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Research on material deformation in double-sided shearing with preventing enlargement of sheet material on the die using digital image correlation

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Abstract. In shearing, the effect of preventing the enlargement of sheet material on increasing burnished surface was reported. In this study, double-sided shearing with a suppression plate for preventing the enlargement of sheet material was carried out to investigate the effect of preventing the enlargement of sheet material on the material deformation and crack initiation. During shearing, the material deformation was observed using high speed camera and the distribution of displacement and strain of material were determined from moving images using digital image correlation. The following results were obtained from the observation of the cut surface obtained by shearing and the material deformation during shearing. When the suppression plate prevented the enlargement of the sheet material, the occurrence of cracks in the sheet material around the punch and die cutting edge was delayed. The length of burnished surface increased. For the same reason, the length of burnished surface increased as the trimming allowance of the sheet material was decreased when the enlargement of sheet material was prevented. It was confirmed that preventing the enlargement of sheet material affects the material flow. It is clarified that the equivalent strain around the punch and die cutting edge until crack initiation was increased when the enlargement of sheet material was prevented.

Introduction

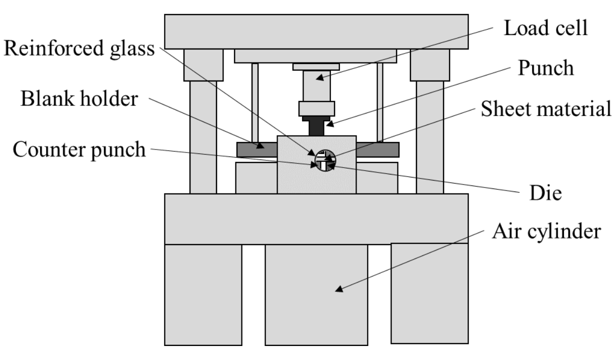
Shearing is the cutting of a sheet material with a punch and a die. The cut surface obtained by shearing consisted of a rollover, burnished surface, fractured surface and burr. The relationship between the crack initiation and hydrostatic pressure was discussed [1]. Influence of fine blanking conditions on the quality of sheared surface have been experimentally investigated [2]. The finite element analysis was performed to investigate the effect of the blank holder and counter punch forces on the material flow features and the cut surfaces in conventional blanking and fine blanking [3]. The FEM analysis was performed to investigate the mechanism of the V-ring indenter. The material flow and stress distribution calculated using FEM were reported [4]. As described above, there has been a useful report on the cut surface by fine blanking. The effect of preventing the enlargement of sheet material on increasing burnished surface was reported using experiment and finite element methods. It has been reported that the preventing the enlargement of sheet material on the die during shearing has an effect on the cut surface [5]. Based on the results of FEM and observation of the product obtained by shearing, the discussion on the formation of the cut surface was reported. In order to further investigate, it is desirable to clarify the material flow by taking moving images during shearing, since cracks occur in the shearing process.

On the other hand, in recent years, the displacement and strain have been determined from digital images of sheet material deformation during experiment [6]. The relationship between the material flow and the formation of rollover was confirmed experimentally using image processing [7]. Measurement of strain, strain rate and crack evolution in shear zone based on the recorded high speed images was reported [8]. It is expected to clarify the effect of preventing the enlargement of sheet material on the displacement using digital image correlation. The purpose of this study is clarifying that the effect of preventing enlargement of sheet material on the material deformation and crack initiation based on the moving images about material deformation during shearing process. In this report, the results of observation of material deformation during experiments show that the effect of preventing enlargement on the punch stroke in which cracks occurred. In addition, the results of clarifying material flow and strain using digital image correlation method are reported.

