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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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A R T I C L E I N F O

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Flying speed
Noise level
Bevel punch

A B S T R A C T

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.

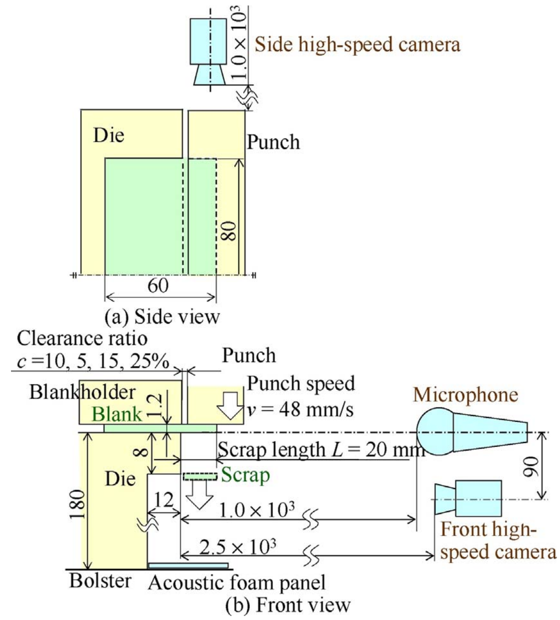

Fig. 1. Procedure for observing deformation and flying behaviours in trimming of ultra-high strength steel sheets.

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.

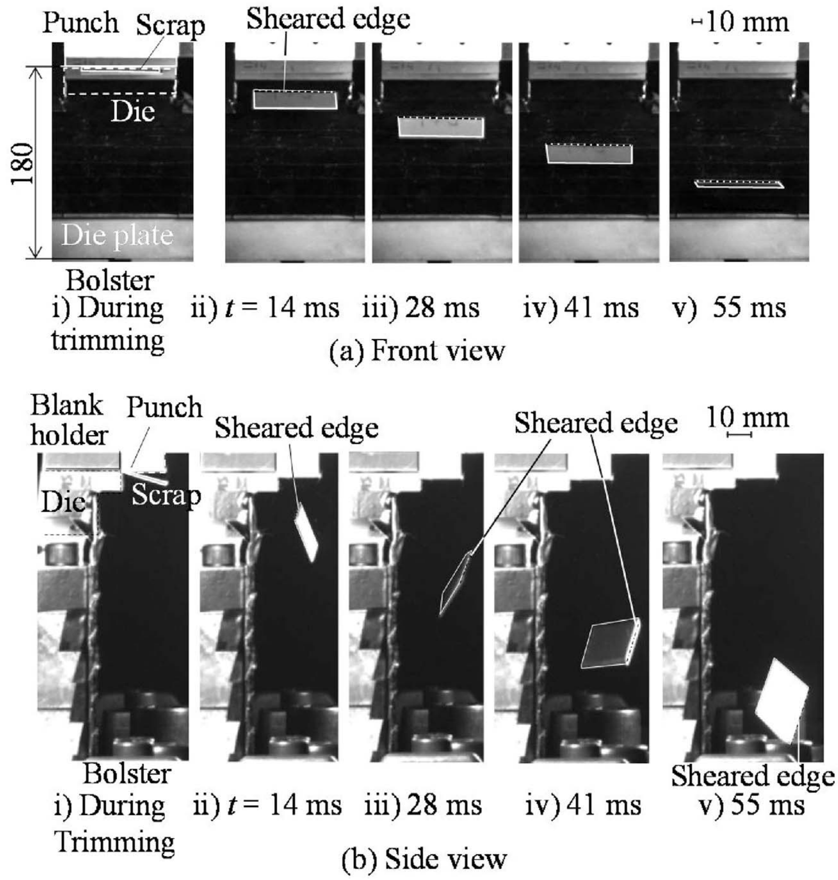

Fig. 2. Deformation and flying behaviour in trimming of 980 MPa sheet for $c = 10\%$.

