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Improvement in formability by control of temperature in hot stamping of ultra-high strength steel parts

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ABSTRACT

The formability in hot stamping of an ultra-high strength steel part was improved by preventing a temperature drop of the flange increasing resistance to drawing. The temperature drop was reduced by high speed forming using a servo press and by less contact with a die and blankholder using spacers thicker than the sheet. In addition, hardening of the flange was prevented by slow cooling for the less contact using the spacers to facilitate trimming of the hot-stamped part. From a hot deep drawing experiment with a hemispherical punch, the effectiveness of the present approaches of temperature control was demonstrated.

1. Introduction

For the reduction in weight and improvement of crash safety for automobiles, hot stamping of quenchable steel sheets is attractive. By heating the steel sheets, the forming load is remarkably reduced, the springback is prevented and the formability is improved [1,2]. In addition, the stamped parts are hardened by quenching with dies, and thus the ultra-high strength steel parts having a tensile strength of approximately 1.5 GPa are obtained under a low forming load [3].

Although most of hot-stamped parts are formed by bending, drawn parts tend to increase because of high formability. For bending, the prevention of springback is a key issue, whereas the improvement of formability is significant for deep drawing. In deep drawing, a temperature distribution in a sheet during stamping has a great influence on deformation behaviour of a sheet becomes major. Even if the sheet is uniformly heated, cooling during stamping becomes non-uniform due to partial contact with tools, temperatures in the bottom and flange of the cup are low and that in the sidewall is high as shown in Fig. 1. Since the flow stress is non-uniformly distributed by the temperature distribution, the deformation behaviour of the sheet is influenced by the cooling behaviour, i.e. deformations of portions with and without contact with tools becomes small and large due to high and low flow stresses, respectively. Although Merklein et al. [4] and Bariani et al. [5] investigated formability of steel sheets at uniform temperatures, the effect of temperature distribution is more remarkable for hot stamping processes. It is desirable in industry to develop approaches for controlling the temperature distribution during hot stamping.

Tailored die-quenching and tempering are approaches of temperature control for producing parts having a strength distribution in hot stamping. In tailored die-quenching, a partially heated sheet is hot-stamped [6], and the cooling rate during die-quenching is partially decreased by heated tools [7] and grooved tools [8] in tailored tempering, respectively. Although the temperature control is utilised to optimise mechanical properties of products, the application to improvement of formability has hardly been carried out. Only a sidewall of a cup formed into a gear was resistance-heated in spline forming of an ultra-high strength steel gear drum [9]. Lee et al. [10] reduced the springback in V-bending of non-quenchable high strength steel sheets using local heating around a punch corner.

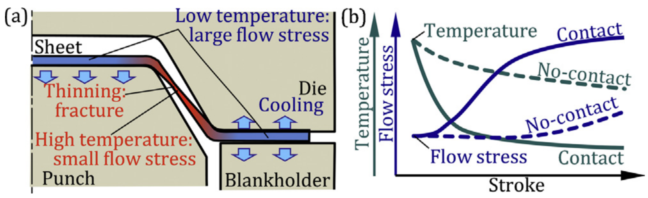

Fig. 1. Effect of temperature distribution on deformation behaviour of sheet in hot deep drawing. (a) Effect of temperature distribution and (b) variations of temperature and flow stress during hot drawing.

In the present study, the formability in hot stamping of an ultra-high strength steel part was improved by preventing temperature drop with high speed forming using a servo press and a flange gap. In addition, quenching of a flange of the part trimmed after hot stamping was prevented to facilitate a trimming operation.

2. Improvement of formability by high speed forming using servo press

A heated sheet is cooled even in several seconds during hot stamping, and the temperature distribution in the sheet becomes non-uniform due to partial contact with tools as shown in Fig. 2(a),

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the temperature is low in the flange and bottom of the cup in contact with the tools and is high in the sidewall without contact. Particularly, the temperature drop in the flange is crucial to the formability because of increase in resistance to drawing. Although hydraulic presses having a comparatively low slide speed are conventionally employed to attain holding at the bottom dead centre of the press cycle for die-quenching, the temperature drop during forming is large. On the other hand, in mechanical presses having a high slide speed, the slide motion is not controllable. Although compressed gas accumulators have been installed in a hydraulic press used for hot stamping to increase the forming speed, the control of the accumulators is not easy.

Mechanical servo presses having high flexibility for control of motion have been recently developed. In these presses driven by servo motors, the slide motion is accurately controlled by real-time feedback of ram position measured with sensors like the conventional machine tools, and thus complicated motion is attainable. Osakada et al. [11] reviewed applicability of servo presses to forming processes. Since both control and high speed of slide motion are attained in the mechanical servo presses, the temperature drop in hot stamping is prevented, and thus the formability is improved as shown in Fig. 2(b). In this chapter, the effect of the forming speed on the deformation behaviour of the sheet is evaluated.

