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Improvement of joinability in mechanical clinching of ultra-high strength steel sheets using counter pressure with ring rubber

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Abstract

A mechanical clinching using counter pressure of a rubber ring was developed to join the galvanised ultra-high strength steel sheets having low ductility. In the proposed process, the interlock was increased by the increment of metal flow with the counter pressure of rubber ring in the die cavity. The ultra-high strength steel sheets having 45% of reduction area was used in the mechanical clinching. The effect of the shape of rubber ring on the deforming behaviour of the sheets was investigated. The joinability was improved under the appropriate shape of rubber ring, and then the sheets were successfully joined with the counter pressure. The maximum static load and the fatigue limit of the joined sheets were measured in the tension-shearing and cross-tension tests. It was effective for the improvement of joinability in the mechanical clinching of ultra-high strength steel sheets to use the counter pressure of the rubber ring.

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Keywords: Joining; Mechnical clinching; Ultra-high strength steel sheet; Counter pressure; Rubber

1. Introduction

The use of high strength steel sheets tends to increase to reduce the weight of automobiles. The mild steel panels tend to be replaced with thin high strength steel ones for the reduction. The ultra-high strength steel sheets having a tensile strength more than 1GPa are particularly attractive. The stamped high strength and ultra-high strength steel panels are conventionally joined by the resistance spot welding. Although the static load of the joint by the

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resistance spot welding increases with the tensile stress of steel sheets, Futamura et al. (2008) show the increment in the fatigue strength of the joint is not large. The fatigue strength is important for the automobile parts. The development of a joining process for attaining high fatigue strength of joints for the high strength and ultra-high strength steel sheets is desirable.

Galvanised steel sheets are useful to improve life of automobile panels. In resistance spot welding of galvanised steel sheets, the wear of welding electrode becomes large due to the lower electrical resistance and melting temperature of the coating layer. Zhang et al. (2008) reported that the wear of electrode tips for the galvanised high strength steel sheets increased because of high strength of the sheets.

Mechanical clinching is a cold joining process of sheets by local hemming with a punch and a die. The mechanical clinching is used for joining of automobile parts (Barnes et al., 2000). Krause et al. (1995) showed the fatigue load of aluminium alloy sheets joined by mechanical clinching was larger than that by resistance spot welding. The fracture behaviour and stress distribution in a tensile-shear fatigue test of clinched joints were investigated by Carboni et al. (2006). Mori et al. (2012) have clarified the mechanism of high fatigue strength for aluminium alloy sheets joined by mechanical clinching. Abe et al. (2014) showed that the fatigue strength of ultra-high strength steel sheets increases by mechanical clinching.

The mechanical clinching of the ultra-high strength steel sheets having low ductility is not easy although Varis (2002, 2003) has joined the high strength steel sheets. In the joining of ultra-high strength steel sheets, the fracture of the sheets tends to occur and the punch load becomes large due to high flow stress of the sheet. Abe et al. (2012) joined the ultra-high strength steel sheets by the control of the metal flow with the optimum die shape and a cemented carbide punch having high compressive strength. The joining of the ultra-high strength steel sheets having more lower ductility is difficult. It is desirable to develop a joining process for the ultra-high strength steel sheets having lower ductility.

In this paper, a mechanical clinching using counter pressure of a rubber ring was developed to join the galvanised ultra-high strength steel sheets having low ductility. The effects of shape of the rubber ring on the joinability in the mechanical clinching are investigated under the different die depth. The maximum static load and the fatigue limit of the joined sheets were measured in the tension-shearing and cross-tension tests.

