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Numerical simulation of the auto claw-pole thixoforming process

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Abstract. Thixoforming is an effective near-net-shape forming process to produce components with complex geometry and in fewer forming steps. In this study, thixoforming was used to replace the conventional hot forging to form the auto claw-pole. The finite element code Forge2008© was used to simulate the auto claw-pole thixoforming process. The results show that initial billet temperature, punch speed, die temperature and friction have strong impact on the forming process. Finally, 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 a promising technology which combines the advantages of conventional hot forging and casting [1-4]. The metal forming itself takes place in the range of temperatures where the alloy is in a semi-solid state. The thixotropic material behaviour leads to material flow with low forces [4]. This makes it possible to produce complex geometry parts in one forming step with loads much lower than in conventional hot forging. Comparing thixoforming with conventional casting, the forming temperatures are lower leading to porosity and shrink reduction [4]. 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 [1-8].

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 [8]. 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 [8]. 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 [3]. Therefore, a clear understanding of steel thixoforming is much more essential to support necessary foundation for forming the auto claw-pole by this method. Hence, in this study, numerical simulation method was used to 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 [9]. In this work, the finite element code Forge2008© was used to simulate the auto claw-pole thixoforming process.

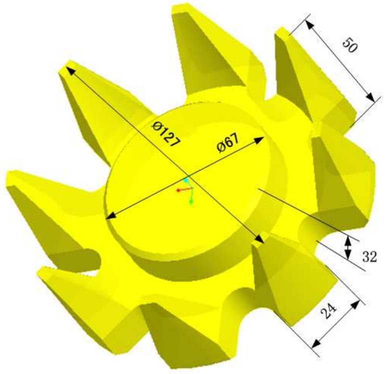


Fig. 1 The auto claw-pole

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 [3, 8]. 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 [8-10].

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 [8-10].

The constitutive law is: [8-10]

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

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

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 [3].

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

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

Identifying process parameters for simulation of the auto claw-pole thixoforming process: in this work, four main process parameters were investigated: the initial billet temperature (T_{billet}), the die temperature (T_{die}), the punch speed (v) and friction coefficient μ, which were specified as follows: T_{billet}=1430~1460°C, v= 40~215 mm/s, T_{die}=20~400°C and μ=0.15~0.4 [10].

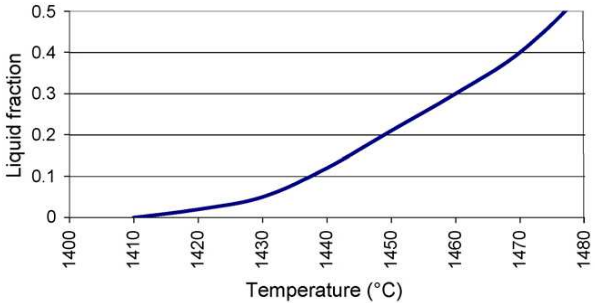


Fig. 2 Liquid fraction vs temperature obtained by DSC

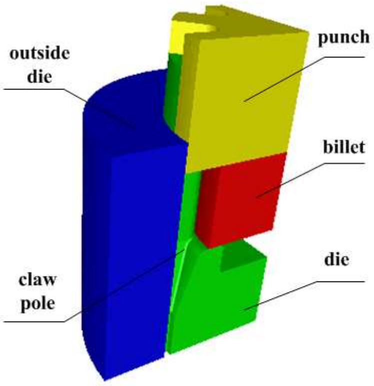
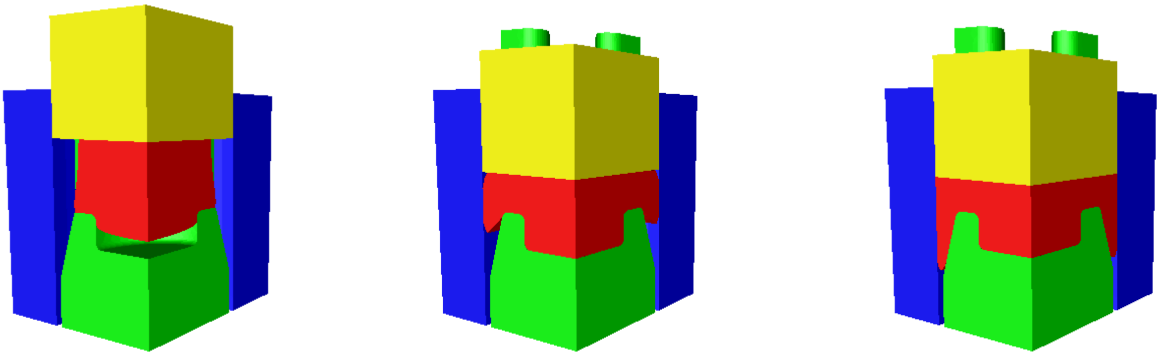


Fig. 3 Modelling of the auto claw-pole thixoforming process

Result and analysis

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 the large cavity, and second stage is claw-poles filling. In first stage, due to high billet temperature, less material resistance and good material fluidity, forming load is low and steady. In second stage, due to the lower billet temperature, higher material resistance and bad fluidity, forming load increases rapidly (Fig. 7).