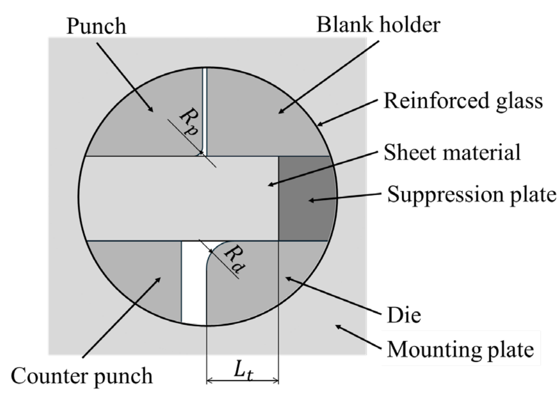
Experiment

Double-sided shearing with counter punch was carried out using the experimental equipment shown in Fig.1. The horizontal enlargement of the sheet material due to shearing is constrained by the suppression plate. Shearing without the suppression plate also was carried out. The width of the punch was 14.8 mm and the clearance was 5% of the thickness of the sheet material. The radius of punch cutting edge was 0.01mm and the radius of the die cutting edge was 0.2 mm. The sheet material was aluminum (JIS A5052P-O) with length of 19 mm or 23 mm, a width of 20 mm and a thickness of 2 mm. When the specimen with length of 19 mm was used, the width of trimming allowance width (L_t) is 2 mm, which is 100% of thickness of sheet material. For sheet material with length of 23 mm, the trimming allowance width (L_t) is 4 mm, which is 200% of thickness of the sheet material. The reinforced glass had a length of 40mm, a width of 63 mm and a thickness of 10.2 mm. The counter punch force of 1380 N was applied to a sheet material with a counter punch. Blank holding force was also applied to the sheet material with a blank holder to prevent warpage of the sheet material.

During shearing, the deformation of sheet material was observed through reinforced glass using a high speed camera. The resolution of the high speed camera was 1280×1024 pixels. The frame rate was 50fps. The shearing speed was set to 1mm/min. In this experiment, shearing was carried out without lubrication. The observation surface of sheet material was polished with #800 sandpaper to apply a pattern to the observation surface. The punch stroke (P_s) in shearing was measured from moving images. Images at P_s 0.01mm intervals were created from moving images, and the distribution of displacement and strain were determined using the digital image correlation software MatchID 2023.2.



(a) Entire experimental apparatus



(b) Enlarged view of area around the cutting edge

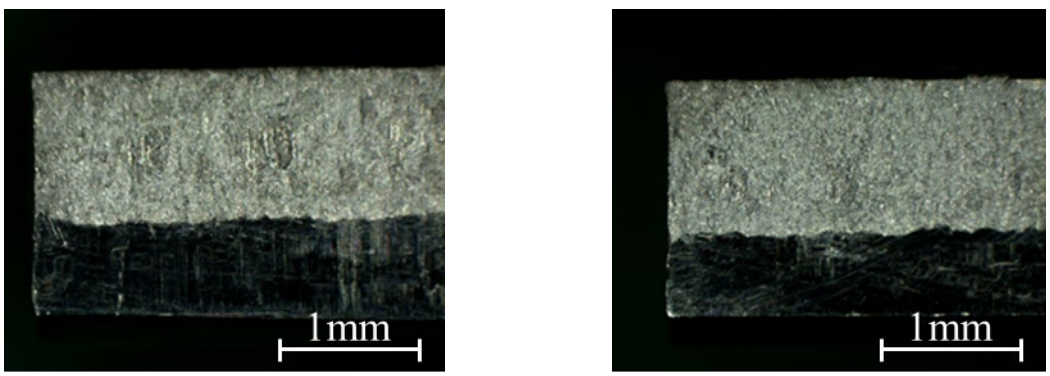
Fig. 1. Experimental apparatus with the suppression plate.

Result and discussion

Cut surface. The cut surface of sheet material under the punch obtained by shearing for L_t=4 mm are shown in Fig. 2. The fractured surface of sheet material with the suppression plate is smaller than that without the suppression plate. The cut surface of sheet material under the punch obtained by shearing for L_t=2 mm are shown in Fig. 3. Similarly, the fractured surface of sheet material with the suppression plate is smaller than that without the suppression plate. As the trimming allowance decreases, the fractured surface of the sheet material with the suppression plate becomes smaller.

