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Impact of process parameters on the auto claw-pole thixoforming process

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Abstract. Thixoforming of steel is a potential forming technology, which can realize near-net-shape forming process with good quality in one forming step. In this paper, thixoforming process was used to replace the conventional hot forging process to form the auto claw-pole. The finite element code Forge2008© was used to simulate the auto claw-pole thixoforming process. The impact of three main process parameters such as initial billet temperature, punch speed and die temperature on the forming process were investigated. The reasonable process parameters for the auto claw-pole thixoforming were obtained: initial billet temperature 1430~1440°C, punch speed 100~200mm/s and die temperature 300~400°C.

Introduction

Thixoforming is an effective near-net-shape forming process which is particularly well-adapted to producing components with complex geometry and has the advantage of requiring fewer forming steps. Besides, the load required to deform material is much lower than in the case of conventional hot forging due to smaller resistance and good material fluidity. At present, although thixoforming of low melting point alloys as aluminum or magnesium alloys is now an industrial reality, thixoforming of high melting point alloys as steel is still at the research level [1-7]. In the steel thixoforming process, many problems need to be solved, such as heating problem, tool problem, forming load, die filling process etc [1-4, 7].

The auto claw-pole is made by low carbon steel, which has complex geometry and high requirement of mechanical properties (Fig. 1). At present, conventional hot forging is widely used to form the auto claw-pole. By using this method, there are many disadvantages, such as low material usage efficiency, numerous amount of post machining procedures and low production efficiency etc. In this work, a new process, thixoforming is used to replace the conventional hot forging to form the auto claw-pole. Using thixoforming process to form the auto claw-pole has many advantages, such as increase in material usage efficiency, improvement in product quality, decrease in post machining procedures etc. However, the consequences of such behaviour on the flow during thixoforming, is still neither completely characterized and nor fully understood, especially for high melting point alloys. Therefore, a clear understanding of steel thixoforming process is much more essential to support necessary foundation for forming the auto claw-pole by this method. Hence, in this work, numerical simulation method was used to the simulate auto claw-pole thixoforming process, and then, the impact of main process parameters on forming process was investigated.

During thixoforming, billet includes liquid phase and solid phase. Therefore, comparing with conventional hot forging and casting, the forming process in thixoforming become more and more complex, so that, simulation becomes much more difficult. Up to now, a lot of researchers have successfully used commercial software to simulate thixoforming process [8-10]. In this work, the finite element code Forge2008© was used to simulate the auto claw-pole thixoforming process.

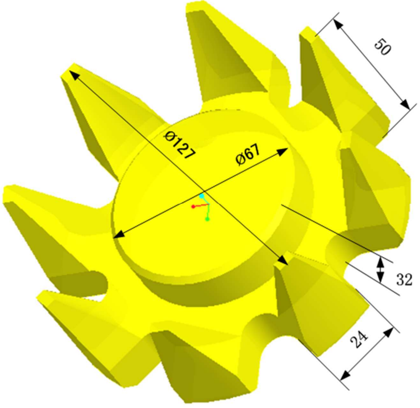


Fig. 1 The auto claw-pole

Modelling the auto claw-pole thixoforming process

The auto claw-pole is made by low carbon steel. In this work, C38 steel was used to simulate, which has chemical composition as in Tab. 1 [4]. In this model, the constitutive law used is quite simple and mainly driven by the liquid fraction, and so the temperature. Thus, the structure of the raw material and its evolution are not explicitly represented. Even if this is a limitation of the calculation results, the error on the flow behavior is small for high solid fraction. Thermal exchanges are already taken into account by the finite elements code [5, 7].

Table 1. C38 steel chemical composition (wt 10^{-3}%)

C	Mn	P	S	Si	Al	N	Ni	Cr	Cu
418	751	10	21	198	21	65	77	144	133

The constitutive law is a classical Spittel one (which is the default law used by the solver) when material temperature is lower than solidus and a modification of this Spittel equation is made when the material temperature is higher than solidus. The modification induces a linear decrease of the consistency by multiplying it by a factor going from one zero between the solidus transition between semi-solid and solid behavior during cooling [5, 7].