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

Fig. 4 The auto claw-pole thixoforming process

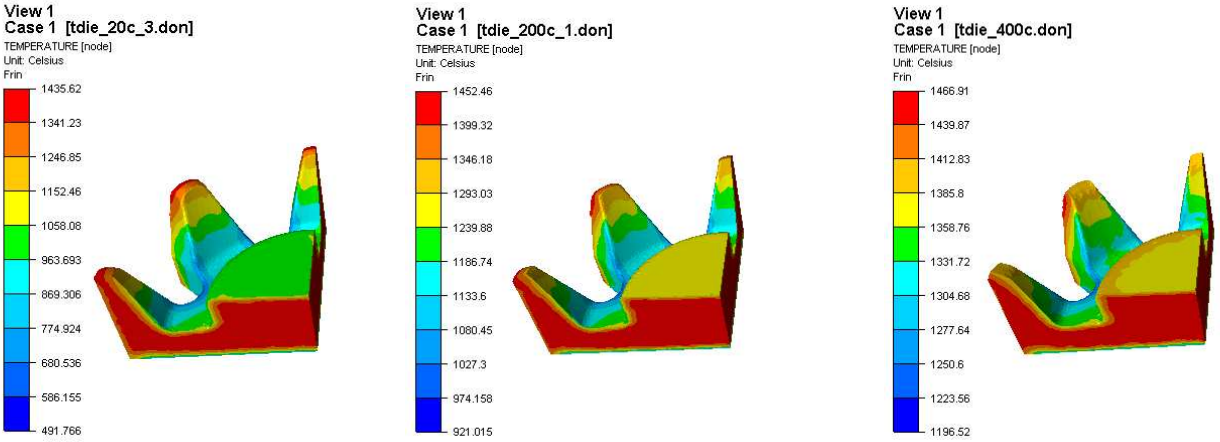
The temperature distribution field of billet at the end of forming process is shown in Fig. 5. These results have shown that during the forming process, billet temperature was getting lower and distributed inhomogeneously. The temperature inside is much higher than the surface temperature. The lowest temperature of billet in following three different cases reached to 491°C (Fig. 5a), 921°C (Fig. 5b) and 1196°C (Fig. 5c), respectively.

In this study, the degree of homogeneous temperature distribution (DHTD), f_T, is defined in Eq. (3):

$$f_T = 1 - \frac{T_{billet} - T_{\min}}{T_{billet}} \tag{3}$$

Where: $T_{\min}$ - the lowest temperature on the billet surface at the end of the forming process;
T_{billet} – the initial billet temperature.

The value of f_T ranges from 0 to 1. Greater the f_T is, more the homogeneous distribution of billet temperature is and vice versa.



(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 impact of process parameters on DHTD is shown in Fig. 6. It can be seen that:

DHTD is slightly affected by the initial billet temperature. At the same punch speed and die temperature, DHTD has slightly decreased as T_{billet} increases (e.g. curve E, G; curve F, C, curve B, D). High initial billet temperature leads to decreasing in heat exchange between billet and die, as the result, the temperature difference of surface and inside increases, or DHTD decrease.

Punch speed have significant impact on DHTD. At the same initial billet temperature and die temperature, DHTD has greatly increased as punch speed increases. Die filling time is reduced at higher punch speed resulting in considerable decrease of the time of heat exchange between billet and die. Finally, billet temperature distribution is more homogeneous or DHTD increases.

DHTD is quite measurable affected by die temperature, especially at low punch speed where the impact is quite clear. When punch speed is as low as 40mm/s or 100 mm/s, the increasing of die temperature lead to rapid increase in DHTD (curve B, D or C, F). However, at the higher punch speed (215mm/s), DHTD has slightly changed when die temperature has increased (curve E, G).