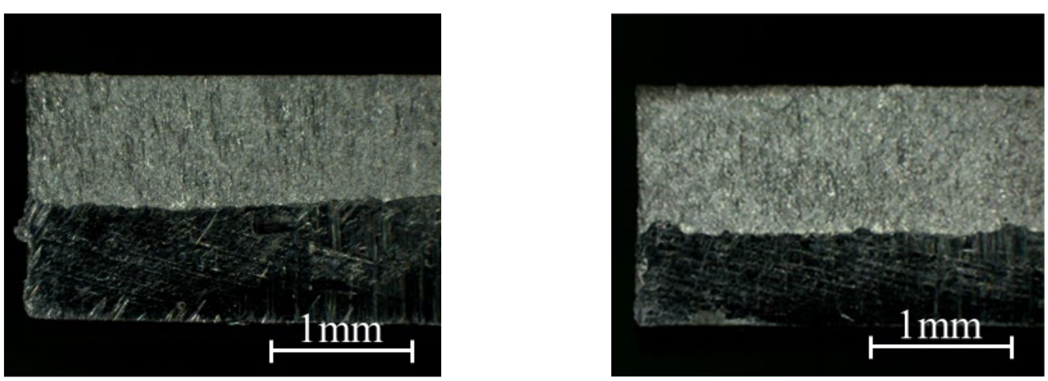
The cut surface of sheet material on the die obtained by shearing for L_t=4 mm are shown in Fig. 4. The fractured surface of sheet material with the suppression plate is smaller than that without the suppression plate. The cut surface of sheet material on the die obtained by shearing for L_t=2 mm are shown in Fig. 5. Similarly, the fractured surface of sheet material with the suppression plate is smaller than that without the suppression plate. As the trimming allowance decreases, the fractured surface of the sheet material with the suppression plate becomes smaller.

The composition of the cut surface near the surface in contact with the reinforced glass is shown in Fig. 6. When the horizontal enlargement of sheet material was prevented, the length of the fractured surface decreased, and the length of the burnished surface increased both on the product and scrap side. It was also observed that the length of the burnished surface increased as the trimming allowance decreased when the horizontal enlargement of sheet material was prevented.



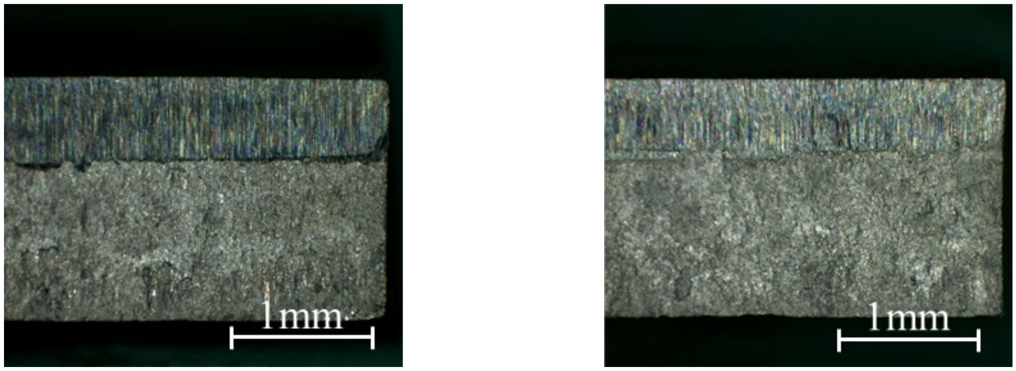
(a) With suppresion plate (b) Without suppresion plate

Fig. 2. Cut surface of the sheet material under the punch obtained by shearing for L_t=4 mm.



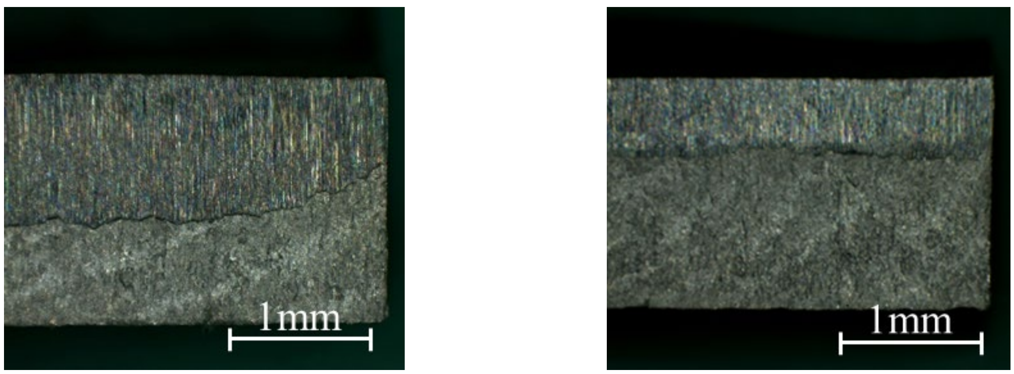
(a) With suppresion plate (b) Without suppresion plate

Fig. 3. Cut surface of the sheet material under the punch obtained by shearing for L_t=2 mm.



