Comparison of Heat Transfer Performance Between Coated Boron Steel and Uncoated Boron Steel During Hot Stamping

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Abstract. The interfacial heat transfer coefficient (IHTC) is a critical thermophysical parameter indicating the ability of heat transfer between different bodies. In this paper, an advanced temperature acquisition system was established based on direct measurement, a theoretical model of interfacial heat transfer and an inverse algorithm of the IHTC was developed. Besides, the influence of contact pressure and martensitic transformation on IHTC of coated boron steel (Usibor 1500P) and uncoated boron steel (B1500HS) were investigated and compared. The results show that the IHTC of uncoated boron steel increases with the increase of contact pressure. However, little effects on the IHTC are generated by contact pressure regarding coated boron steel. Moreover, it was also found that IHTC first increased and then decreased during martensitic transformation.

Keywords: Interfacial heat transfer coefficient (IHTC) · Hot stamping · Boron steel

1 Introduction

During hot stamping process, the interfacial heat transfer coefficient (IHTC) is one of the most critical thermophysical parameter reflecting the heat transfer ability at the contact face between sheet and tool.

An advanced temperature acquisition system is essential to obtain the temperature of sheets and tools for calculating IHTC. And there are many factors affecting the value of IHTC, such as contact pressure, blank thickness and surface roughness. Chang et al. [1] employed Beck's method to calculate the IHTC of uncoated boron steel 22MnB5 and found that the IHTC increased with higher pressure but decreased with thicker oil coating. Liu et al. [2] studied the effect of contact pressure, lubricant, surface roughness, tool material and initial blank temperature on IHTC, and obtained the value of IHTC

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under different hot stamping conditions. Hu et al. [3] found that the effects of oxide scale and contact pressure on IHTC were relatively obvious during rapid cooling process.

In this paper, an advanced temperature acquisition system was established, and the IHTC algorithm was improved. The effects of contact pressure and martensitic transformation on IHTC were investigated, respectively. Furthermore, the difference of heat transfer performance between coated and uncoated boron steels during hot stamping was compared.

2 Experimental Setting and IHTC Calculation Methods

Usibor 1500P (known as the coated boron steel) and B1500HS (known as the uncoated boron steel) were the used materials in this paper. Each sample was processed to a circular shape with a 60 mm diameter and a k-type armored thermocouple was instrumented to measure the core temperature. In order to determine the IHTC between blank and tool, the temperatures of seven positions were measured, i.e., one in the upper tool, one in the core of the blank, five in the lower tool. The five measurement positions of the lower tool were 1, 3, 5, 7, and 9 mm away from the upper surface of the lower tool, respectively. Moreover, 5 elastic supporters were served in the tool to prevent the energy loss of the blank before hot stamping. And a balancing device was designed and installed to ensure a uniform loading on the blank through a spherical contact face primarily, as shown in Fig. 1.

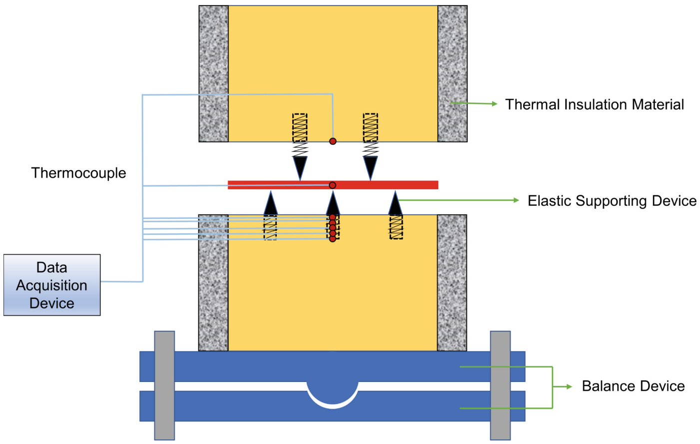

Fig. 1. Illustration of heat transferring experiment setup.