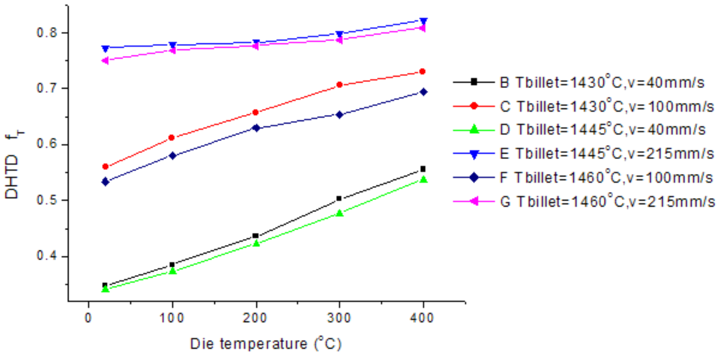


Fig. 6 The relationships between DHTD and process parameters

The relationships between forming load and punch stroke are shown in Fig. 7. These curves may be divided into two stages. In the first stage, due to high billet temperature and good material fluidity lead to slow and steady increase in forming load. In the second stage, due to lower billet temperature, higher solid fraction, worse material fluidity and higher material resistance lead to rapid increase in forming load.

The impact of process parameters on forming load is shown in Fig.8, corresponding to friction coefficient μ=0.20. It can be seen that initial billet temperature, punch speed and die temperature have considerable impact on forming load:

- Forming load decreases measurably as die temperature increases (curve B~G);
- Forming load slowly decreases as initial billet temperature increases (curve B and D; C and F; E and G);
- Forming load decreases rapidly as punch speed increases (curve B and C; D and E; F and G).

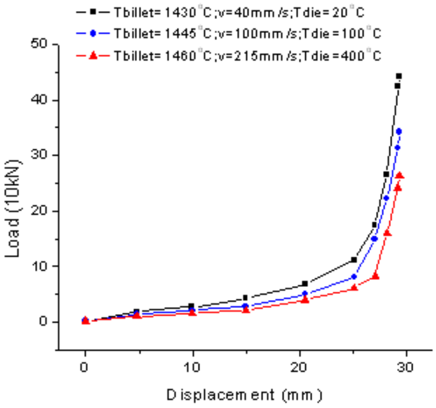


Fig.7 Load – punch stroke curve

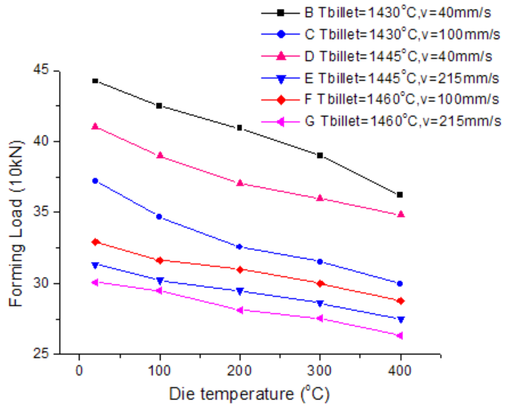


Fig. 8 Relationships between forming load and process parameters, corresponding friction coefficient μ=0.20

As described above, it can be easily seen that, the strongest impact factor on forming process is punch speed, followed by die temperature and initial billet temperature. The high initial billet temperature induces good material fluidity and fine filling capability, but it has bad influence on microstructure and reduces product quality. However, low billet temperature may be reduced material fluidity and decreased filling capability, which may lead to incomplete filling defect and so high requirement of forming load [3, 8]. Besides, low punch speed leads to billet temperature cool rapidly, as results of that forming load increases rapidly and DHTD reduces considerably. But high punch speed induces high metal flow speed that leads to turbulence flow, resulting in possible air-entrapment and shrinkage porosity defects. In addition, low die temperature induce billet temperature distribution inhomogeneous, "cold shut" and too high forming load problems [7, 8]. Thus, die must be heated. But die heating temperature should not be too high because it may reduce die lifetime [5, 6]. Therefore, 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.

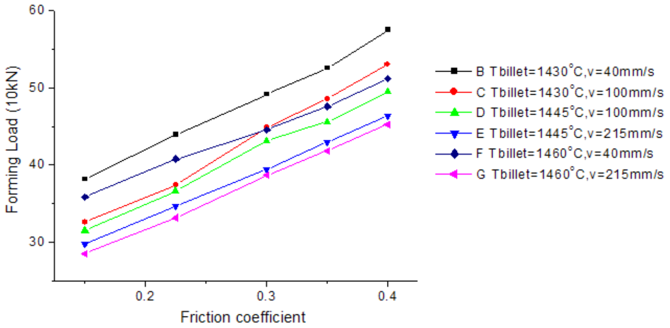


Fig. 9 The impact of friction on forming load, corresponding T_{die}=300°C

During thixoforming, friction has two main effects: it increases the load needed to fill the cavity and it wears the tool and so decreases its lifetime [10]. In this study, the impact of friction coefficient on forming load is shown in Fig. 9, corresponding to die temperature 300°C. It can be seen that forming load increases remarkably as the friction increases. However, initial billet temperature, punch speed and die temperature have slightly impact on the relationships between forming load and friction coefficient (curve B ~ G are linear increment and parallel).

