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Investigation of the factors influencing the interfacial heat transfer coefficient in hot stamping

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ABSTRACT

In hot stamping of advanced high strength steel (AHSS) parts, the interfacial heat transfer coefficient (IHTC) between part and die has a direct impact on the temperature distribution in the part and consequently affects the microstructure and mechanical properties of the part. In this paper, a cylindrical-die experimental model was designed, experiments on boron steel 22MnB5 were conducted, the Beck's non-linear estimation method was used to calculate the IHTC, and the factors that influence IHTC were investigated. First, the influence of surface topography was studied. Both contact pressure and blank surface roughness impact the topography at the interface between die and blank. The interfacial topography determines the actual contacting area, which impacts the interfacial heat flow resistance and consequently the value of IHTC. The IHTC correlates highly with contact pressure by a positive power function. It also increases significantly with decreasing surface roughness but slows down when the roughness is less than 1 μm and saturates at high contact pressure. Second, the influence of material thermo-physical properties was analyzed. The IHTC between 22MnB5 blank and #45-tool-steel die is approximately twice as much as that of H13-tool-steel die. The martensitic transformation yields a positive gain on IHTC by approximately 30%. The combination of phase transformation induced thermal conductivity increasing and latent heat releasing results in a sharp increase of the IHTC near the M_s point. Third, the influence of anti-oxidation surface coating was evaluated. Although the oxidation preventive oil coating can reduce oxidation of the blank to a certain degree, it weakens the heat transfer performance. The IHTC decreases more with a thicker coating.

1. Introduction

The hot stamping process is defined as the boron steel sheets such as 22MnB5 are heated to over 900 °C for completely uniform austenitizing and then transferred to water-cooling dies for stamping and quenching at cooling rates of over 27 °C/s. Turetta et al. (2006) investigated the formability of 22MnB5 in hot stamping operations. Karbasian and Tekkaya (2010) further reviewed the thermal, mechanical, microstructural, and technological fields of this forming process. Hot stamped high-strength steel parts have the advantages of high strength, high hardness, little springback and significant weight reduction, all of which make hot stamping the best process for producing complex automotive structural components such as A-pillars, B-pillars and side impact beams etc.

During forming and quenching of the hot stamping process, heat transfers between high-temperature blank and low-temperature die. The interfacial heat transfer coefficient (IHTC) between blank and die is an important thermophysical parameter indicating heat transferability. The IHTC directly impacts the temperature distribution in the blank and consequently affects the mechanical property and microstructure of the formed part. The IHTC is needed in numerical simulation (finite element analysis etc.) of heat transfer problems and the accurate IHTC is necessary for reliable simulation results.

In heat transfer theory, the IHTC is a parameter to describe the heat transfer between interfaces and considered as a constant value in ideal condition (Yang and Tao, 2006). However, an ideal condition is difficult to achieve in practice and the IHTC is influenced by many complicated factors. Ikeuchi and Yanagimoto (2011) have demonstrated that the contact load, the temperature of blank and die, the surface roughness and the thermophysical properties of the material all influence the IHTC. Merklein et al. (2009) investigated the IHTC for given contact pressure and temperature

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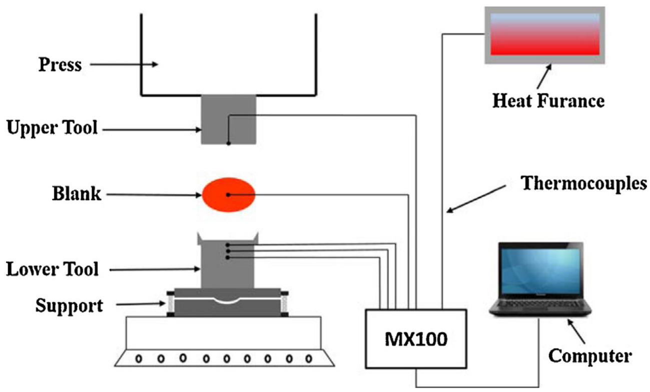

Fig. 1. Schematic illustration of the experiment setup.