According to the theories of Newton's law, the IHTC between blank and tool can be expressed by Eq. (1).

$$\mathrm{IHTC} = \frac{q}{T_{blank} - T_{tool\_surface}} \tag{1}$$

where T_{blank} and $T_{tool\_surface}$ are the temperatures of the blank and tool surface, respectively. The Beck's optimization method is used to calculate the optimized tool surface temperature $T_{tool\_surface}$ [4]. q is the heat flux at contact face, which is calculated by Eq. (2).

$$q = \frac{c_{eq} pl(T_i - T_{i+1})}{\Delta t} \tag{2}$$

where c_{eq} is the equivalent heat capacity of the blank, ρ is the density, l is half the specimen thickness, T_i is the temperature of blank, Δt is the time segment, i.e., 0.05 s in this paper. The subscription i indicates the time step.

3 Results and Discussion

3.1 Heat Transfer Performance of Coated and Uncoated Boron Steel

The temperatures of uncoated blank and lower tool were recorded and analyzed to determine IHTC. As shown in Fig. 2, the cooling curves are sensitive to pressure, up to 50 MPa. Subsequently, the IHTC of uncoated blank increases with a higher pressure.

For coated steel, it can be seen from Fig. 3 that when the contact pressure is lower than 1.0 MPa, the IHTC increases with the pressure. But when the pressure is higher than 1 MPa, the change of IHTC with pressure is not obvious.

3.2 The Effect of Martensitic Transformation

The release of latent heat of the martensitic transformation significantly affects the value of IHTC. Therefore, it is necessary to compare the equivalent IHTC of coated

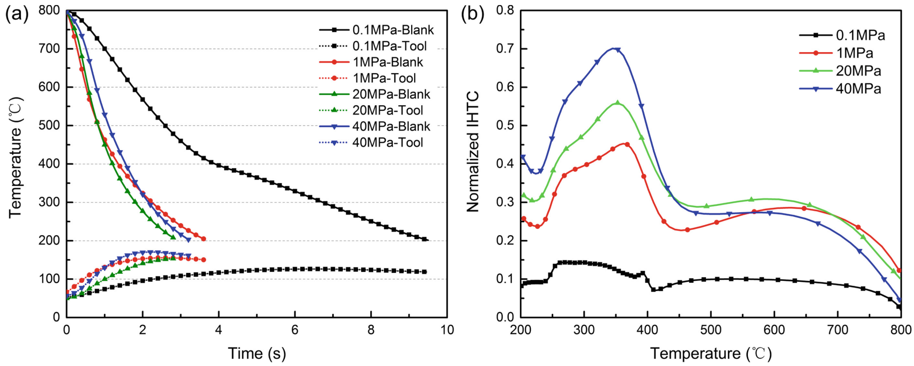

Fig. 2. (a) The temperatures of uncoated blank and lower tool and (b) the IHTC of uncoated boron steel.

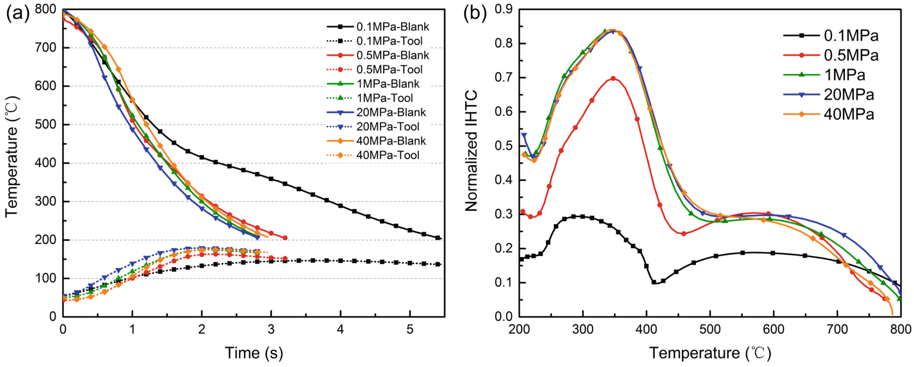

Fig. 3. (a) The temperatures of coated blank and lower tool and (b) the IHTC of coated boron steel.

