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Forming and quenching behaviours in hot stamping of thin quenchable sheets

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Abstract. A thin aluminium-coated quenchable steel sheet was hot-stamped to investigate the effect of the thickness. The sheets having 0.6, 1.0 and 1.6 mm in thickness were heated at 900 °C by a furnace and formed after 7 s from the furnace. The cooling rates of 0.6 mm and 1.0 mm in thickness from 900 °C to 400 °C under air cooling were 20.9 °C/s and 13.6 °C/s, respectively. The hardness of the air-cooled sheets having 1.0 mm in thickness was 300 HV1, whereas that of the sheet having 0.6 mm in thickness was 380 HV1 because of the high cooling rate. The Vickers hardness of the U-bent sheets of 0.6 and 1.0 mm after 7 s from the furnace without the holding time at the bottom dead centre were 500 and 430 HV1, respectively.

1. Introduction

For the reduction in weight for automobiles, the use of high strength steel sheets remarkably increases. Although the high strength steel parts have superior mechanical properties, stamping operations become difficult due to the high strength. To overcome problems encountered in cold stamping of the high strength steel sheets, hot stamping of quenchable steel sheets is effective. By heating the sheets, the forming load is small and the springback is prevented [1]. In addition, the hot-stamped parts are hardened by die-quenching, a tensile strength of approximately 1.5 GPa [2].

The increase in strength of the sheet leads to the reduction in thickness. Although the thickness of conventional sheets for hot stamping is between 1.0 and 2.6 mm, hot stamping of thinner sheets is required for the weight reduction. Since thin sheets are rapidly cooled, deformation and quenching behaviours are different from those of the conventional sheets above 1 mm. Lee et al. [3] have investigated the formability of hot deep-drawing in sheets having 0.6 mm in thickness.

In the present study, deformation and quenching behaviours in hot stamping of a thin quenchable steel sheet were investigated. A 22MnB5 sheet having 0.6 mm in thickness was hot-bent into a U shape. The holding time at the bottom dead centre was changed.

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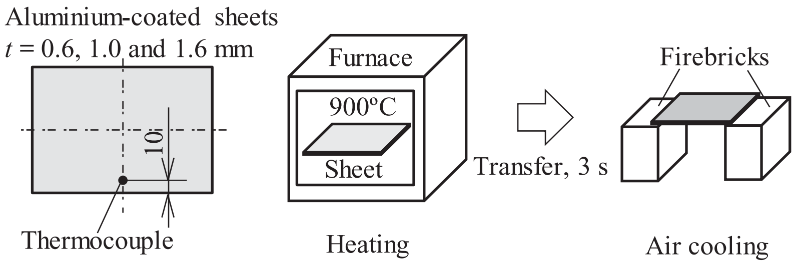

Figure 1. Procedures for measuring heating and air cooling behaviours.

Table 1. Chemical composition of quenchable steel sheet 22MnB5 [mass%].

C	Mn	Si	Al	B	Ti	Cr
0.23	1.22	0.27	0.04	0.0032	0.035	0.2

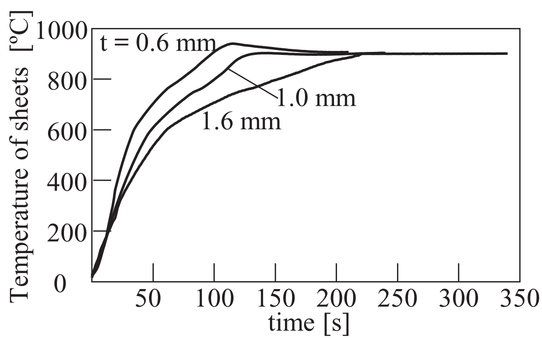

Figure 2. Heating curves of sheets at 900 °C for $t = 0.6$, 1.0 and 1.6 mm.

