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Deformation behaviour and reduction in flying speed of scrap in trimming of ultra-high strength steel sheets

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ABSTRACT

The deformation behaviour of a sharing sheet and the flying behaviour of a cut scrap in trimming of ultra-high strength steel sheets were observed to reduce the flying speed of the scrap and noise level. As the sheet strength increased, the peak trimming load became large, and thus the flying speed of the scrap increased. Although the flying speed of the scrap for the mild steel sheet was close to the free-fall speed, the speed for the 1180 MPa sheet was accelerated to about two times of the mild steel sheet. The maximum sound pressure level in trimming increased with increasing sheet strength and punch speed. To reduce the flying speed of the scrap in trimming of the ultra-high strength steel sheets, the whole, local and double bevel punches were applied. For the whole bevel punch, not only the trimming load but also the flying speed decreased because of gradual release of energy. For the double bevel punch, however, the sudden release of energy at the end of shearing brought about a high flying speed. It was found that the whole bevel punch was effective in reducing the flying speed of the scrap and the noise level in trimming of ultra-high strength steel sheets.

1. Introduction

To improve the fuel efficiency of automobiles, the reduction in weight of automobile parts is crucial. Although aluminium and magnesium alloy are lightweight materials, high strength steel sheets are mostly used for body-in-white parts as replacement of conventional mild steel sheets because of cheaper cost and an extremely large amount of production. Particularly, the application of ultra-high strength steel sheets having a tensile strength more than 1 GPa is attractive for not only the weight reduction but also the collision safety improvement. High strength steel sheets are classified into IF (Interstitial Free) steel, DP (Dual Phase) steel, TRIP (TRansformation Induced Plasticity) steel, martensitic steel, etc. (Kalpakjian and Schmid, 2014). The IF steel sheets have high formability, whereas the strength is lower than 440 MPa and not high. The martensitic steel sheets have high strength but less ductility. The ultra-high strength steel sheets used for stamping of body-in-white parts are mostly made of DP and TRIP steel and have an appropriate balance of strength and formability.

Although formed products from the ultra-high strength steel sheets have excellent mechanical properties, forming operations increasingly become difficult due to low formability, short tool life, large springback, etc. As the strength of the sheets increases, the ductility decreases. The ultra-high strength steel sheets are mainly applied to bending processes having a comparatively small amount of deformation. Most of industrial bending processes of the high strength steel sheets include stretch flanging, and the ultra-high strength steel sheets tend to fracture due to tensile stress generated during stretch flanging. Sartkulvanich et al. (2010) investigated the effect of the quality of the sheared edge on the fracture in stretch flanging of high strength steel sheets. In stretch flanging of ultra-high strength steel sheets, Mori et al. (2010) applied a smoothing process of the sheared edge to prevent the fracture, and Abe et al. (2013) proposed a gradually contacting punch for relieving tensile stress around the edge of the corner in bending. On the other hand, Abe et al. (2014) heightened deep drawability of ultra-high strength steel sheets by preventing seizure with coated dies. Ko et al. (2015) examined galling resistance of tool steels in stamping of ultra-high strength steel sheets.

The springback in stamping becomes large with increasing strength of sheets, and that for ultra-high strength steel sheets is considerably large. Mori et al. (2007) reduced the springback in bending of ultra-high strength steel sheets by bottoming using a mechanical servo press. Osakada et al. (2011) pointed out the effectiveness of slide motion control using servo presses for reducing the springback. Komgrit et al. (2016) reduced the springback in U-bending of ultra-high strength steel sheets by pushing the bottom of the U-bent sheet with a counter punch. Wang et al. (2017) designed stamping dies for ultra-high strength steel

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sheets by compensating the springback using finite element simulation.

Edges of formed sheets are trimmed in final stamping stages, and shearing is generally employed for trimming because of high productivity. Most of the sheared-edge surface of the ultra-high strength steel sheets is rough fracture surface and the quality is low (Mori et al., 2010). Lara et al. (2013) exhibited that the fatigue strength of the ultra-high strength steel sheets is strongly dependent on the quality of the sheared edge, i.e. the fatigue strength for the low-quality edge is low. Kopp et al. (2016) measured large lateral force deteriorating the product accuracy and tool wear in shearing of high strength steel sheets. Gustafsson et al. (2016) examined the effects of the clearance and clamping in shearing of ultra-high strength steel sheets. To reduce the trimming force for ultra-high strength steel sheets, Mackensen et al. (2010) introduced a punch having a single bevel, and Feistle et al. (2015) notched trimming lines on the steel sheet. Hirsch et al. (2011) examined the effect of tool steels on the tool life in shearing of ultra-high strength steel sheets. Han et al. (2016) simulated a trimming process of an ultra-high strength steel part.