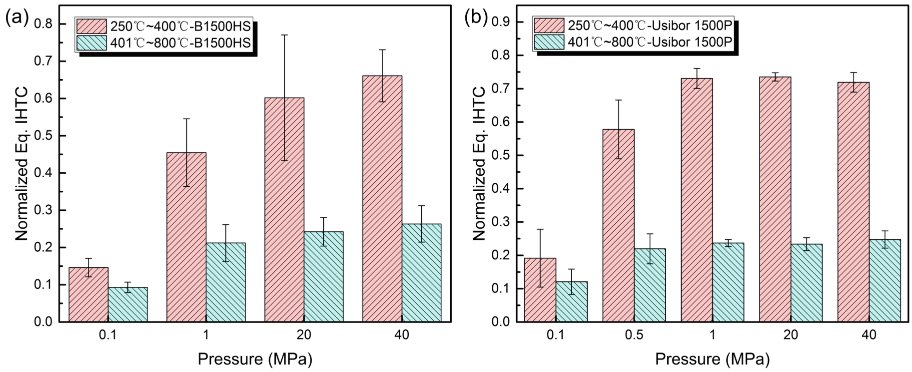

Fig. 4. The Eq. IHTC of (a) uncoated and (b) coated boron steel at different pressures.

and uncoated blanks at different pressures. Since the martensite starting temperature (Ms) is about 400 °C, two equivalent IHTC are introduced to analyze the effect of martensitic transformation. Figure 4 shows the relationship between the equivalent IHTC and the contact pressure of coated and uncoated boron steel. it can be observed that the equivalent IHTC yielded during the phase transformation is much higher than that before the martensitic transformation due to the latent heat release.

3.3 Establishment of an IHTC Theoretical Model for Uncoated Steel

The heat of the blank is mainly transferred through the contact spots and uncontacted air gaps, and the contact heat transfer coefficient h_c can be expressed by [5]:

$$h_c = \frac{1}{L_g}\left(\frac{A_C}{A}\frac{2k_{blank}k_{tool}}{k_{blank}+k_{tool}} + \frac{A_v}{A}k_f\right) \tag{3}$$

where k_{blank} and k_{tool} are the thermal conductivities of the blank and tool, respectively. k_f is the thermal conductivity of air in gap. A_v and A_C are the uncontacted area and actual contact area of blank and die. A is the theoretical contact area between blank and die, $A = A_C + A_v$. The ratio of actual contact area to nominal area is [6] $A_C / A = P / H$, P is the contact pressure and H is the Vickers hardness of softer materials. And L_g is the relative reference distance between blank, which is expressed by [7] $L_g = R(1 - P / E)$, $1 / E = (1 - v_1^2) / E_1^2 + (1 - v_2^2) / E_2^2$. v_1, v_2 and E_1, E_2 are the Poisson's ration and the Young's modulus of blank and die, respectively. The initial contact gap R can be expressed by roughness Rt. Thus, the contact heat transfer coefficient obtained from the above Eq. is:

$$h_c = \frac{1}{R(1 - P / E)} \left(\frac{P}{E} \frac{2k_{blank} k_{tool}}{k_{blank} + k_{tool}} + \left(1 - \frac{P}{E}\right) k_f \right) \quad (4)$$

4 Conclusion

The main conclusions obtained are as follows:

(1) The heat transfer performance of the uncoated boron steel (B1500HS) is promoted by contact pressures. However, the heat transfer performance of the coated boron steel (Usibor 1500P) is only sensitive to lower pressure (<1 MPa).
(2) The equivalent IHTC yielded during the phase transformation is much higher than that before the martensitic transformation due to the latent heat release.
(3) A theoretical model for calculating the heat transfer coefficient in the hot stamping process for uncoated blank is proposed, and the relevant parameters in the model can be easily measured.

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