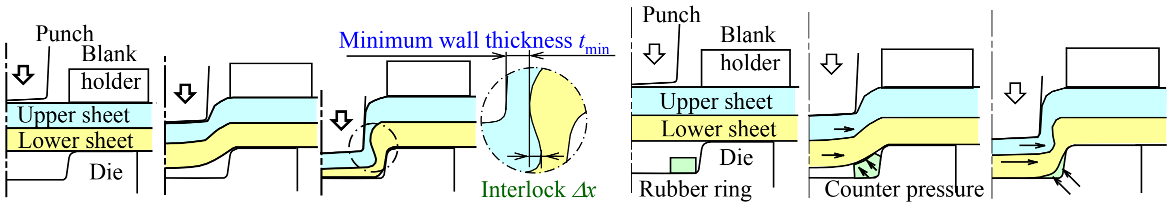
Nomenclature

h	die depth
s	punch stroke
t_{min}	minimum wall thickness of upper sheet
t_{r}	thickness of the rubber ring
Δx	interlock

2. Mechanical clinching using counter pressure with ring rubber

Schematic illustrations of mechanical clinching without and with counter pressure of a rubber ring are shown in Fig. 1. In the mechanical clinching without counter pressure, the sheets are hemmed with the punch and die to generate the interlock between the lower and the upper sheets. The upper and lower sheets are joined by being hooked on the interlock generated by the flaring between the corners of the punch and die. The requisites for the joining are given by the generation of interlock and no facture of both upper and lower sheets. In the mechanical clinching of the ultra-high strength steel sheets, the interlock tends to be small to prevent the occurrence of facture of sheets because of low ductility of the sheets. Appropriate strength of the joined sheets is generated from the interlock Δx and the minimum wall thickness of upper sheet t_{min}. In the mechanical clinching with the counter pressure of rubber ring, the bottom of the lower sheet is subject to counter pressure of rubber ring. The interlock becomes large by increment of the metal flow with the counter pressure of rubber ring.

The conditions of mechanical clinching with the rubber ring are given in Fig. 2. To give the counter pressure to the lower sheet, the rubber ring is installed in the bottom of die cavity. The rubber ring is made of urethane having hardness of Shore A95. The outer and inner diameters of rubber ring are 8mm and 4mm, respectively. The effect of thickness of the rubber ring t_r on the deforming behaviour of the sheets is investigated under the different die depth h. The diameters of die and punch are 8.5 and 5.2 mm, respectively. The final punching load was fixed to 70 kN without plastic deformation of the punch. The punch was made of cemented carbide VM-50 (Japanese Cemented Carbide Tool Industrial Standard) having high compressive load.



(a) Without counter pressure of rubber ring

(b) With counter pressure of rubber ring

Fig. 1. Mechanical clinching (a) without counter pressure of rubber ring and (b) with counter pressure of rubber ring.

The mechanical properties of the ultra-high strength steel sheet are shown in Table 1. The ultra-high strength steel sheets having a nominal tensile strength of 980MPa (JAC980YN) and a thickness of 1.2 mm were used. The sheets are galvanised dual-phase steel. The initial thickness of coating layer is 13 μm.

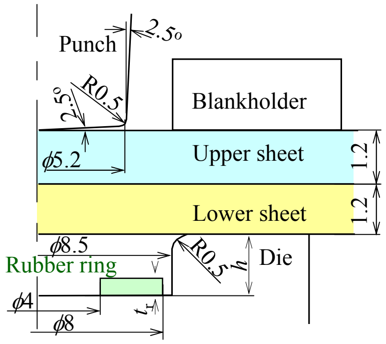
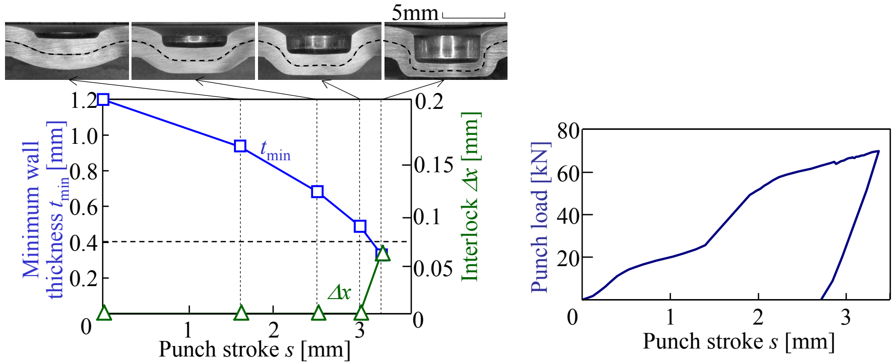


Fig. 2. Conditions of mechanical clinching with rubber ring.