2. Air cooling behaviour of thin sheet without forming

2.1 Procedure of heating and air cooling

As the thickness of the sheet decreases, the temperature drop rate becomes large. A quenchable steel sheet 22MnB5 having a thickness between 1.0 and 2.6 mm generally used for hot stamping is not hardened under air cooling because of no martensitic transformation for a low cooling rate.

First the behaviour of a thin sheet under air cooling was examined. The procedure for measuring the heating and air cooling behaviours of the sheets is illustrated in Fig. 1. Aluminium-coated quenchable 22MnB5 steel sheets having the thickness $t = 0.6$, 1.0 and 1.6 mm were employed for the experiment. The chemical composition of the quenchable steel sheets is given in Table 1. The sheets were heated at 900 °C in the electrical furnace and held in 120 s after attaining at 900 °C. The heated sheets were transferred on the firebricks with a steel tong, and were air-cooled. The temperature of the sheet during heating and air cooling was measured with the thermocouple attached to the sheet.

2.2 Deflection during heating

The heating curves of the sheets at 900 °C for the thickness $t = 0.6$, 1.0 and 1.6 mm are shown in Fig. 2. As the thickness decreases, the time by 900 °C becomes small.

The deflection of the sheets heated at 900 °C in the electrical furnace is shown in Fig. 3. The deflection was observed with an infrared thermograph. As the thickness of the sheet decreases, the

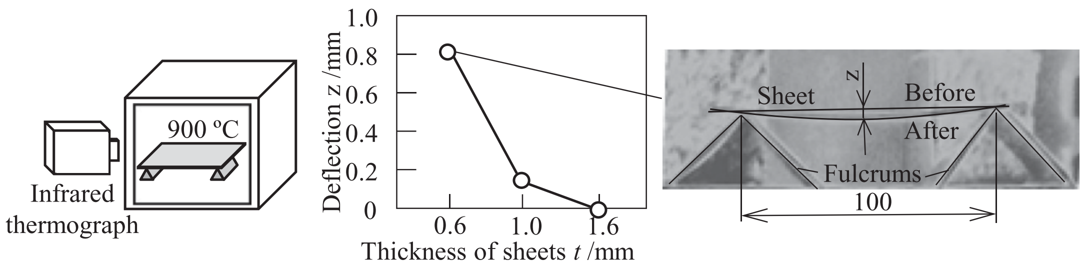

Figure 3. Deflection of sheets heated at 900 °C in electrical furnace.

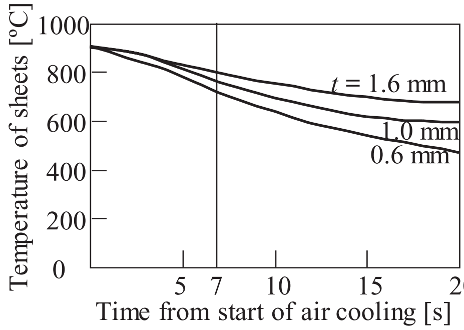

Figure 4. Air cooling curves of sheets for $t = 0.6$, 1.0 and 1.6 mm.

deflection of the sheet during heating increases due to the dead weight, and no deflection occurs above 1.6 mm mostly used for hot stamping. In a roller furnace generally used for hot stamping, the sheets do move for a large deflection. In addition, the heated thin sheet becomes too soft to transfer from the furnace to the dies.

2.3 Air cooling behaviour

The air cooling curves of the sheets for $t = 0.6$, 1.0 and 1.6 mm are shown in Fig. 4. As the thickness of the sheets decreases, the temperature drop increases.

The relationship between the temperature dropping rate under air cooling and the thickness of the sheet is shown in Fig. 5. For the small dropping rate of $t = 1.0$ and 1.6 mm, the latent heat for the ferrite transformation was generated, whereas the ferrite transformation did not appear $t = 0.6$ mm and the dropping rate was partly larger than 30 °C/s for the martensitic transformation.