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.

In the auto claw-pole thixoforming, initial billet temperature, punch speed and die temperature have strong impact on forming process. Forming load and DHTD increases as initial billet temperature, punch speed and die temperature increases. However, high values of these parameters could probably lead to occur defects and decrease product quality. Friction has considerable impact on forming load. Forming load remarkably increases as the friction coefficient increases.

Through simulation and analysis, the reasonable values of 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.

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References

[1] A. Rassili, H.V. Atkinson: A review on steel thixoforming. Trans. Nonferrous Met. Soc. China, 2010, Vol. 20(2010), p. 1048-1054.

[2] PUTTGEN W, BLECK W, HIRT G, SHIMAHARA H: Thixoforming of steel - A status report. Advanced engineering material, Vol. 4 (2007), p. 231-245.

[3] Eric Becker, V. Favier, et al: Impact of experimental conditions on material response during forming of steel in semi-solid state. J. of mat. processing tech., Vol. 210 (2010), p. 1482-1492.

[4] L. Khizhnyakova, M. Ewering, G. Hirt et al: Metal flow and die wear in semi-solid forging of steel using coated die. Trans. Nonferrous Met. Soc. China, Vol. 20 (2010), p. 954-960.

[5] J. C. Pierret, A. Rassili, G. Vaneetveld et al: Stability of steel thixoforming process. Trans. Nonferrous Met. Soc. China, Vol. 20 (2010), p. 937-942.

[6] A. Rassili, J.C. Pierret, G. Vaneetveld et al: X38CrMoV5 hot-work tool steel as tool material for thixoforging of steel. Trans. Nonferrous Met. Soc. China, Vol. 20 (2010), p. 713-718.

[7] V.L. Dao, S.D. Zhao, Q. Zhang: Numerical simu. of a thixocasting pro. for AISI420 stainless steel air-turbine blade. Trans. Nonferrous Met. Soc. China, Vol. 20 (2010), p. 926-930.

[8] V.L Dao, S.D. Zhao et al: Impact of process parameters on the auto claw-pole thixoforming process. Advanced Materials Research (was accepted).

[9] ATKINSON H. V.: Modelling the semisolid processing of metallic alloys. Progress in materials science, Vol. 50 (2005), p. 341-412.

[10] J.C. Pieret, A. Rassili et al: Friction coffienients evaluation for steel thixoforging. Int J Mater Form, Vol. 3 (2010), p. 763-766.

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10.4028/www.scientific.net/AMM.66-68

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10.4028/www.scientific.net/AMM.66-68.1605

DOI References

[1] A. Rassili, H.V. Atkinson: A review on steel thixoforming. Trans. Nonferrous Met. Soc. China, 2010, Vol. 20(2010), pp.1048-1054.
http://dx.doi.org/10.1016/S1003-6326(10)60629-2
[2] PUTTGEN W, BLECK W, HIRT G, SHIMAHARA H: Thixoforming of steel - A status report. Advanced engineering material, Vol. 4 (2007), pp.231-245.
http://dx.doi.org/10.1002/adem.200700006
[4] L. Khizhnyakova, M. Ewering, G. Hirt et al: Metal flow and die wear in semi-solid forging of steel using coated die. Trans. Nonferrous Met. Soc. China, Vol. 20 (2010), pp.954-960.
http://dx.doi.org/10.1016/S1003-6326(10)60613-9
[5] J. C. Pierret, A. Rassili, G. Vaneetveld et al: Stability of steel thixoforming process. Trans. Nonferrous Met. Soc. China, Vol. 20 (2010), pp.937-942.
http://dx.doi.org/10.1016/S1003-6326(10)60610-3
[6] A. Rassili, J.C. Pierret, G. Vaneetveld et al: X38CrMoV5 hot-work tool steel as tool material for thixoforging of steel. Trans. Nonferrous Met. Soc. China, Vol. 20 (2010), pp.713-718.
http://dx.doi.org/10.1016/S1003-6326(10)60568-7
[9] ATKINSON H. V.: Modelling the semisolid processing of metallic alloys. Progress in materials science, Vol. 50 (2005), pp.341-412.
http://dx.doi.org/10.1016/j.pmatsci.2004.04.003
[10] J.C. Pieret, A. Rassili et al: Friction coffienients evaluation for steel thixoforging. Int J Mater Form, Vol. 3 (2010), pp.763-766.
http://dx.doi.org/10.1007/s12289-010-0882-1