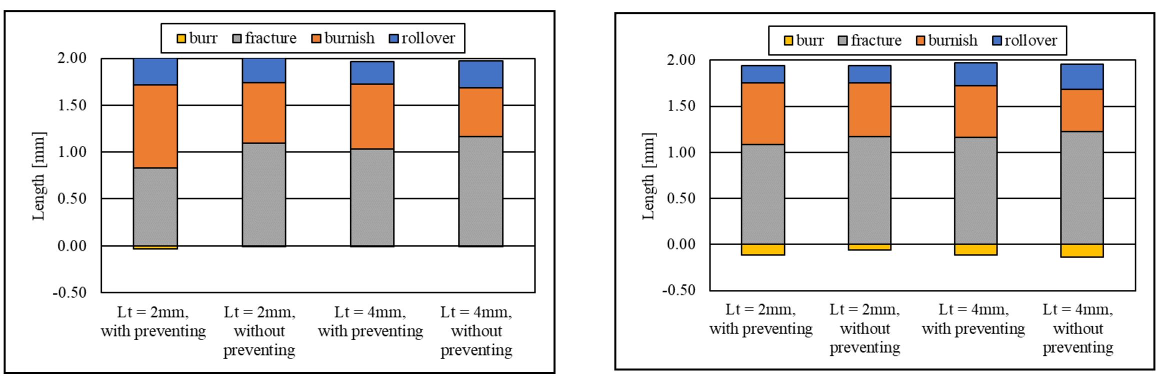
(a) With suppresion plate (b) Without suppresion plate

Fig. 4. Cut surface of the sheet material on the die obtained by shearing for L_t=4.mm.



(a) With suppresion plate (b) Without suppresion plate

Fig. 5. Cut surface of the sheet material on the die obtained by shearing for L_t=2 mm.

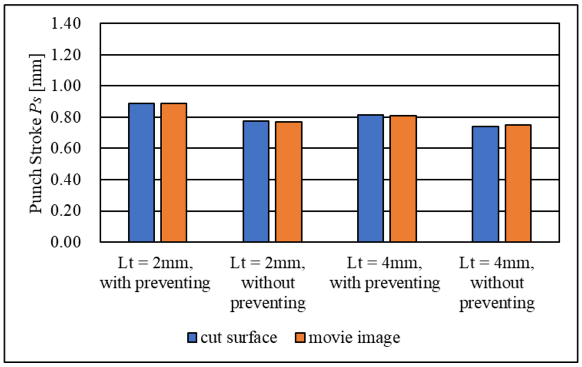


(a) Product (sheet material under the punch) (b) Scrap (sheet material on the die)

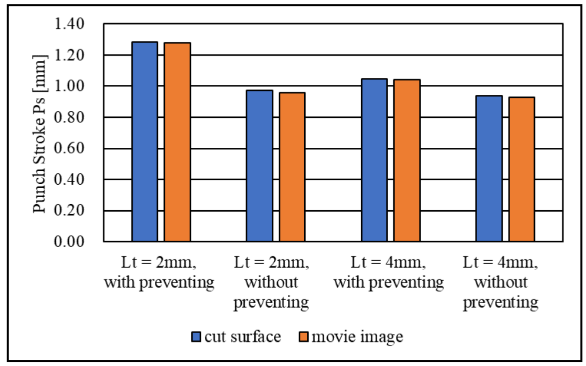
Fig. 6. Measurement of cut surface (a) product, (b) scrap.

Crack initiation. In order to investigate the effect of preventing enlargement of sheet material, the punch stroke at crack initiation was confirmed. Two different methods were used to confirm the punch stroke in which the crack occurred.

