing die is calculated by dividing the hardness holding time by one forging cycle time, and the die service life is expressed as the possible maximum production quantity. The outline of a method for estimating die service life affected by plastic deformation is shown in Fig. 2

4.RESULT & DISCUSSION

This product has the height of 320 mm, maximum diameter of 131mm and a long extruded part. This discrete part requires a minimum machining and high dimensional accuracy. Unfortunately, abrasive wear or plastic deformation of the die occurred at the stepped corners as shown as point 1, 2 in Fig. 4, the die service life of this part depends on the change of the initial shape and dimension of these stepped corners during hot forging. The forming analysis conditions and the variations of process variables for estimating die service life are listed in Tables 1 and 2, respectively. The

distributions of damage value at final stage obtained from the FE analysis is shown in Fig. 6, these values appeared highly at two stepped corners.

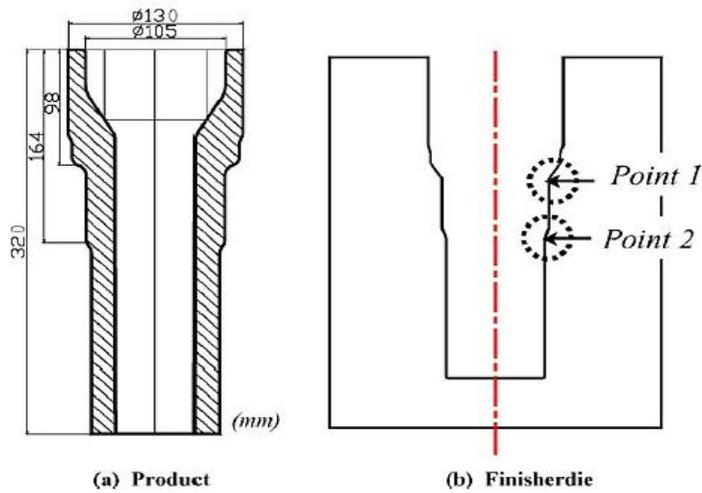


Figure.3: Final Product

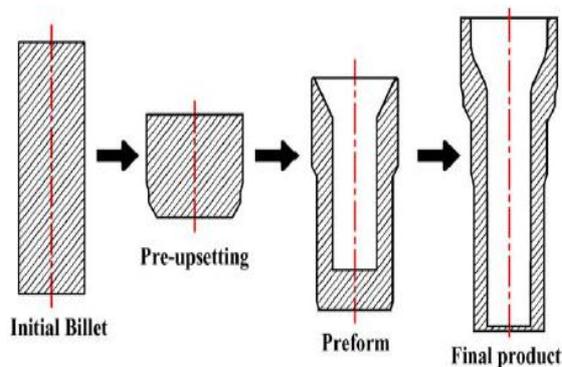


Figure.4: Forging Process to be carried out for Final Product

The damage factor can be used to predict fracture in forming operations [7]. Therefore, the damage degree of these corners may directly relate to die service life. When the initial die temperature is low, it may influence product quality. When the initial die temperature is high, die hardness decreases. When the forming velocity becomes faster, the contact time between the hot deforming material and the dies is shortened and the equivalent temperatures become low. The initial die temperature control and selection of deformation velocity are very important to the die life.

Following are the basic process parameters are considered for this study.

Table 1: Process conditions of FE analysis

Billet		
1	Material	AISI 1045
2	Thermal conductivity (N/s °C)	74.93
3	Emissivity	0.3
4	Heat capacity (N/mm °C)	3.602
Die		
1	Material	H 13
2	Thermal conductivity (N/s °C)	28.6
3	Emissivity	0.3
4	Heat capacity (N/mm °C)	3.574
5	Surface treatment	Ion-nitride

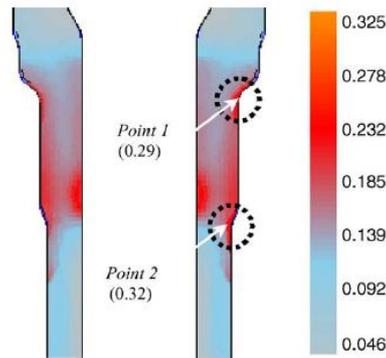
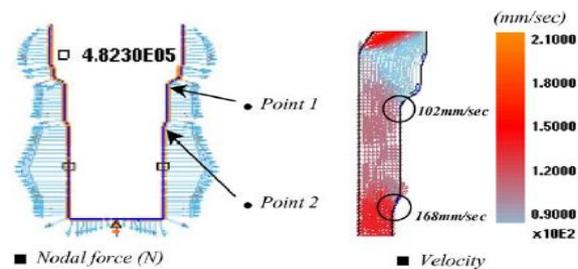


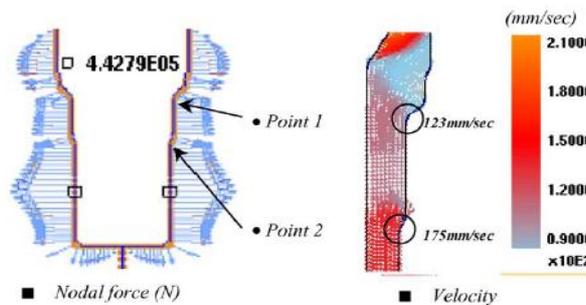
Figure.5: Damage factor of a final product.