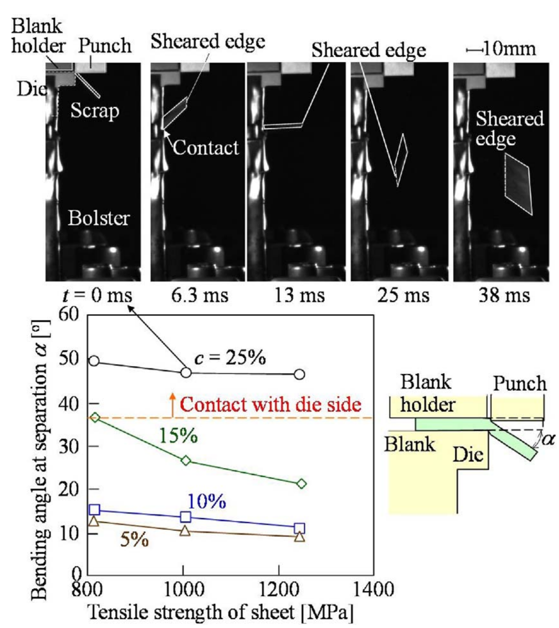

Fig. 3. Relationship between bend angle of scrap at separation and tensile strength of sheet.

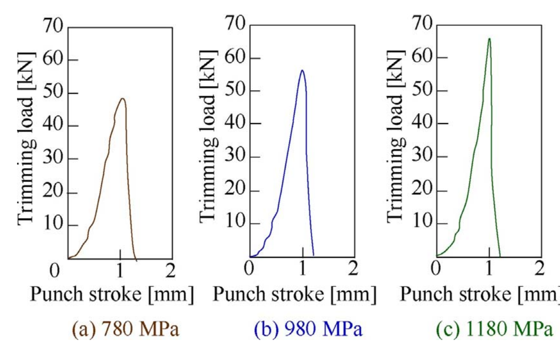

Fig. 4. Trimming load-punch stroke curves for $c = 10\%$.

3.2. Flying speed of scrap and sound pressure level

The flying history of the scrap for $c = 10\%$ is shown in Fig. 7. The distance l in the z-direction between the top surface of the die and the centre of the scrap was measured with the front high-speed camera. Although the scrap falls down while rotating, the distance is almost proportional to the time from the separation. The slope of the linear function becomes large with increasing sheet strength.

The relationship between the flying speed of the scrap and the peak trimming load for $c = 10\%$ is shown in Fig. 8, where v is the punch speed. The free-fall speed was measured by dropping the scrap from a height of 180 mm. As the peak trimming load increases, the flying speed of the scrap increases. Although the flying speed of the scrap for the mild steel sheet is close to the free-fall speed, the speed for the 1180 MPa sheet is accelerated to about two times of the mild steel sheet.

The effect of the clearance ratio on the flying speed of the scrap is shown in Fig. 9. The flying speed of the scrap slightly decreases with increasing clearance ratio.

The relationship between the flying speed of the scrap and the scrap length for $c = 10\%$ is shown in Fig. 10. The flying speed decreases with increasing scrap length due to the increase in weight.

The effect of the peak trimming load on the maximum sound pressure level for $c = 10\%$ is shown in Fig. 11, where the sound pressure level of the driving press without trimming was about 80 dB. The

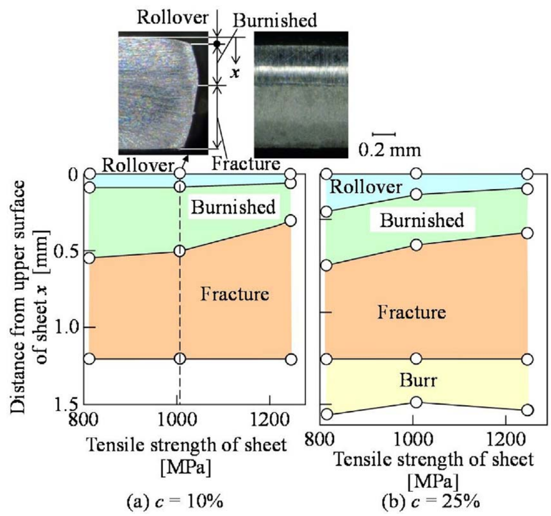

Fig. 5. Quality of sheared edge of cut sheet.

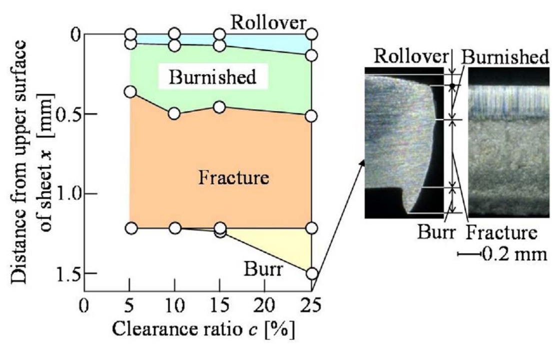

Fig. 6. Effect of clearance on quality of sheared edge for 980 MPa steel sheet.