In trimming operations, the noise and vibration are generated by sudden elastic recovery of a press and tools due to the release of the load by breaking through the sheet, and these become high with increasing trimming force. Siskova and Juricka (2013) reported that exposure to excessive noise for a long time damages the health of workers. Otsu et al. (2003) demonstrated that the motion control using a servo press was effective in reducing the noise level in shearing of high strength steel sheets. Ghiotti et al. (2010) and Murakawa et al. (2011) installed magneto-rheological dampers and a hydraulic inertia damper in a press to reduce the noise, receptivity. Not only the noise but also flying of cut scraps is caused by the released energy in trimming. For trimming of ultra-high strength steel sheets, the scraps jump due to the collision with the base and, and the jump out of a scrap disposal box results for an excessive flying speed. This causes damage to tools, presses and workers. Since the trimmed scraps are not large, jumping becomes remarkable. It is desirable in forming industry to reduce the flying speed of the cut scraps.

In this study, deformation behaviour of a sharing sheet and flying behaviour of a cut scrap in trimming of ultra-high strength steel sheets were observed to reduce the flying speed of the scrap and noise level. For the reduction, bevel punches were developed.

2. Procedure for observing deformation and flying behaviours in trimming of ultra-high strength steel sheets

The procedure for observing deformation behaviour of a shearing sheet and flying behaviour of a cut scrap in straight trimming of ultra-high strength steel sheets is shown in Fig. 1. The deformation and flying behaviour were taken by both front and side high-speed cameras, and the flying speed of the scrap was calculated with the front camera. The frame rate was 800 fps with a resolution of 640 × 480 pixels in monochrome. The noise was measured with the microphone set near the front camera. The punch and die were made of high-speed steel SKH51 having a hardness of 60 HRC. The sheets were trimmed with a flat punch using an 800 kN servo press under a trimming speed of 48 mm/s. The ratio c of the clearance between the punch and die to the sheet thickness was between 5 and 25%, the scrap length L was between 5 and 20 mm. The dimensions of the sheets were 80, 60 and 1.2 mm in the length, width and thickness, respectively. The punch stopped at 3 mm downward from the top surface of the die in trimming. The experiment was performed three times for each condition and the results were averaged.

The mechanical properties of the ultra-high strength steel sheets having 1.2 mm in thickness are shown in Table 1. The tensile strength of the sheets ranges from 352 to 1242 MPa. The 980 MPa and 1180 MPa sheets are the ultra-high strength steel sheets having a tensile strength more than 1 GPa, and are made of DP steel.

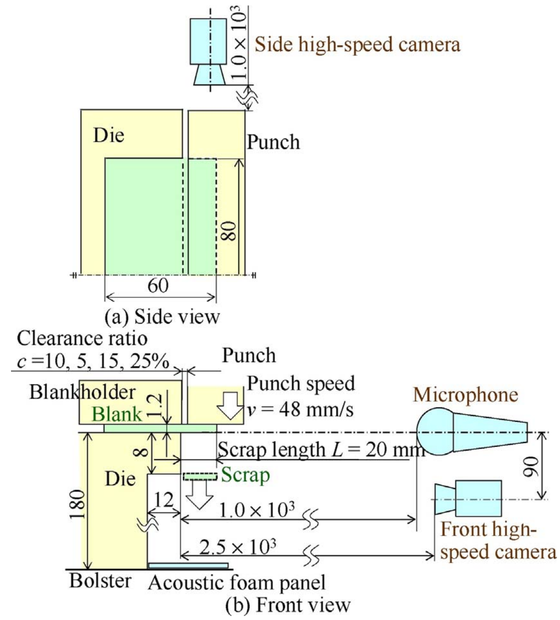

Fig. 1. Procedure for observing deformation and flying behaviours in trimming of ultra-high strength steel sheets.

Table 1
Mechanical properties of ultra-high-strength steel sheets.

Sheet	Yield stress [MPa]	Tensile strength [MPa]	Elongation [%]	Reduction in area [%]
1180 MPa	864	1242	8.1	26.6
980 MPa	643	1004	12.6	37.4
780 MPa	591	813	17.3	56.0
590 MPa	430	629	26.2	61.0
270 MPa	209	352	39.3	69.1

3. Results of deformation and flying behaviours in trimming

3.1. Deformation and flying behaviours

The deformation and flying behaviour in trimming of the 980 MPa sheet for c = 10% are shown in Fig. 2, where t is the time from the separation of the scrap and remaining sheet. The sheet slightly bends during trimming, and the cut scrap is rotated during falling by bending.

The relationship between the bend angle α of the scrap at the separation and the tensile strength of the sheet is shown in Fig. 3. As the clearance increases, the bend angle becomes large because of the increase in stroke at the separation. The bend angle α decreases with increasing tensile strength of the sheet. Above 37° in bend angle, the scrap was in contact with the sidewall of the die. This causes damage to the die.

The trimming load-punch stroke curves for c = 10% are shown in Fig. 4. The trimming loads have a peak around a punch stroke of 1 mm, and the peak load increases with increasing sheet strength.

The quality of the sheared edge of the cut sheet is shown in Fig. 5. As the sheet strength increases, the fracture surface increases and the rollover decreases. For c = 25%, the fracture surface is smaller than that for c = 10%, whereas the large burr appears.

The effect of the clearance on the quality of the sheared edge for the 980 MPa sheet is shown in Fig. 6. The rollover increases with increasing clearance. Because the large burr appeared above c = 15%, the flying speed of the scrap and the sound pressure level were measured below c = 15% in the following experiment.