Following figures of hot forging product to be analyzed are based on plastic deformation and abrasive wear. One of automobile components, spindle part, is manufactured in three stages composed of upsetting and two forward/backward hot forging operations. Fig. 6 shows the process design result for the hot forming of spindle part. The die service life of this part depends on the change of the initial shape and dimension of these stepped corners during hot forging. The forming analysis conditions and the variations of process variables for estimating die service life are listed in Tables 1, respectively. The distributions of damage value at final stage obtained from the FE analysis is shown in Fig. 6A, 6B, 6C. these values appeared highly at two stepped corners.

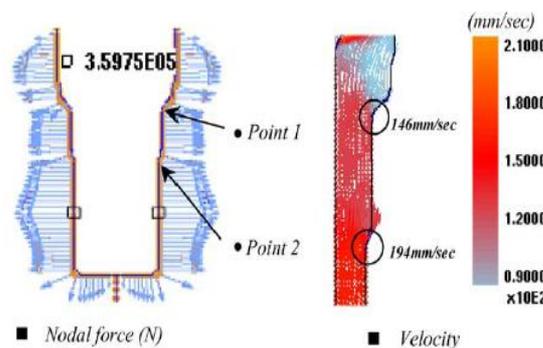


(a) Initial die temperature: 200 °C

Figure.6.a.



(b) Initial die temperature: 300 °C



(c) Initial die temperature: 400 °C

Figure.6.b.

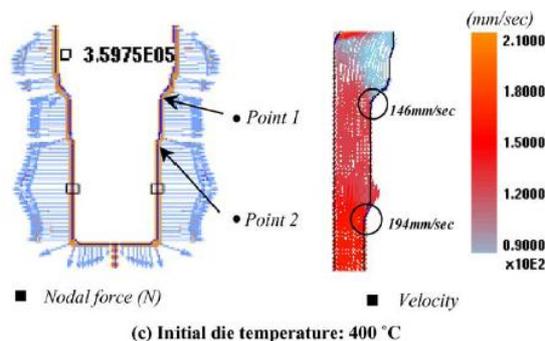


Figure.6.c

Figure. 6 : Initial Die Temperature and T-T curve for various temperatures.

6.a: at 200°C, 6.b: at 300°C, 6.c: at 400°C,

In metal forming process, both plastic deformation and friction contribute to the heat generation. The temperatures developed in the process influence lubrication conditions, tool life, the properties of the final product, and the rate of production [4]. Above all, when the initial die temperature is high, the temperature difference between inside and outside of a billet becomes small, and this small temperature difference assists the sound metal flow. On the other hand, a high surface temperature may reduce die service life. But the low temperature of die surface can disturb metal flow and cause the surface defects. As can be seen in Fig.6.a , the temperature on die surface at two stepped corners (point 1, 2) increase differently, due to initial die temperature effect, for the same forging process. For the initial die temperature 400°C at point 1, the die temperature is initially higher, but the maximum temperature is lower than for either 200 or 300°C. Also, these results clearly indicate that the temperature gradient for the initial die temperature 400°C is very large at point 2. The results of abrasive wear and stress analysis of finisher die are shown in Fig.6.c, when initial die temperature is 400°C, the wear depth (δ) at point 2 is approximate 1.898 mm, and is about four times of that at 200°C. This is not surprising because the relative velocity between die and workpiece at point 2 for initial die temperature 400°C is higher than for either 200 or 300°C. Moreover, as initial die temperature increases, the hardness of the steel near the surface of the die decreases.

5.RESULTS

The results of the die service life estimation according to initial die temperatures for plastic deformation and abrasive wear are summarized in Tables 2. As the initial die temperature increases, the production quantity decreases. The possible maximum production quantity affected by abrasive wear is higher than that by the plastic deformation of a die. Generally, the yield strength of steels decrease at higher temperatures and yield strength is also dependent on prior heat treatment.

Table 2: Die service life for the initial die temperature in terms of plastic deformation

Parameter	Initial Die Temperature (°C)					
	200		300		400	
	Point 1	Point 2	Point 1	Point 2	Point 1	Point 2
Equal temperature (°C)	579	545	584	585	602	623
Effective stress (MPa)	1360	1443	1243	1343	1166	1283
Tempering parameter (M)	18.2	18.1	18.2	18.2	18.2	18.3
Life time (h)	11.15	45.79	8.3	7.86	2.9	1.55
Product quantity (ea)	4462	18317	3330	3142	1194	620

6. CONCLUSIONS

In this study, a method for estimating the service life of hot forging dies by plastic deformation and abrasive wear is suggested, and this is applied to predict the product quantity, according to two main process variables, forming velocity and initial die temperature. Through the applications of the suggested methods, the following conclusions were obtained.

- 1) The Plastic deformation occurred due to the local temperature rise led to the reduction of the service life of hot forging dies is a dominating factor than abrasive wear for the thermal softening of dies. When the forming velocity increased, the die service life caused by abrasive wear decreased.
- 2) The plastic deformation appeared to be the major limiting factor for die service life. Especially, When the initial die temperature increased, the die service life by both plastic deformation and abrasive wear decreased.

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