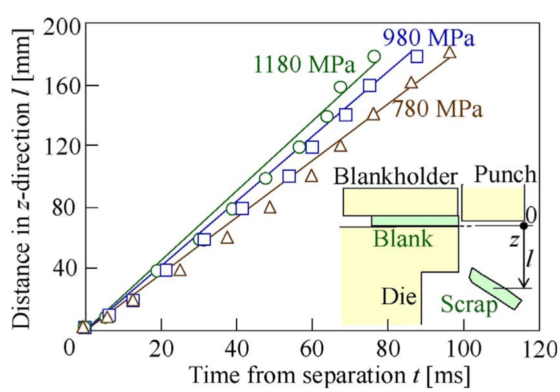

Fig. 7. Flying history of scrap for c = 10%.

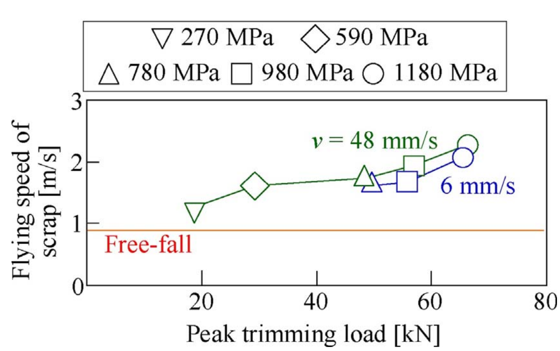

Fig. 8. Relationship between flying speed of scrap and peak trimming load for c = 10%.

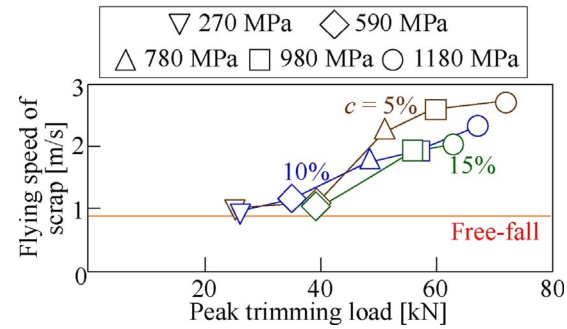

Fig. 9. Effect of clearance ratio on flying speed of scrap.

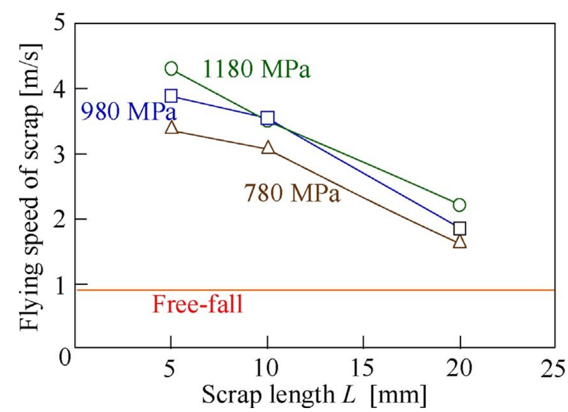

Fig. 10. Relationship between flying speed of scrap and scrap length for c = 10%.

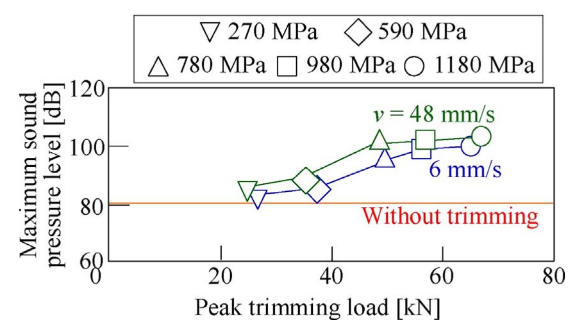

Fig. 11. Effect of peak trimming load on maximum sound pressure level for c = 10%.

maximum sound pressure level in trimming increases with increasing sheet strength and punch speed. The trimming operation of ultra-high strength steel is noisy.

4. Reduction in flying speed of scrap by bevel punches

4.1. Whole, local and double bevel punches

To reduce the flying speed of the scrap in trimming of the ultra-high strength steel sheets, the whole, local and double bevel punches shown in Fig. 12 were employed. The sheet is gradually sheared with the bevel punches, and thus the peak trimming load decreases. Bahrami et al. (1998) examined the effect of the shear angle on noise in shearing with bevel punches. The angle of the bevel punches was fixed at 5°.