First, the punch stroke at crack initiation around tool cutting edge was calculated from composition of the cut surface. Punch stroke at crack initiation around punch cutting edge is the sum of the length of the rollover of scrap, the burnished surface of scrap and the burr of product. Similarly, punch stroke at crack initiation around die cutting edge is the sum of the length of the rollover of product, the burnished surface of product and the burr of scrap. From the above, punch stroke at crack initiation around punch and die cutting edge was calculated from the length of cut surface of Fig. 6. The punch stroke at crack initiation by composition of the cut surface is shown in Fig. 7. It is shown in the blue bar. Another method was to find the punch stroke at crack initiation from the moving images by visual observation. The punch stroke at crack initiation around punch and die cutting edge was confirmed visually from moving images taken by the high speed camera. The punch stroke at crack initiation by moving images is also shown in Fig. 7. It is shown in orange bar. There is no significant difference between the results measured by two methods. It is clarified that crack in the sheet material around the punch cutting edge occurs faster than cracks in the sheet material around die cutting edge. Punch stroke at crack initiation increased when the enlargement of sheet material was prevented. From the above, it is considered that the reduction of fractured surface by preventing the enlargement of sheet material is an effect of the delay in the occurrence of crack near the die cutting edge.



(a) Around the punch cutting edge



(b) Around the die cutting edge

Fig. 7. Punch stroke at crack initiation (a) punch, (b) die.

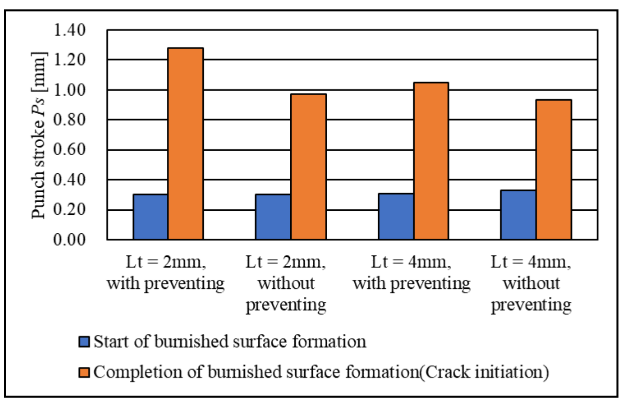


Fig. 8. Punch stroke about burnished surface formation for product.

Burnished surface formation. The duration of the formation of the burnished surface was confirmed from the moving images taken by the high speed camera. The punch strokes in which the formation of the burnished surface was started on the product and the punch strokes in which the formation of the burnished surface was completed were visually confirmed, and the results are shown in Fig. 8. It should be noted that the punch stroke at which the formation of the burnished surface begins is the punch stroke at which the sheet material begins to contact with the side of die. The punch stroke at which the formation of the burnished surface is completed is the punch stroke when a crack occurs near the die cutting edge. Fig. 8 shows that the punch stroke at which the formation of the burnished surface started did not vary much according to the shearing conditions. On the other hand, the punch stroke at which the formation of the burnished surface was completed is different according to shearing conditions. The increase in the length of the burnished surface due to preventing horizontal enlargement of sheet material may be attributed to the suppression of crack initiation around die cutting edge.

Distribution of displacement of material. From moving images taken by the high speed camera, distribution of displacement of sheet material was determined using digital image correlation. Fig. 9 shows distribution of horizontal displacement and displacement vector for L_t=2 mm. The material flow in the horizontal direction away from the die cutting edge on the die was also reduced when the enlargement of sheet material was prevented. In the case of the L_t=2 mm without the suppression plate, the lower part of the sheet material on the die was displaced significantly away from the die cutting edge. This is due to the warping of the material on the die.

Fig. 10 shows distribution of displacement after crack initiation around punch cutting edge for L_t=2 mm. It should be noted that the region of interest for digital image correlation was set only around the die cutting edge, where no cracks had occurred in order to prevent crack from affecting the determination of displacement. The material flow in the horizontal direction away from the die cutting edge was reduced on the die even after crack initiation around punch cutting edge when the enlargement of sheet material was prevented. Therefore, in shearing with the suppression plate, the material flow on the die may be drawn into the die hole.