The constitutive law is: [5, 7]

$$\sigma = A e^{m_1 T} \varepsilon^{m_2} e^{\frac{m_4}{\varepsilon}} \dot{\varepsilon}^{m_3}, \quad if \quad T < T_{sol} \tag{1}$$

$$\sigma = A\left(\frac{T_{liq} - T}{T_{liq} - T_{sol}}\right) e^{m_1 T} \varepsilon^{m_2} e^{\frac{m_4}{\varepsilon}} \dot{\varepsilon}^{m_3}, \quad if \quad T_{sol} < T < T_{liq} \tag{2}$$

Where σ is stress, ε is strain, $\dot{\varepsilon}$ is strain rate, T is temperature, T_{liq} is liquidus temperature, T_{sol} is solidus temperature and A, m_1~m_4 are constants depending on the steel grade. For C38 steel, the values of the constant parameters are given in Table 2. A and m_1~m_4 came from the database of Forge2008, T_{liq} and T_{sol} were obtained by Differential Scanning Calorimetry (DSC) as Fig. 2 [4].

As the auto claw-pole has two symmetric planes, in order to reduce computation time, only 1/4 geometry modelling was used to simulate (Fig. 3).

Identifying process parameters for simulation of the auto claw-pole thixoforming process: in this study, three main process parameters were investigated: the initial billet temperature (T_{billet}), the die temperature (T_{die}) and the punch speed (v), which were specified as follows: T_{billet}=1430~1460°C, v= 40~215 mm/s, T_{die} 20~400°C [4].

Table 2. Values of constant used in Eqs. (1) and (2)

Parameter	A	m_1	m_2	m_3	m_4	T_{sol}/ °C	T_{liq}/ °C
Value	1515.8759	-0.00269	-0.12651	0.14542	-0.05957	1410	1510

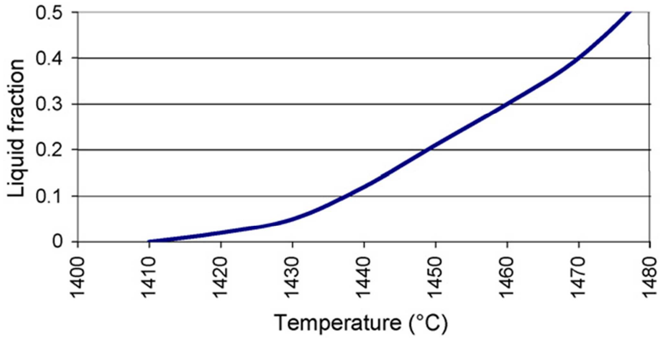


Fig. 2 Liquid fraction vs. temperature obtained by DSC

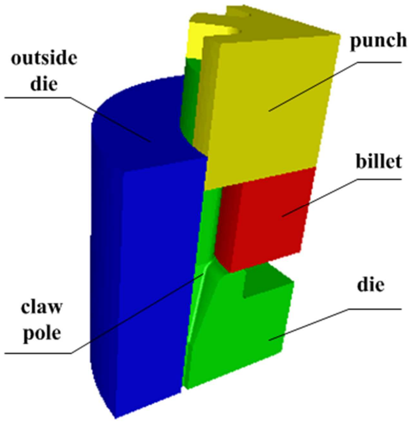
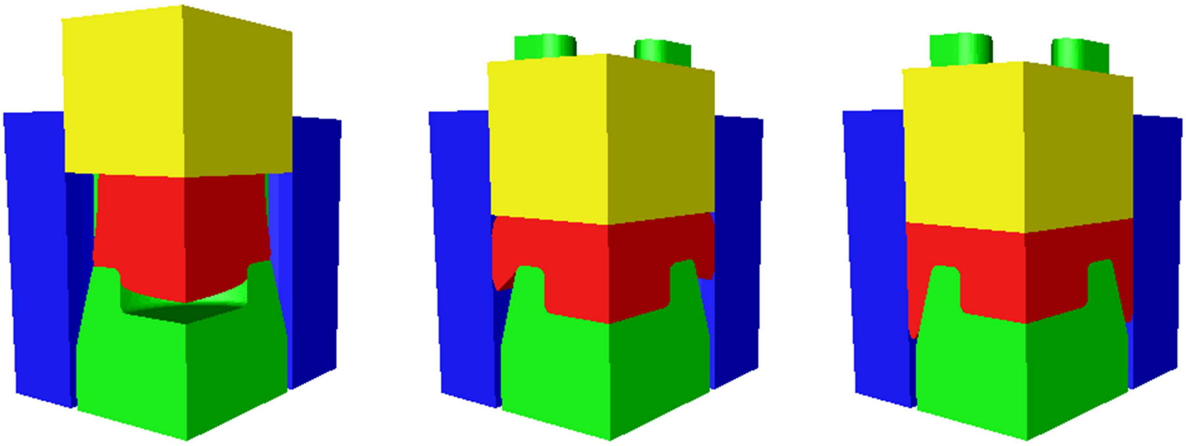