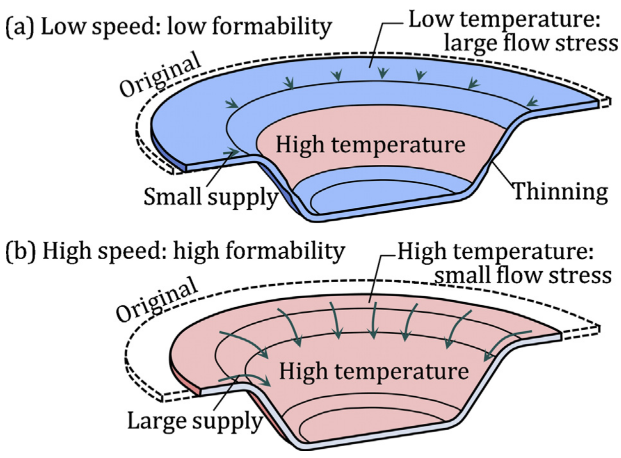

Fig. 2. Deformation behaviour of sheet during hot deep drawing under (a) low and (b) high speeds.

The equipment for hot deep drawing with a hemispherical punch is illustrated in Fig. 3. The non-coated quenchable 22MnB5 steel sheet (C: 0.21, Si: 0.25, Mn: 1.2, B: 0.001 mass%) having 1.6 mm in thickness was employed for the experiment. The sheet was heated at 910 °C in 240 s by an electrical furnace and the temperature after transferring to the dies just before stamping was 850 °C. The temperature distribution in the sheet during hot stamping was measured with an infrared thermography. A 1500 kN mechanical servo press was used, where the forming speed was between v = 26 and 149 mm/s and the minimum and maximum speeds are equivalent to hydraulic and mechanical presses, respectively. The blankholder force generated by cushions was 6.4 kN and no lubricant was applied to sheets and tools.

The hot and cold-stamped cups for the punch stroke s = 40 mm are shown in Fig. 4. For v = 26 mm/s, the hot-stamped cup fractures outside the border of the portion in contact with the punch, whereas the fracture is prevented for the v = 149 mm/s. The formability was improved by high speed forming using the servo press due to the prevention of the temperature drop.

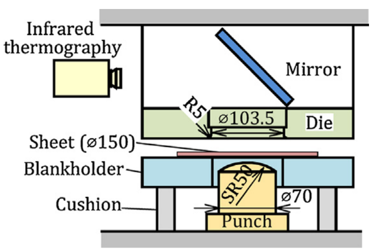

Fig. 3. Equipment for hot deep drawing with hemispherical cylinder punch.

Fig. 4. Hot and cold-stamped cups for s = 40 mm. (a) Hot, v = 26 mm/s, (b) hot, v = 149 mm/s and (c) cold, v = 26 mm/s.

The distributions of temperature on the surface of the sheet measured with the thermography for s = 40 mm and v = 26 and 149 mm/s are shown in Fig. 5. For v = 26 mm/s, the temperature of the portion in contact with the punch is largely reduced, whereas the temperature drop for 149 mm/s is smaller due to the short contact time.

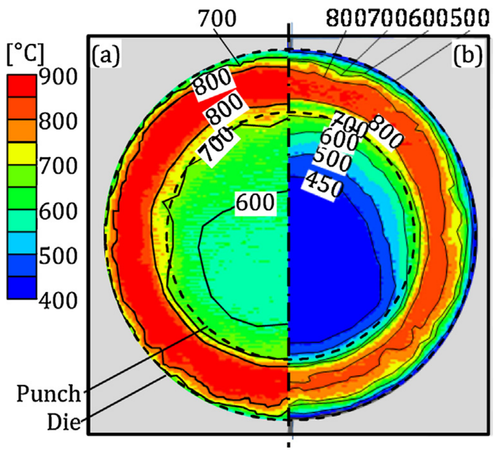

Fig. 5. Distributions of temperature on surface of sheet for s = 40 mm. (a) v = 149 mm/s and (b) v = 26 mm/s.

The distributions of the temperature and the reduction in thickness of the cup are shown in Fig. 6. The temperature drop of the portion in contact with the punch for v = 26 mm/s is much larger than that for 149 mm/s, and deformation for s = 35 mm is concentrated outside the border of the portion in contact with the punch due to small flow stress. Finally the cup was fractured by the deformation concentration. The temperature distribution during forming has a great influence on the deformation behaviour of the sheet.

The relationship between the flange temperature after 1.9 s from the end of forming and the forming speed for s = 35 mm is

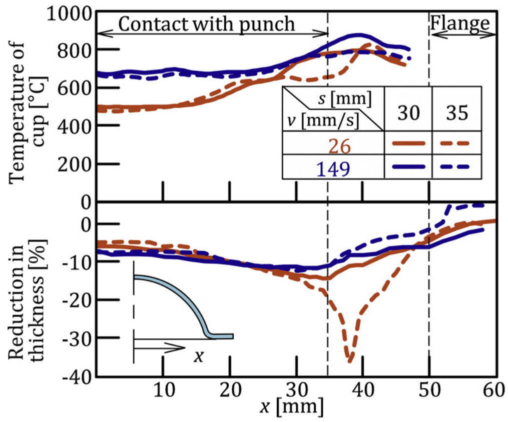

Fig. 6. Distributions of temperature and reduction in thickness of cup.