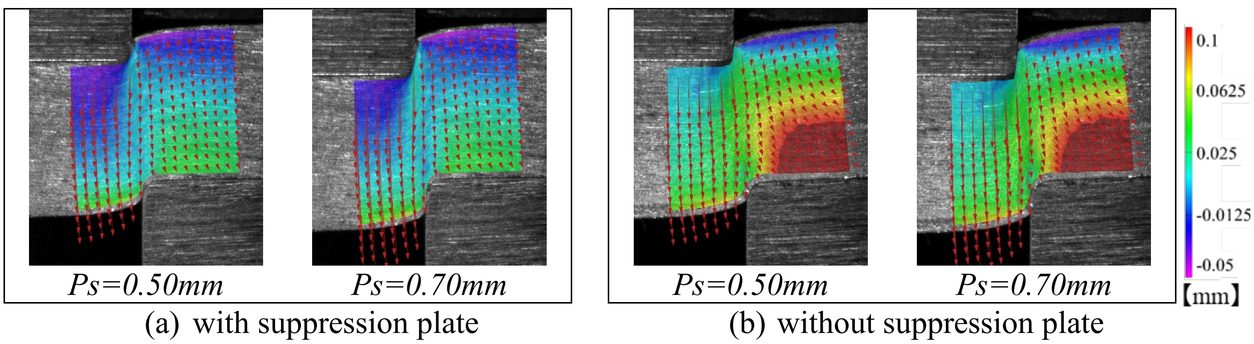


Fig. 9. Variation of distribution of horizontal displacement and material flow for L_t=2 mm.

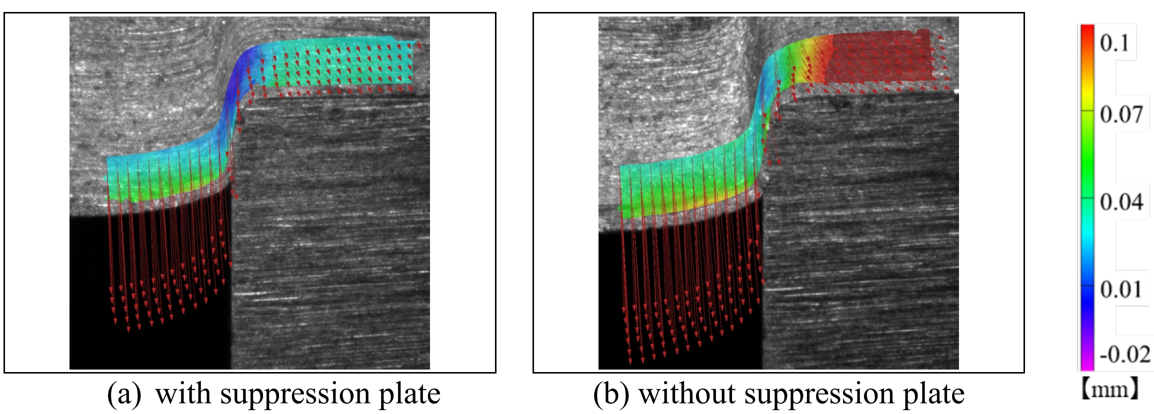
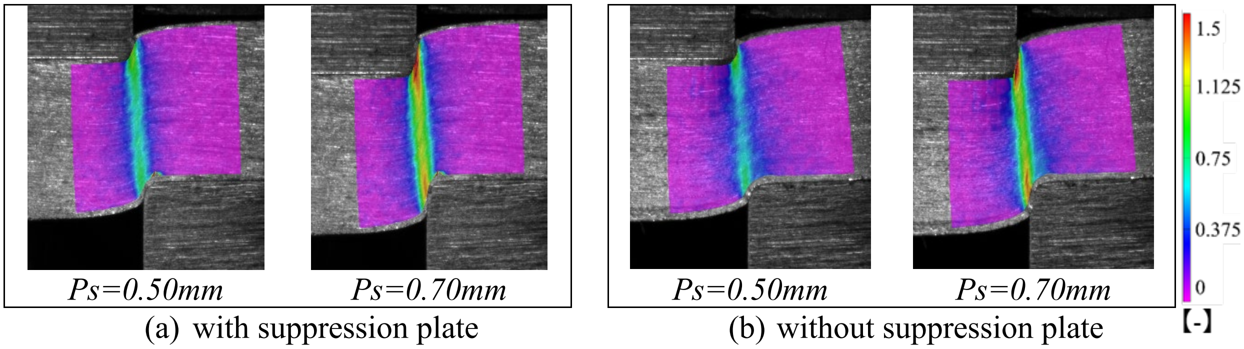