Fig. 3 Modelling of the auto claw-pole thixoforming process

Result and ana0lysis

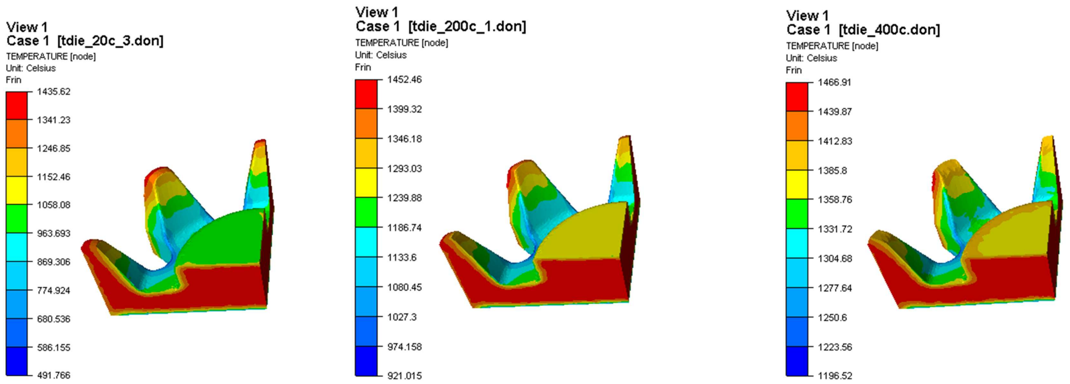
The forming process of the auto claw-pole thixoforming process is shown in Fig. 4. This process may be divided into two stages: First stage is the filling of large cavity, and the second stage is claw-poles filling. In the first stage, due to high billet temperature, less material resistance and good material fluidity forming load is low and steady. In the second stage, due to the lower billet temperature, higher material resistance and bad material fluidity result which lead to forming load increase rapidly (Fig. 6).



(a) Begin forming (b) Full filling large cavity (c) full filling claw-poles

Fig. 4 The auto claw-pole thixoforming process

The temperature distribution field of billet at the end of forming process is shown in Fig. 5, corresponding to T_{billet}=1430°C, v=40 mm/s, T_{die}=20°C (Fig. 5a); T_{billet}=1445°C, v=100mm/s, T_{die}=200°C (Fig. 5b) and T_{billet}=1460°C, v=40mm/s, T_{die}=400°C (Fig. 5c). These results have shown that during the forming process, billet temperature was getting lower and distributed inhomogeneously. The temperature inside is much higher than the surface temperature. The inhomogeneous temperature distribution strongly depends on process parameters. The lowest temperature of billet in following three different cases reached to 491°C (Fig. 5a), 921°C (Fig. 5b) and 1196°C (Fig. 5c), respectively. The results about the impact on degree of inhomogeneous temperature distribution have shown, the punch speed being the strongest factor, followed by the die temperature and the initial billet temperature.



(a) (b) (c)

Fig. 5 Temperature distribution, corresponding to: (a) T_{billet}=1430°C, v=40mm/s, T_{die}=20°C; (b) T_{billet}=1445°C, v=100mm/s, T_{die}=200°C and (c) T_{billet}=1460°C, v=215mm/s, T_{die}=400°C

The relationships between forming load and punch stroke are shown in Fig. 6. These curves may be divided into two stages, which are similar to forming process (Fig. 4). In the first stage, due to high billet temperature and good material fluidity lead to slow and steady increase in forming load. The second stage, corresponding to claw-pole filling process, due to lower billet temperature, higher solid fraction, worse material fluidity and higher material resistance lead to rapid increase in forming load. In this study, the highest forming load of the auto claw-pole thixoforming reached to 442.28kN, corresponding to T_{billet}=1430°C, v=40mm/s and T_{die}=20°C. But this value is significantly lower than forming load of hot forging (the results of simulations of the auto claw-pole hot forging process, the lowest forming load reached to 1150kN).