Table 1. mechanical properties of ultra-high strength steel sheet.

Tensile strength [MPa]	Elongation [%]	Reduction area[%]
1008	16.2	45



(a) Minimum wall thickness and interlock

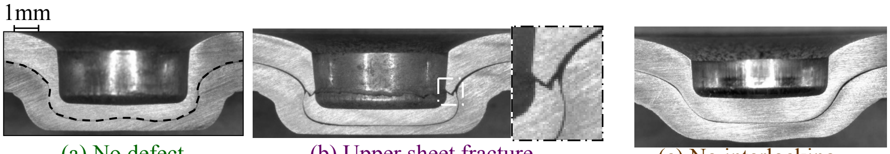
(b) Punch load

Fig. 3. Histories of (a) minimum wall thickness, interlock and (b) punch load for h=1.2mm and t_r= 0.9mm.

3. Improvement of joinability

Histories of the minimum wall thickness, the interlock and the punch load for h=1.2 mm and t_r= 0.9 mm are shown in Fig. 3. Although the minimum wall thickness decreases with the punch stroke s, the upper and lower sheets are successfully joined without fracture by being hooked on the interlock generated with counter pressure.

The joining defects are shown in Fig. 4. In the no defect, the upper and lower sheets are successfully joined by the interlock. In the upper sheet fracture, the facture is occurred in the sidewall of dent portion in the upper sheet because of low ductility of the sheet. In the no interlocking, the sheets are separated without the interlock.



(a) No defect, h=1.2mm, t_r=0.7 mm

(b) Upper sheet fracture, h=1.5mm, t_r=0.7 mm

(c) No interlocking, h=1.2mm, t_r= 0.3mm

Fig. 4. Joining defects. (a) no defect, (b) upper sheet fracture and (c) no interlocking.

The effects of thickness of the rubber ring and the die depth on the joinability are given in Fig. 5. In the large die depth, the fracture tends to occur. The sheets are joined with appropriate thickness of the rubber ring in the small die depth.

The effect of the thickness of rubber ring on the interlock and the minimum wall thickness are shown in Fig. 6. The interlock increases with thickness of the rubber ring, whereas the minimum wall thickness decreases.

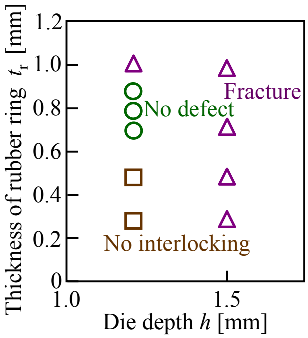


Fig. 5. Effects of thickness of rubber ring and die depth on joinability.

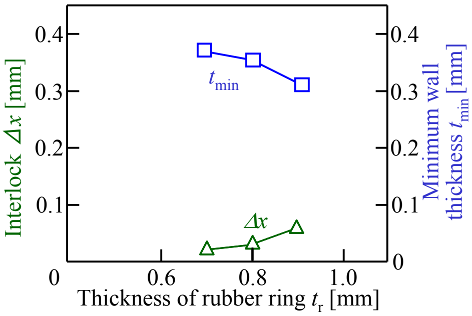
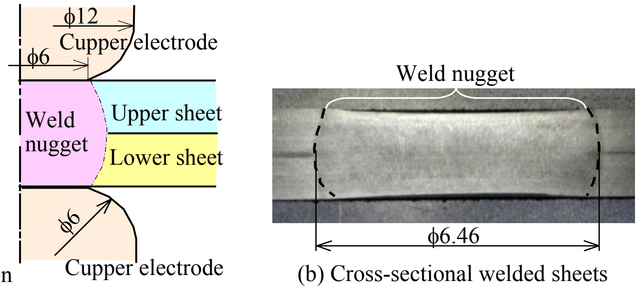


Fig. 6. Effect of thickness of rubber ring on interlock and minimum wall thickness.