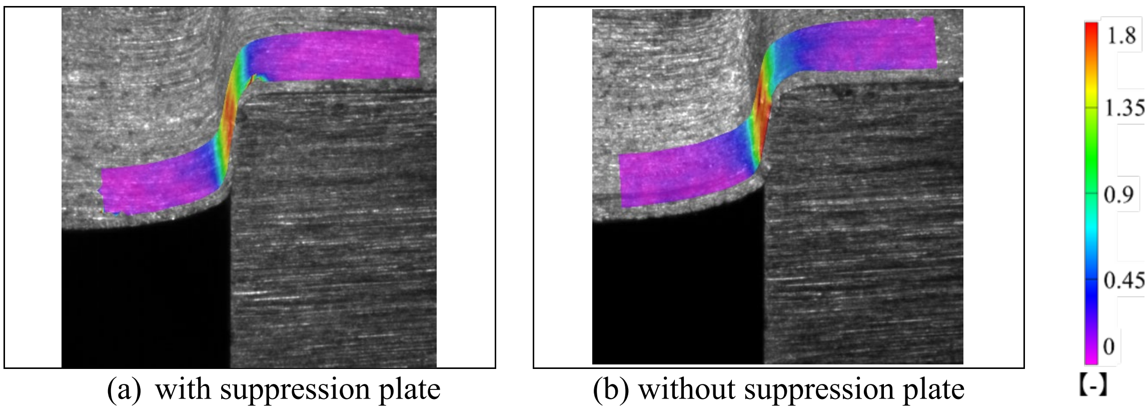
Fig. 10. Variation of distribution of horizontal displacement and material flow after crack initiation around punch cutting edge for L_t=2 mm (P_s =0.90 mm).

Materials Research Proceedings 44 (2024) 674-682 https://doi.org/10.21741/9781644903254-72



(a) with suppression plate (b) without suppression plate

Fig. 11. Variation of distribution of equivalent strain for L_t=2 mm.



(a) with suppression plate (b) without suppression plate

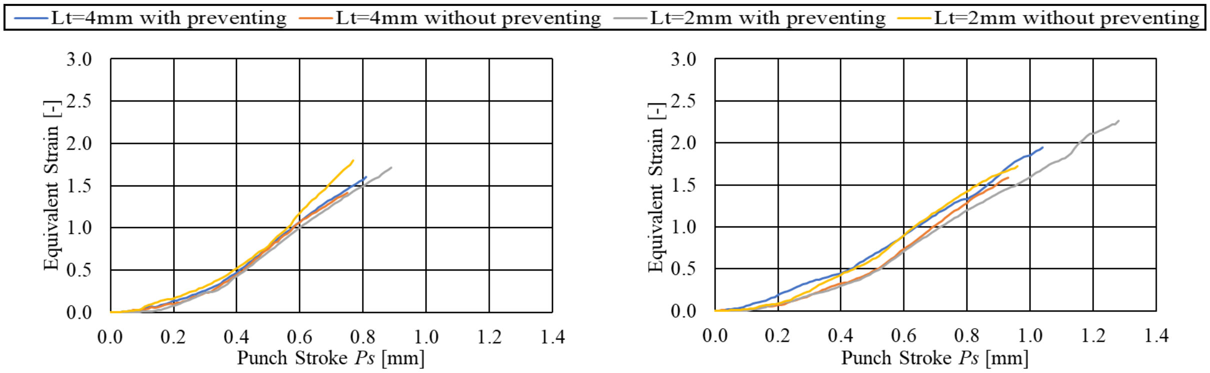
Fig. 12. Variation of distribution of equivalent strain after crack initiation around punch cutting edge for L_t=2 mm (P_s =0.90 mm).

Distribution of equivalent strain. From moving images taken by the high speed camera, distribution of strain of material was determined using digital image correlation. Fig. 11 shows distribution of equivalent strain for L_t=2 mm. At the same punch stroke, there was no significant difference in equivalent strain regardless of preventing enlargement of sheet material.

Fig. 12 shows distribution of equivalent strain after crack initiation around punch cutting edge for L_t=2mm. There was no significant difference in equivalent strain regardless of preventing enlargement of sheet material even after crack initiation around punch cutting edge.