The deformation and flying behaviour in trimming of the 980 MPa sheet with the whole and local bevel punch for c = 10% are shown in Fig. 13. The scrap rotates during falling for both whole and local bevel punches.

The deformation and the flying behaviour in trimming of the 980 MPa sheet with the double bevel punch for c = 10% are shown in Fig. 14. The sheet is gradually trimmed from both ends. The scrap falls

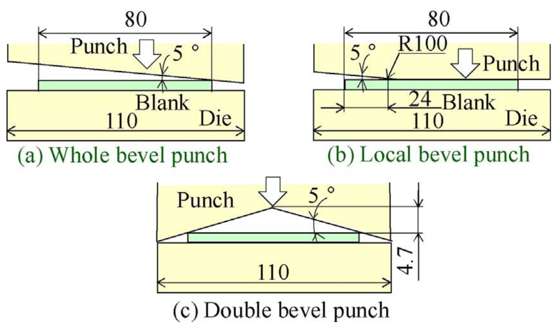

Fig. 12. Whole, local and double bevel punches for reducing flying speed of scrap.

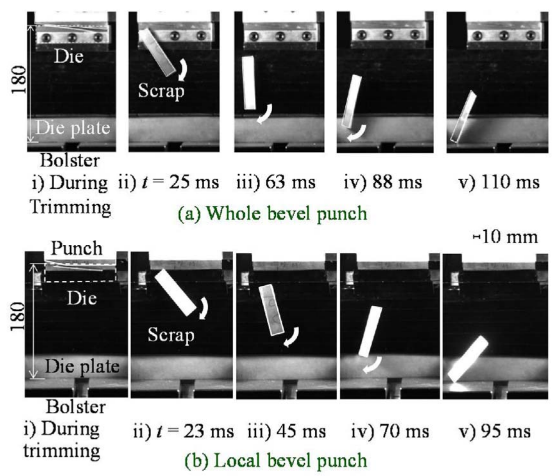

Fig. 13. Deformation and flying behaviour in trimming of 980 MPa sheet with whole and local bevel punch for c = 10%.

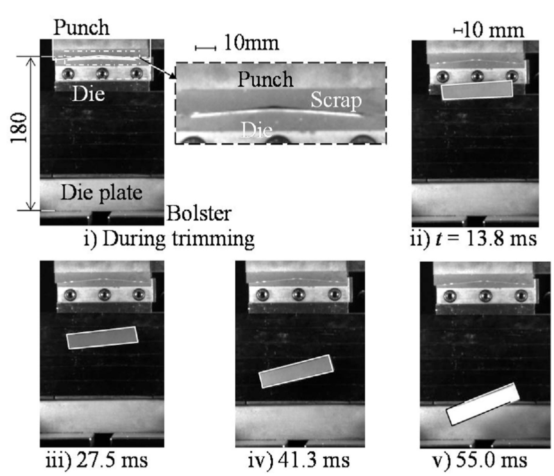

Fig. 14. Deformation and flying behaviour in trimming of 980 MPa sheet with double bevel punch for c = 10%.

down without rotation because of symmetrical shearing.

4.2. Effect of bevel punches on flying speed of scrap and maximum sound pressure level

The trimming load-punch stroke curve for the 980 MPa sheet and c = 10% is shown in Fig. 15. Using the bevel punches, the trimming load can be decreased due to gradual shearing, whereas the punch stroke becomes long. Particularly the trimming load for the whole bevel punch is considerably low.

The quality of the sheared edge for the 980 MPa sheet and c = 10%

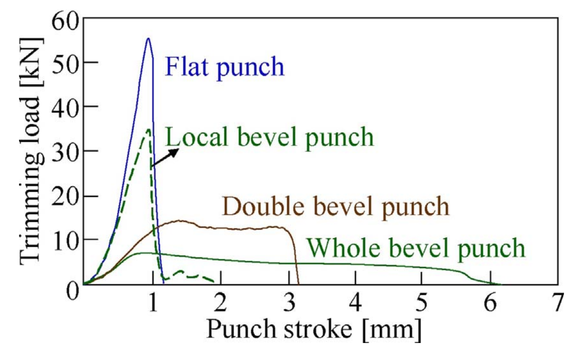

Fig. 15. Trimming load-punch stroke curve for 980 MPa steel sheet and c = 10%.

