Hot semi-punching of quenchable steel sheet

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Abstract

Hot semi-punching of a quenchable steel sheet was carried out to eliminate laser cutting conventionally used for hot stamping of ultra-high strength steel parts. A quenchable steel sheet is semi-punched without separation of punching scraps during hot stamping, and subsequently, the scraps are removed from the hot-stamped part at room temperature. Additional channels for taking punching scraps out of dies are not required. Minimum remainder without detachment of punching scraps and no clearance between the die and punch were optimal for the hot semi-punching process. The hot punching and cold removing loads of the quenched sheet were considerably smaller than the cold punching load, the quality of the hole edge was high and the delayed fracture around the sheared edge was prevented.

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1. Introduction

Although stamped automobile body panels are punched to make many holes for joining, paint removing, attachment, etc., it is not easy to punch die-quenched parts having high strength. The tool life is remarkably reduced by large punching load, and worn tools bring about the deteriorations in dimensional accuracy of the punched hole and in quality of the sheared edge, as described by So et al. (2009). In addition, punching of the die-

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quenched parts has a risk of delayed fracture induced by tensile residual stress. Although laser cutting is generally employed for the die-quenched parts, the productivity is low and the production cost is high, particularly for many small holes in automobile body panels. Frintz (2011) summarised recent improvements of productivity and production cost for laser cutting of the die-quenched parts.

If hardening of punching portions in hot stamping is locally prevented, the problems for cold shearing of hot-stamped parts can be solved, as described by Picas et al. (2009). Mori and Okuda (2010) developed a tailored tempering process with grooved tools for forming a product having a strength distribution. Mori et al. (2013) developed a tailored die quenching process of steel parts having strength distribution using bypass resistance heating in hot stamping. Maeno et al. (2014) prevented hardening of a trimmed flange by slow cooling using spacers thicker than the sheet. Mori et al. (2005) applied resistance heating to a hot stamping process. On the other hand, Mori et al. (2012a) developed a punching process of ultra-high strength steel products using local resistance heating, and Mori et al. (2012b) extended local resistance to punching of small holes of a die-quenched sheet by controlling the temperature distribution.

Since heated sheets are soft, So et al. (2012) punched the sheets during hot stamping. In punching during hot stamping, the structure of tools becomes complicated, because hot stamping including die quenching is generally a one-shot process. A large cooling speed in die quenching is required to attain high strength of stamped products. In addition, it is not easy to design additional channels for taking out punching scraps from dies, because dies used for hot stamping have cooling channels for die quenching.

In the present study, hot semi-punching and cold scrap removing processes are developed to make holes in hot stamped parts. For hot semi-punching, additional channels for taking punching scraps out of the dies are not required. Deformation behaviour of a quenchable steel sheet in hot semi-punching and cold scrap removing was examined.

2. Hot semi-punching and cold scrap removing processes

To eliminate laser cutting generally used in the hot stamping operation, a quenchable steel sheet is semi-punched during hot stamping, whereas the punching scraps are not removed from the hot-stamped part as shown in Fig. 1. Subsequently, the scraps are removed from the hot-stamped part at room temperature. The semi-punching scraps slightly remain in the hot-stamped part to transfer to the cold scrap removing process. Since the scraps are not removed during hot stamping, additional channels for taking out punching scraps are not necessary for the hot-stamping dies. The cold scrap removing load is small due to the slight remainder. Naturally the hot semi-punching load is also small due to small flow stress of the heated sheet.

First, a hot semi-punching operation without forming was performed to examine the deformation behaviour in semi-punching and cold scrap removing. The experimental setups of hot semi-punching and cold scrap removing are shown in Fig. 2. A non-coated quenchable steel sheet 22MnB5 (C: 0.21, Mn: 1.2, Si: 0.25, B: 0.0014 mass%) having 1.6 mm in thickness was employed for the experiment, and the tensile strength and elongation of this sheet measured from the tensile test are shown in Fig. 3. The 70 mm square sheet was heated at 1100 °C with an electrical furnace and was punched at 850 °C after manual transference to the dies. A 1500 kN CNC servo press was used for stamping. The amount of remainder in semi-punching was adjusted by inserting shim spacers between the punch and the press slide, and the remainder rate r to the sheet thickness was changed. The clearance
between the punch and die in cold scrap removing was comparatively large due to easy positioning of the semi-punched hole.