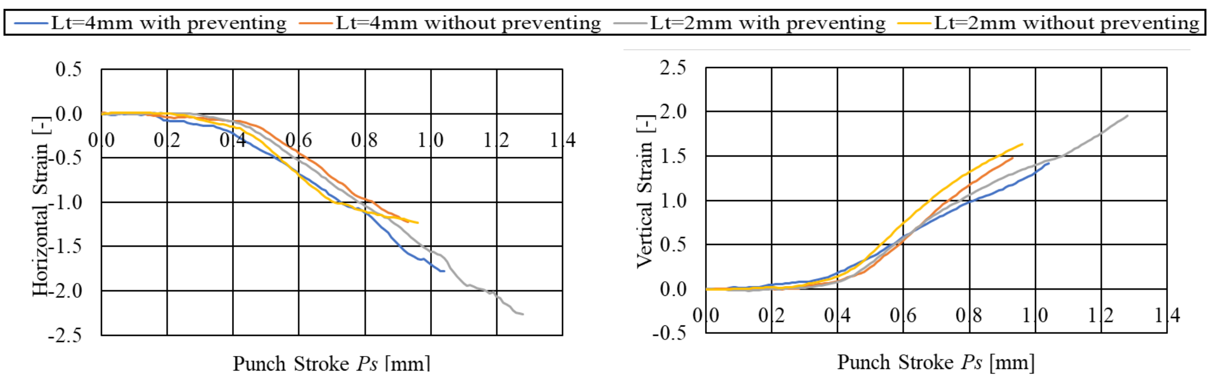
Relationships between equivalent strain and punch stroke. The relationships between equivalent strain and punch stroke for the location where the equivalent strain was maximum around tool cutting edge in the punch stroke at crack initiation shown in Fig. 6 were determined using digital image correlation. The relationships between equivalent strain and punch stroke are shown in Fig. 13. It should be noted that the results were determined until the punch stroke at crack initiation. The equivalent strain at crack initiation increased when material enlargement was prevented. The equivalent strain in the punch stroke at crack initiation increased as the trimming allowance was decreased when enlargement of sheet material was prevented. Similarly, Fig. 13(b) shows that the equivalent strain at crack initiation around die cutting edge increased when material enlargement was prevented. Hence, it is clarified that preventing enlargement of sheet material had little effect on the trend of increasing equivalent strain and increased the equivalent strain until crack initiation.

Materials Research Proceedings 44 (2024) 674-682 https://doi.org/10.21741/9781644903254-72



(a) Punch (b) Die

Fig. 13. History of equivalent strain on crack initiation point (a) punch, (b) die.



(a)Horizontal strain (b)Vertical strain

Fig. 14. History of normal strain on crack initiation point around die cutting edge.

Normal strain along the horizontal and vertical direction. The relationships between normal strain along the horizontal or vertical direction determined using digital image correlation and punch stroke, at the point of Fig. 13(b) are shown in Fig. 14. Fig. 14(a) shows that compressive strain along the horizontal direction of the material around the die cutting edge increased when material enlargement was prevented for L_t=4 mm. For L_t=2 mm, the compressive strain along the horizontal direction of the sheet material around the die cutting edge was larger when material enlargement was not prevented. Further investigation is needed about this, but the sheet material on the die warped up for L_t=2 mm without the suppression plate according to section Distribution of displacement of material, and the material deformation was different from other conditions. Further investigation of the strain for L_t=2 mm is considered to be necessary in the future. Fig. 14(b) shows that tensile strain along the vertical direction of the material around the die cutting edge decreased when material enlargement was prevented for both L_t=2mm and L_t=4mm.

Conclusion

In order to clarify that the effect of preventing the horizontal enlargement of sheet material on the die on the material deformation in double-sided shearing, deformation of the material was observed in shearing. The distribution of the displacement and strain were also determined from moving images taken by high speed camera using digital image correlation. The following conclusion were drawn.

1) When the enlargement of sheet material on the die was prevented in the shearing, the length of the burnished surface increased. It was also observed that the length of the burnished surface increased as the trimming allowance was decreased when the enlargement of sheet material was prevented.

2) The increase in the length of the burnished surface due to preventing horizontal enlargement of sheet material was attributed to the delay of crack initiation around the die cutting edge.
3) At the same punch stroke, there was no significant difference in equivalent strain regardless of preventing enlargement of sheet material. It is clarified that the equivalent strain around the punch and die cutting edge until crack initiation was increased when the enlargement of sheet material was prevented.
4) From the distribution of strain determined using digital image correlation, it was confirmed that tensile strain along the vertical direction of sheet material around the side of the die decreased when the enlargement of sheet material on the die was prevented.

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