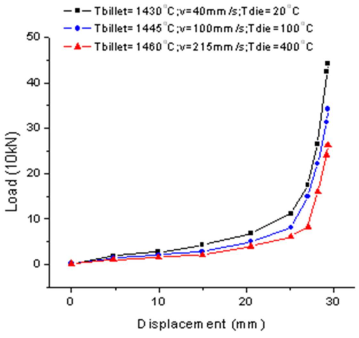


Fig.6 Load – punch stroke curve

The relationships between forming load and punch speed are shown in Fig. 7. It can be seen that, punch speed has strong impact on forming load. As punch speed increases, forming load decreases rapidly. However, if the punch speed is too low, billet temperature will cool rapidly to lower material solidus temperature and thus, the bad material fluidity and difficulty in metal flow results which lead to rapid increase in forming load and may be incomplete filling. Whereas, with very high punch speed, although forming load is quite small and billet temperature distribution is quite homogeneous, the increase of metal flowing speed will induce turbulence flow, which lead to air-entrapment and shrinkage porosity defect. Thus, reduces product quality [4, 6].

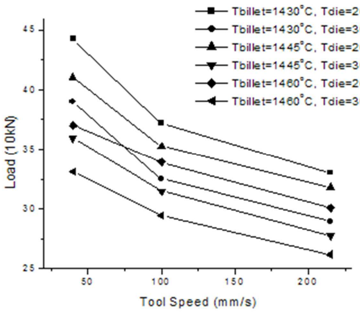


Fig.7 Forming load – punch speed curves

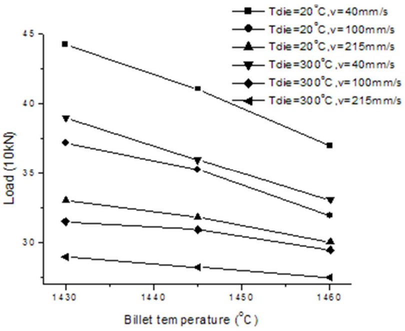
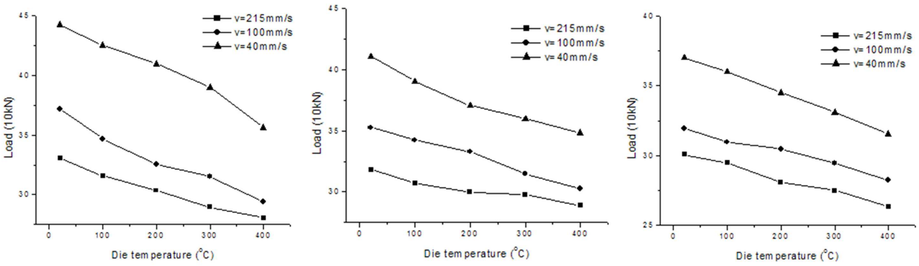


Fig. 8 Forming load–initial billet temperature curves

The curves of forming load – initial billet temperature are shown in Fig. 8. Its have shown that, when initial billet temperature increases, the forming load decreases, but decreased level is considerably lower. The high initial billet temperature induces good material fluidity and fine filling capability but it has bad influence on microstructure and reduces product quality [4]. However, initial billet temperature can not be too low because it leads to reduced material fluidity and low filling capability, which may be induced to appear defects and high forming load.

The relationships between forming load and die temperature are shown in Fig. 9. We can show that, die temperature has significantly impacts on forming process. When the die temperature increases, the forming load decreases. When die temperature is 20°C (cold die), billet temperature distribution is the most inhomogeneous and forming load is the highest. Therefore, die must be heated. But the die temperature should not be too high because it may be reduced die lifetime, except when using especial die material [4, 8].



(a) T_{billet}=1430°C; (b) T_{billet}=1445°C; (c) T_{billet}=1460°C

Fig. 9 Forming load – tool temperature curves

In summary, initial billet temperature, punch speed and die temperature have strong impact on the auto claw-pole thixoforming process. However, these process parameters need to be reasonably chosen. In this study, by the changing process parameters in simulation, the reasonable process parameters for the auto claw-pole thixoforming process were obtained: initial billet temperature 1430~1440°C, punch speed 100~200mm/s and die temperature 300~400°C. These process parameters are important foundation for applying thixoforming process to form the auto claw-pole.

Conclusions

Replacing the conventional hot forging process by thixoforming process to form the auto claw-pole has significant advantages, such as the possibility of achieving near-net-shape forming with good quality in one forming step, considerably increasing material usage efficiency, measurably reducing forming load etc.

Through simulation, the impact of three main process parameters (initial billet temperature, punch speed, die temperature) on the auto claw-pole thixoforming process was revealed. The most impact on thixoforming process is the punch speed, followed by the die temperature and the initial billet temperature.

Through simulation and analysis, the reasonable values of three main process parameters for the auto claw-pole thixoforming process were obtained: initial billet temperature 1430~1440^{o}C, punch speed 100~200mm/s and die temperature 300~400^{o}C.

Acknowledgements

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