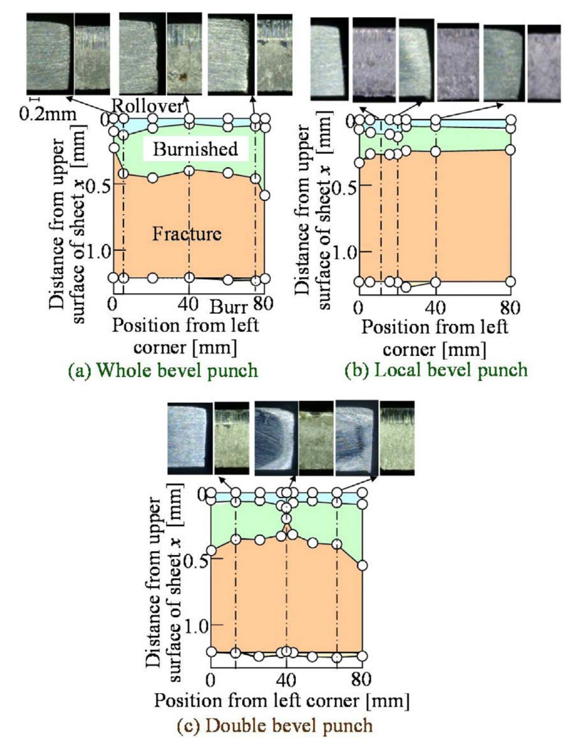

Fig. 16. Quality of sheared edge for 980 MPa sheet and c = 10%.

is shown in Fig. 16. The quality of the sheared edges for the bevel punches is distributed over the edge. For the whole double bevel punches, the ratios of burnished surface decrease from the beginning to the end of trimming. The ratio of burnished surface for the local bevel punch is comparatively small.

The relationship between the flying speed of the scrap and the peak trimming load for c = 10% is shown in Fig. 17. The flying speed of the scrap increases with increasing peak trimming load. Particularly, the flying speed for the whole bevel punch is close to the free-fall one due to the low trimming load. On the other hand, the flying speed for the double bevel punch is considerably high.

The effect on the clearance ration on the quality of the sheared edge for the 980 MPa sheet is shown in Fig. 18. For the whole bevel punch below c = 15%, the burr does not appear, whereas the burr locally occurs for the local bevel punch.

The relationship between the flying speed of the scrap and the clearance ratio for the whole bevel punch and the 980 MPa sheet is shown in Fig. 19. For the whole bevel punch, the effect of clearance is small and the speed is close to the free-fall one.

The effect of the bevel punches on the flying speed of the scrap is illustrated in Fig. 20. In trimming with the flat punch, the trimming load becomes large due to shearing of the entire thickness at the same

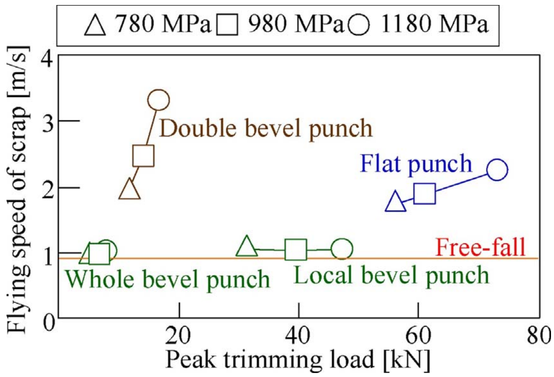

Fig. 17. Relationship between flying speed of scrap and maximum trimming load for c = 10%.

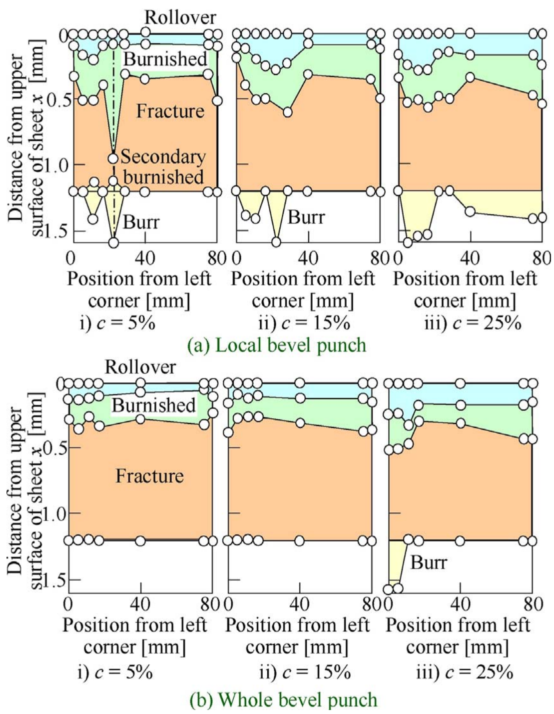

Fig. 18. Quality of sheared edge for 980 MPa sheet.