Electric current	9.0[kA]
Number of cycles	15 at 60Hz [cycles]
Holding cycles	10 at 60Hz [cycles]
Pressure	0.3 [MPa]

(a) Welding condition

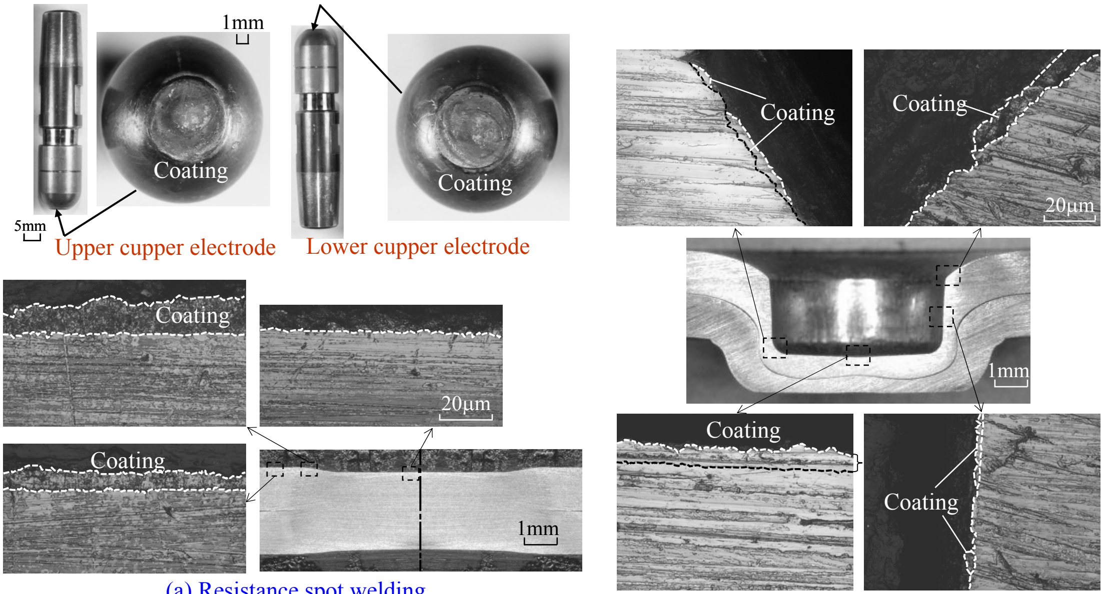


(b) Cross-sectional welded sheets

Fig. 7. (a) Conditions of resistance spot welding and (b) cross-section of welded sheets.

The conditions of resistance spot welding and the cross-section of welded sheets are illustrated in Fig. 7. The sheets are joined with a weld nugget.

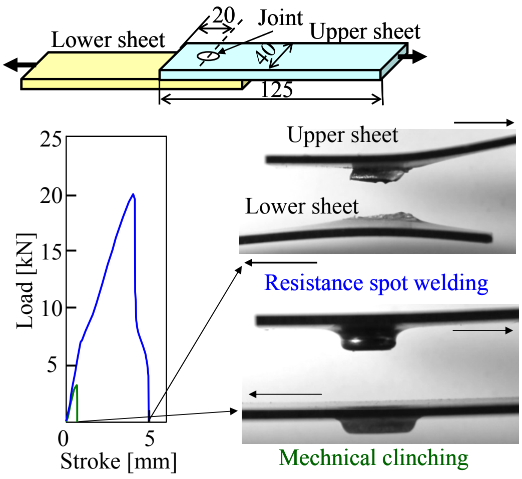
The coating layers on the surface of the sheets after the resistance spot welding and the mechanical clinching are shown in Fig. 8. In the resistance spot welding, the cohesion of the coating on the electrodes occurs. The coating layers on the surface of weld nugget disappear by compression and heating of the welding. In the mechanical clinched sheets, the coating layer on the side wall of the punch partly disappears.



