Measurement of heat transfer coefficient of boron steel in hot stamping

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Abstract

The characteristic of the heat transfer coefficient of the boron steel for hot stamping process was studied in this paper. For obtaining the 1400MPa high strength product by the hot stamping process, the microstructure of blank has to be transformed from austenite to fully martensite by the quenching process in closed tools. The heat transfer coefficient between the blank and tools then becomes an important role which may affect the cooling rate and the final microstructure distribution of the blank. In this study, the experimental platform was built, and the inverse calculating method was used for obtaining the heat transfer coefficient. The influence of the contact pressure on the heat transfer coefficient was also investigated, and it reveals that the contact pressure affect the interface heat transfer most. From the FEM simulations, it also shows that the temperature histories of the blank and tools are good agreement to the experiment results, which imply the feasibility of the experiment platform and the method for obtaining the heat transfer coefficient.

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1. Introduction

In order to develop the light weight vehicle, the hot stamping process which is also called press hardening process has been widely used in the automotive structure parts. By hot stamping process, the blank is heated up to 900°C and transformed to the austenite, and then the blank is formed and quenched in the tools. Because the hot stamping process includes the mechanical-thermal-metallurgy mechanisms, it is difficult to predict the formability and final strength of the product parts. So, using the FEM in the hot stamping product development is suitable. However, due to its complex forming mechanisms, there are lots of parameters should be measured to use in the FEM models. The heat transfer coefficient is one of the most important parameters which are needed in the FEM model and also a parameter which may directly affect the strength of final product.

Salomonsson et al. (2008) has constructed an experimental setup and obtained the heat transfer coefficient of two hot stamping materials. Salomonsson et al. (2009) discussed the influence of the contact pressure on the heat transfer coefficient. Abdul Hay et al. (2010) investigated the thermal contact resistance between the tools and the hot stamping material. It was found that the singularity phenomenon of thermal contact resistance which is due to the martensite transformation. Hu et al. (2013) discussed the influence of the oxide thickness on the heat transfer coefficient. Merklein et al. (2009) investigated the influence of the tool temperature on the heat transfer coefficient for the tailor properties applications. In this study, the experiment platform was constructed and the inverse calculating method was used for obtaining the heat transfer coefficient. The influence of the contact pressure on the heat transfer coefficient was also investigated. The feasibility of the heat transfer coefficient obtained from this study was also discussed.

Nomenclature

\( h \)  heat transfer coefficient  
\( \rho \)  density  
\( V \)  volume  
\( C_p \)  heat capacity  
\( A \)  contact area  
\( t \)  time  
\( T(t) \)  current blank temperature  
\( T_0 \)  initial blank temperature  
\( T_w \)  surrounding temperature

2. Method for obtaining the heat transfer coefficient

2.1. Experiment platform

The heat transfer coefficient experiment was conducted in the MTS 810 machine. In order to apply enough contact pressure between the blank and tools, the blank size is set as 45 x 45 mm and the diameter of the tools is 70mm. For calculating the tools surface temperature, the tools are drilled holes for inserting thermal couples to measure the temperature within the tools. The blank was also drilled a hole for inserting a thermal couple to measure the temperature of the blank. The K-type thermal couples were used for measuring the temperature in the experiments. The material of blank is boron steel with 1.8mm thickness. The material of the tools is SKD61 hot work tool steel.
2.2. The Inverse Calculating Method

The temperature histories of the blank and tools from experiments were used in the inverse calculating method to obtain the heat transfer coefficient between the blank and the tools. The method is quoted from Merklein et al. (2009). The Newton’s cooling law (2007) used to calculate the heat transfer coefficient is shown in the following equation:

$$h = \frac{\rho V C_p}{At} \ln \left[ \frac{T(t) - T_\infty}{T_0 - T_\infty} \right].$$

A FEM model was built to simulate the experiment procedure. And the simulation results were compared with the experiment to verify the feasibility of the heat transfer coefficient obtained from experiments and calculating method. The FEM models were constructed by the DEFORM software, and the full model including the blanks and the tools is shown in Fig. 1.

3. Results and discussions

In order to obtain the heat transfer coefficient, the blank temperature and tool temperature were measured by the thermal couples. Fig. 2 shows the temperature histories of the blank and the tools at 20 MPa contact pressure. The blank temperature decreases from 798.6 °C to 210.1 °C rapidly in 3 seconds and the tools temperature increases from 30.3 °C to 153.2 °C in 3 seconds. The heat transfer coefficient with the cooling time at 20 MPa is shown in Fig. 3. From the experimental results, it was found that the heat transfer coefficient increases intensively at the first second when the temperature difference between the blank and the tool is larger.
In the hot stamping process, the blank is quenched in the closed tools. The heat transfer coefficient between the blank and the tools is affected by the contact pressure, which also affects the cooling rate of the blank. The heat transfer coefficient at different contact pressures is shown in Fig. 4. It reveals that the average heat transfer coefficient increases from 1764.3 \text{W/m}^2\text{K} to 3782.0 \text{W/m}^2\text{K} as the contact pressure increases from 0 to 30 MPa. It implies that the heat transfer coefficient increases as the contact pressure increases. The heat transfer coefficient obtained from experiments in the present study is also compared to the literature results by Abdul Hay et al. (2010), Hu et al. (2013), Geiger et al. (2008), Tondini et al. (2009) as shown in Fig. 5. It can be found that the experiment results in the present study have the same tendency to the literature results, which the heat transfer coefficient increases as the contact pressure increases. However, it can also be found that the heat transfer coefficient also has the quite differences between the present study and literature results. It may cause by the reasons including the differences of the material of blank, the oxide thickness of the blank, the surface roughness of the blank and tools, the material of tools, the experiment procedures, and so on.

Fig. 4. Heat transfer coefficient of blank and tools at different contact pressures.

Fig. 5. The comparison of heat transfer coefficient between the present study and literature.
For realizing the feasibility of the experiment results from the experiment platform, the heat transfer coefficients from the experiment and calculating method were put into the FEM model to simulate the experiment procedure. Fig. 6 shows the simulation results and experiment results of the temperature histories of the tool. It is found that using the heat transfer coefficient as a function of time in FEM model can obtain more accurate results compared to using the constant heat transfer coefficient in FEM model.

Moreover, because of the inverse calculating method is suitable as the transverse heat transfer is smaller compared to the longitudinal heat transfer in the tool, the temperature histories with different transverse positions are obtained from the simulation model to make sure the transverse heat transfer is small in the tools. Fig. 7 is the measure positions in the simulations and Fig. 8 is the simulation results. It shows that the temperature histories with different positions are quite closely. It also shows that the transverse heat transfer is small and the inverse calculating method is appropriate for the experiment.
4. Conclusion

The heat transfer coefficient of boron steel for hot stamping process has been investigated in the present study. The conclusions of this study are shown as following:

(1) The experiment platform and inverse calculating method were constructed for obtaining the heat transfer coefficient of boron steel, and the heat transfer coefficient at different contact pressures of boron steel were obtained by the experiment platform and the inverse calculating method.

(2) From the experiment and analysis results, it shows that the heat transfer coefficient increases as the contact pressure increases.

(3) From the simulation results, it is found that using the heat transfer coefficient as a function of time in FEM model can obtain more accurate results compared to using the constant heat transfer coefficient in FEM model.

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