The relationship between the Vickers hardness of the air-cooled sheet without die quenching and the thickness of the sheet and the microstructures of the sheets are given in Fig. 6. The ferrite transformation occurred for $t = 1.0$ and 1.6 mm, whereas the martensitic transformation partially occurred for $t =$ 0.6 mm and the Vickers hardness was 380 HV1.

3. Quenching behaviour and springback of thin sheets in hot stamping

3.1 Procedure of hot stamping of thin sheets

As the thickness of the sheet decreases, the temperature dropping rate increases in die quenching. Thus, the holding time at the bottom dead centre in hot stamping of the thin sheet can be reduced. To examine

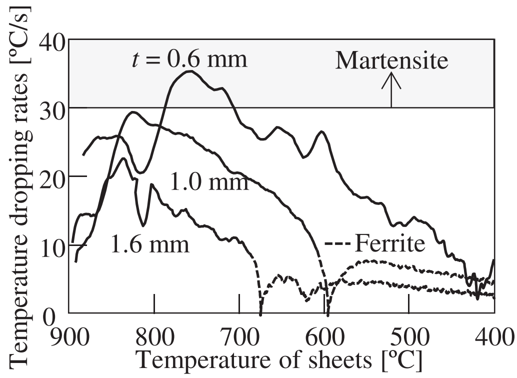

Figure 5. Relationship between temperature dropping rate under air cooling and thickness of sheet.

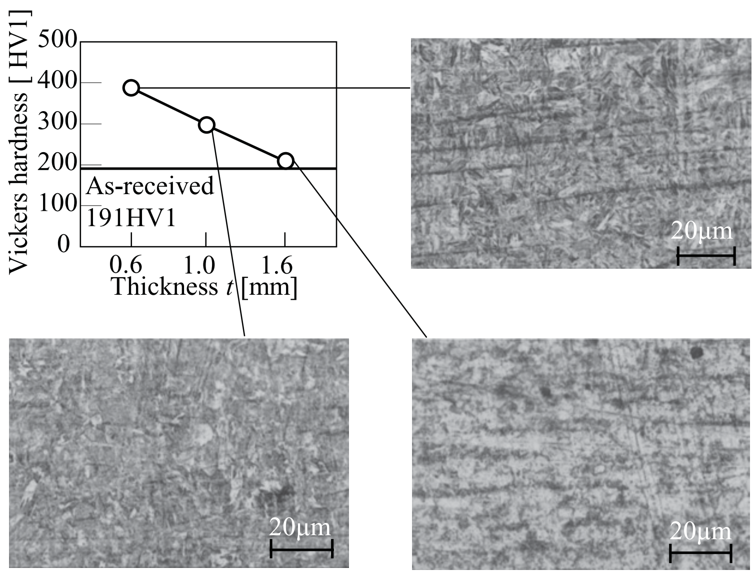

Figure 6. Relationship between Vickers hardness of air-cooled sheet and thickness of sheet and microstructures of air-cooled sheets.

the quenching behaviour of the thin sheet, the sheet was hot-stamped into a U shape. The punch and die used for hot U-shaped bending of the thin sheet are illustrated in Fig. 7. The transfer time to the dies from the furnace was $T_t = 7$–20 s. The forming speed was 375 mm/s and the holding time at the bottom dead centre was $T_h = 0$–1 s.