(a) Resistance spot welding

(b) Mechnical clinching

Fig. 8. Coating layers on surface of sheets after resistance spot welding and mechanical clinching.



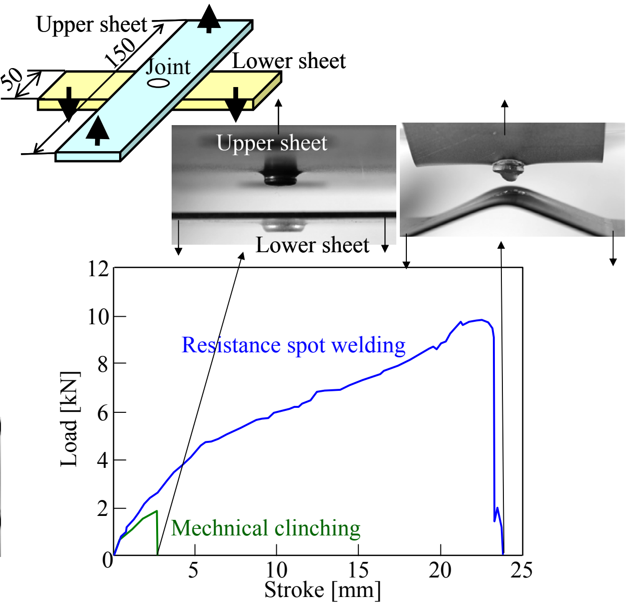


Fig. 9. Load-stroke curves in tension-shearing test.

Fig. 10. Load-stroke curves in cross-tension test.

4. Static and fatigue strengths of joints

The load-stroke curves in the tension-shearing test are shown in Fig. 9. The maximum load for mechanical clinching was 3.3 kN, 18% of that for the resistance spot welding. In the mechanical clinching, the sheets were joined by being hooked on the interlock generated by plastic deformation, and then the upper sheet was pulled from the lower sheet by the rotation of the joint. In resistance spot welding, the fracture occurred around the weld nugget.

The load-stroke curves in the cross-tension test are shown in Fig. 10. The joint load of mechanical clinching was 2.0 kN, 19% of that of resistance spot welding. The separation behaviours of the sheets were the same with that in the tension-shearing test.

The number of cycles to fracture in the cross-tension fatigue test is shown in Fig. 11. In the fatigue test, the repeated load cycle between 0.4kN of tension and unloading was employed under 30 Hz. Although the static load of the mechanical clinched sheets is smaller than that of the welded ones, the number of cycles of the mechanical clinched sheets is larger.

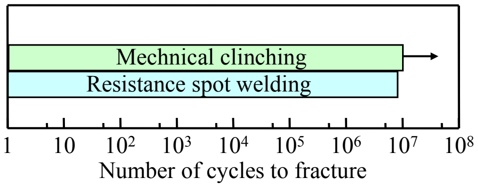


Fig. 11. Number of cycles to fracture in cross-tension fatigue test.

5. Conclusions

The mechanical clinching using the counter pressure of rubber ring was developed to join the ultra-high strength steel sheets. The interlock was increased by the material flow of sheets with the counter pressure of rubber ring. The sheets having 45% of reduction area were successfully joined. Although the maximum static load of clinched sheets was smaller than that of welded sheets, the fatigue load of clinched sheets was larger than that of welded sheets.

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