Fig. 2. Experimental setup of (a) hot semi-punching and (b) cold scrap removing.

The conditions used for hot semi-punching are shown in Table 1. Since the sheet is not completely punched in semi-punching, no clearance between the punch and die is available.

| Conditions used for hot semi-punching. |
|----------------------------------------|
| Heating temperature                   | 1100 °C     |
| Temperature at beginning of forming    | 850 °C      |
| Punch speed in hot semi-punching       | 15 mm/s     |
| Holding time at bottom dead centre     | 5 s         |
| Punch speed in cold scrap removing     | 8.3 mm/s    |
| Remainder rate \(r\)                   | 5 – 50%     |
| Clearance \(c\)                        | 0, 10%      |

3. Results of hot semi-punching and cold scraping

3.1. Hot semi-punching

The hot semi-punched sheet for \(c = 0\)% and \(r = 10\)% is shown in Fig. 3. The punching scrap remains in the sheet. A remarkable oxidation scale appeared on the surfaces because of the non-coated steel sheet, as described by Mori and Ito (2009).

Fig. 3. Hot semi-punched sheet for \(c = 0\)% and \(r = 10\)%. (a) Punch and (b) die sides.
The range of separation of the scrap for the different remainder rates and clearances is shown in Fig. 4. For \( r = 10\% \), the scrap separated from the sheet in \( c = 10\% \), whereas no separation occurred in \( c = 0\% \).

![Fig. 4. Range of occurrence of separation for different remainder rates and clearances.](image)

The relationships between the hot semi-punching load and the remainder rate and between a cold scrap removing load and the remainder rate for \( c = 0\% \) are shown in Fig. 5, where the cold punching load is shown as a comparison. The hot semi-punching load is considerably lower than the cold punching load. In addition, the cold scrap removing load is also small, less than 1 kN, and thus pneumatic and hydraulic cylinders are enough for cold scrap removing.

![Fig. 5. Relationships between hot semi-punching maximum load and remainder rate and between cold scrap removing maximum load and remainder rate for \( c = 0\% \).](image)

### 3.2. Cold scrap removing

The cross-sections and surfaces of the holes after cold scrap removing are shown in Fig. 6. As the remainder rate decreases, the quality of the hole improves, because the surfaces of the hot-punched and cold-removed edge are burnished and fracture, respectively. For \( c = 0\% \) and \( r = 10\% \), the surface is almost burnedished. The semi-punched hole was hardly deformed by cold scrap removing due to the small remainder. No burr appeared, whereas the rollover became large due to hot semi-punching. Since the remainder is necessary only for the transference to the cold scrap removing process, the minimum remainder rate is optimal, i.e. \( c = 0\% \) and \( r = 10\% \).
The surfaces of the holes after cold scrap removing and laser cutting are shown in Fig. 7. In laser cutting, the power was 280 W and the speed was 800 mm/min. Although the rollover was prevented for laser cutting, a mark was caused at the end of cutting by scanning in the hoop direction.

The distribution of Vickers hardness in the thickness direction around the hole edge is shown in Fig. 8. Although the hardness was decreased from that of die quenching by laser cutting, the drop in hardness was not observed for hot semi-punching and cold scrap removing.

The delayed fracture times around the hole edge for cold punching and hot semi-punching and cold scrap removing are shown in Fig. 9, where the delayed fracture time is the time from the soak of the sheet in the 35%
hydrochloric acid to the visual observation of cracks. Although cracks were caused for cold punching, the occurrence of cracks was prevented by heating for hot semi-punching.

Fig. 9. Delayed fracture time around hole edge for cold punching and hot semi-punching and cold scrap removing.

4. Conclusions

Although the use of hot stamping processes of ultra-high strength steel parts considerably increases, punching and trimming of stamped parts are still a bottleneck due to low productivity of laser cutting. Hot punching and trimming included in hot stamping processes are attractive for reducing the production cost. In hot punching and trimming, the design of hot stamping processes becomes complex due to the addition of shearing operations in the one-shot process. The hot punching process is more complicated than the hot trimming process, because tools are positioned inside and many holes are made. The hot semi-punching process is simpler than the hot full punching one because of no treatment of punching scraps.

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