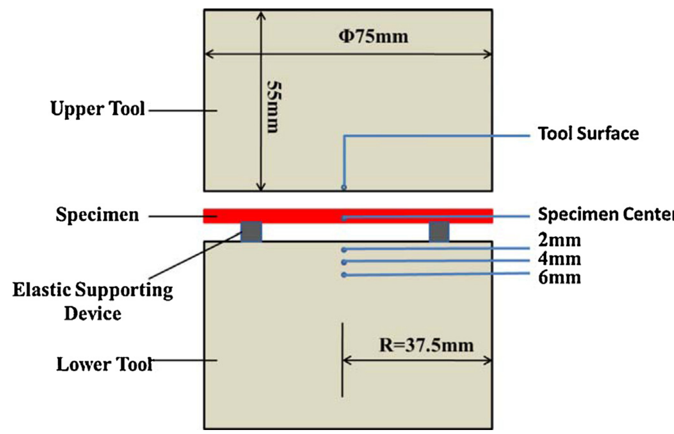

Fig. 2. Dimensions of the heat transfer device and the thermocouple positions.

Fig. 3. Experiment setup showing the specimen and thermocouple wiring.

difference through experiments, and compared the gap heat transfer coefficients (GHTC) for various gap values. Abdulhay et al. (2012) obtained the thermal contact resistance at different locations of a U-shape part with estimated contact pressure from 2 MPa to 30 MPa, and approximated an exponential function relationship between the thermal contact resistance and the contact pressure. Shojaefard and Goudarzi (2008) studied the heat transfer between stainless steel and aluminum based steady-state experiments. Blaise et al. (2013) analyzed the changes of thermal contact resistance of Usibor 1500P steel during hot stamping. Recent years have seen increasing applications of boron steel in hot stamping and emerging studies of the factors that influence the IHTC during forming and subsequent quenching. For example, Hu et al. (2013) studied the effect of oxide scale on IHTC for a typical type of boron steel 22MnB5. There are few investigations, though, on other influencing factors for this material.

There are two relatively mature methods for calculating the ITHC. One method is to treat the problem as inverse heat conduction problem illustrated by Bai et al. (2012), i.e. inversely solve the heat flux and temperature at the interface from the measured temperature fields of the blank and die, given IHTC as boundary conditions, and the optimal IHTC values are obtained by minimizing the difference between the calculated and measured temperatures of the blank and die. The other method is to simulate the temperature field by using finite element model and determine the optimal IHTC value through an iteration process. This method only provides a single equivalent IHTC, which cannot reflect the actual changes of the IHTC during the forming and quenching process. Therefore, the second method is less accurate than the first one.

In this paper, a heat transfer device was designed and an optimization program based on Beck's non-linear estimation method was developed (Beck et al., 1985). The optimal IHTC values were calculated and the influencing factors on IHTC were investigated. The factors include the microstructure at the interface between die and blank, the thermophysical parameters of die and blank, and the anti-oxidation coating on the blank.

2. Experiment description and calculation of IHTC

2.1. Experiment device and temperature acquisition

The experiment setup illustrated in Fig. 1 consists of a 40-ton hydraulic press, an electric furnace, a two-piece cylindrical die (upper and lower), a circular 22MnB5 steel blank of 2.0 mm thickness, five thermocouples, a data acquisition device MX100 and a desktop computer. The spherical contact in the support helps balance the lower die and ensure an uniform contact pressure on the blank. Fig. 2 shows the dimensions of the die and blank, and the temperature collecting positions. One thermocouple is fusion welded onto the surface of the upper die and smoothed flat. The temperature collected by this thermocouple is considered the temperature on the die surface. Three thermocouples are installed in the lower die at 2 mm, 4 mm, 6 mm below the die surface, respectively. One thermocouple is installed right in the middle of the blank.

In the experiment, the blank was heated in the furnace to 900 °C and kept for 3 min, then quickly transferred onto the lower die. The upper die slid down and pressed the blank against the lower die at a certain pressure. Fig. 3 shows the heated specimen and thermocouple wiring. The measured temperatures of the blank and the #45 tool steel die for 1.0 MPa contact pressure are plotted in Fig. 4.

2.2. Calculation of the IHTC

According the Newton's law of cooling, the IHTC can be expressed by

$$h = \frac{q}{\Delta T} \tag{1}$$

where q is the heat flux density between the blank and the die, and ΔT the temperature difference of the blank and the die at their interface. Therefore, it is necessary to obtain the temperatures of the blank and the die, as well as the heat flux density, in order to calculate the IHTC.