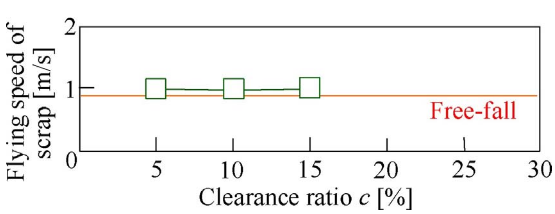

Fig. 19. Relationship between flying speed of scrap and clearance ratio for whole bevel punch and 980 MPa sheet.

time, and thus the frying speed of the scrap is large. For the whole bevel punch, not only the decrease in trimming load but also gradual release of energy during shearing leads to the reduction in flying speed of the scrap. For the double bevel punch, however, the sudden release of energy at the end of shearing brings about the high flying speed.

The effect of the bevel punches on the maximum sound pressure level in trimming for c = 10% is shown in Fig. 21. For the whole bevel punch, the sound pressure level is close to that for the driving press without trimming, and that for the double bevel punch is also low.

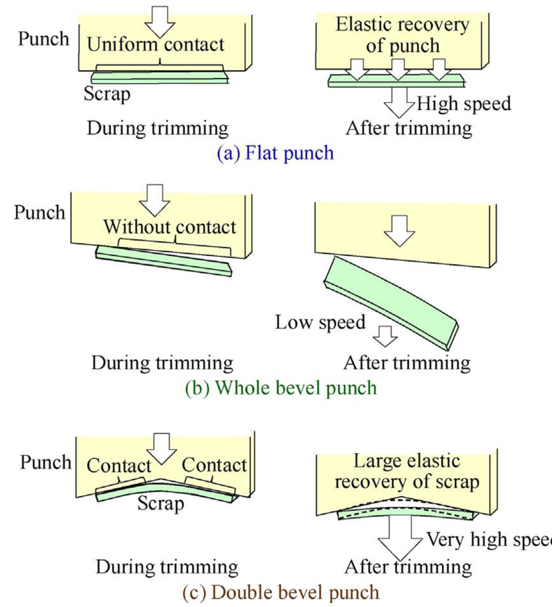

Fig. 20. Effect of bevel punches on flying speed of scrap.

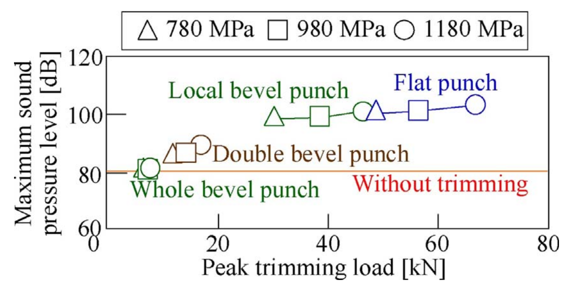

Fig. 21. Effect of punches on maximum sound pressure level in trimming for c = 10%.

5. Conclusions

To improve the fuel efficiency of automobiles, the reduction in weight of automobile parts is crucial. 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. Although formed products from the ultra-high strength steel sheets have excellent mechanical properties, forming operations increasingly become difficult. In trimming of high strength steel sheets, the noise and vibration become high with increasing trimming force. For trimming of ultra-high strength steel sheets, the scraps jump due to the collision with the base, and the jump out of a scrap disposal box results. In this study, the deformation behaviour of sharing sheets and the flying behaviour of cut scraps in trimming of ultra-high strength steel sheets were observed, and the flying speed of the scrap and noise level were reduced by use of the whole bevel punch.

The application of mechanical servo presses having flexible ram motion to stamping operations increasingly expands due to the cost reduction and capability improvement, and the servo presses are effective in reducing the flying speed and the noise level in trimming of the ultra-high strength steel sheets. The sudden release of energy in trimming is relieved by the motion control. Other advantages such as the improvements of tool life, lubrication, sheared edge quality, etc. are provided by the application of servo presses to trimming.

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