3.2 Quenching behaviour and springback

The relationships between the Vickers hardness of the hot-stamped sheet and the temperature of the bottom of the U-bent sheet after 0.5 s after die quenching and the holding time at the bottom dead centre for $T_t = 7$ s are shown in Fig. 8. The temperatures of the sheets for $t = 0.6$ and 1.0 mm are 710 and 760 °C for $T_t = 7$ s, respectively. The temperatures of the U-bent sheets without holding are larger than that of the martensitic transformation. The hardness of the sheet without holding for $t = 1.0$ mm

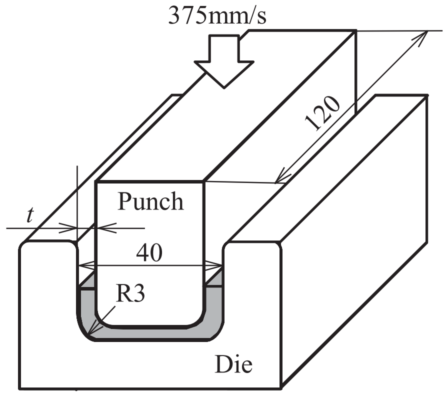

Figure 7. Punch and dies for hot U-shaped bending.

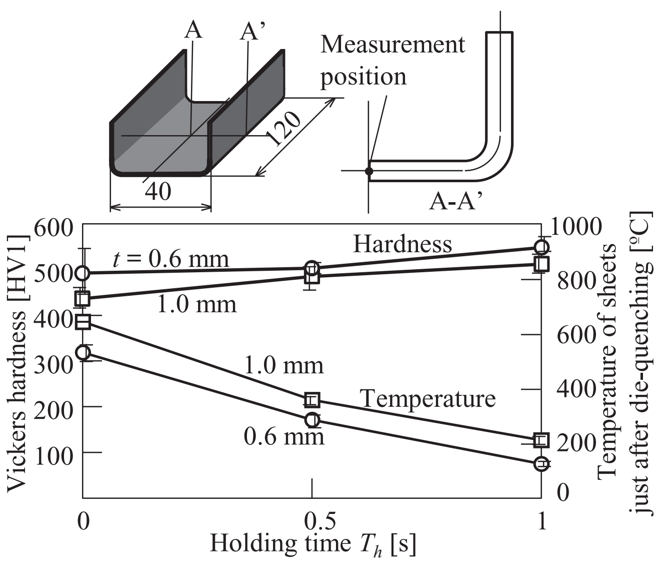

Figure 8. Relationships between Vickers hardness of hot-stamped sheet and temperature of bottom of U-bent sheet after 0.5 s after die quenching and holding time at bottom dead centre for $T_t = 7$ s.

is approximately 430 HV1, whereas that of the sheet for $t = 0.6$ mm is 500 HV1 because of the large temperature drop.

The microstructures of the hot-stamped sheets are shown in Fig. 9. The martensitic transformation occurred for $t = 0.6$ mm and $T_h = 0$ s, and the bainite transformation occurred for $t = 1.0$ mm and $T_h = 0$ s.

The relationship between the springback angle and the holding time at bottom dead centre for $T_t = 7$ s is shown in Fig. 10. As the holding time increases, the springback decreases, and the scatter of the springback angle decreases.

The influence of the temperature drop during transferring on the quenching behaviour was examined. The relationship between the Vickers hardness of the hot-stamped sheets and the transfer time to the dies from the furnace is shown in Fig. 11. The hardness of the sheet for $T_h = 10$ s was not sufficient due to

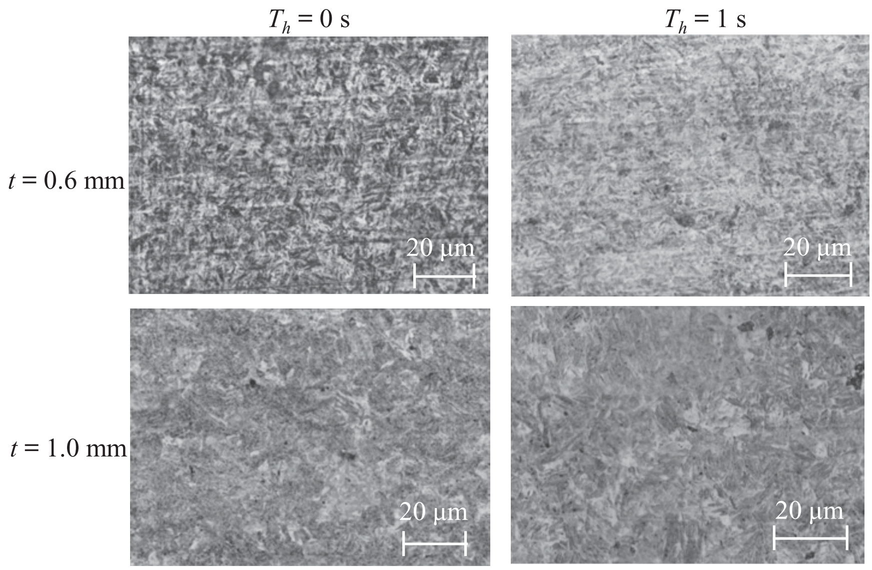

Figure 9. Microstructures of hot-stamped sheets for $T_t = 7$ s.

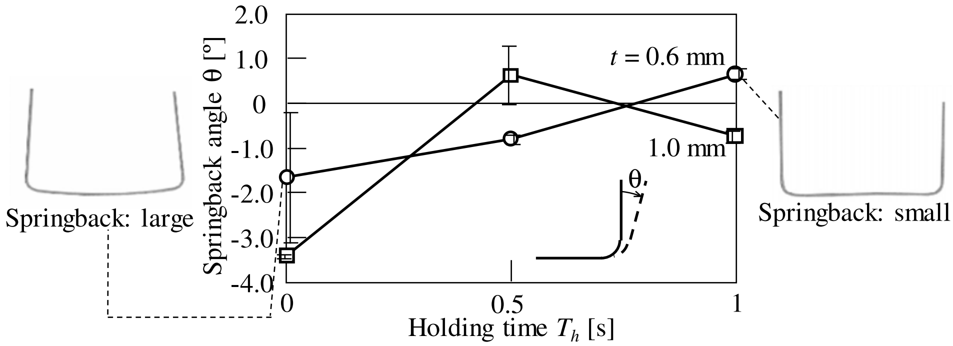

Figure 10. Relationship between springback angle and holding time at bottom dead centre for $T_t = 7$ s.

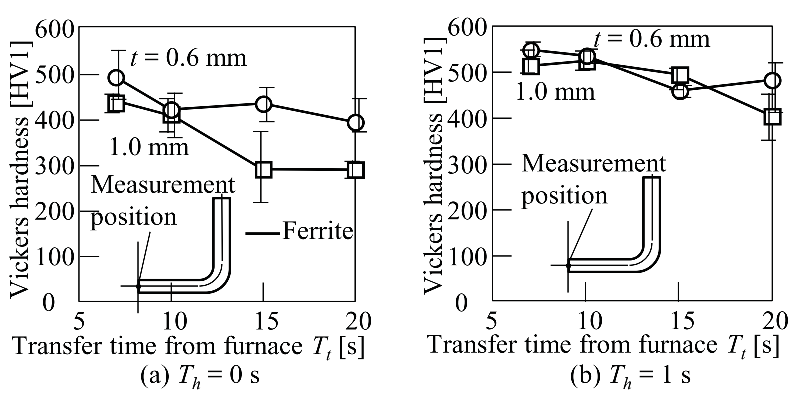

Figure 11. Relationship between Vickers hardness of hot-stamped sheet and transfer time to dies from furnace.

the occurrence of the ferrite transformation before die quenching. The hardness below $T_t = 15\,\mathrm{s}$ for $T_h = 1\,\mathrm{s}$ is larger than 450 HV1 because of sufficient cooling.

4. Conclusions

To reduce the weight of automobile parts, hot stamping of thin sheets is required. In hot stamping of thin sheets, strength and dimensional accuracy of stamped parts are different from those of mostly used sheets having a thickness between 1.2 and 1.8 mm. It is desirable to obtain optimum conditions for thin sheets.

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