Mechanical Clinching Process with Preforming of Lower Sheet for Joining Aluminium and Ultra-High Strength Steel Sheets

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The material flow in the mechanical clinching process with preforming of the lower sheet was improved to increase joint strength for joining an aluminium sheet and an ultra-high strength steel sheet. In this process, the material flow to the radius direction in the final compression increases due to the increased upper sheet material in the cavity of the preformed lower sheet, and then the interlock increases. Finally, the joint strength increases because of the increased interlock.

Key Words: Joining, Mechanical Clinching, Ultra-high Strength Steel Sheets, Aluminium Sheets

1. Introduction

To improve the fuel efficiency of automobiles, the reduction in weight of automobiles is useful. For the weight reduction, the use of high strength steel sheets for body-in-white parts considerably increases as replacement of conventional steel sheets. Particularly, the application of ultra-high strength steel sheets having a tensile strength above 1 GPa is attractive to satisfying the both weight reduction and crash protection. Resistance spot welding is conventionally used to join steel body panels. The static strength of joined ultra-high strength steel sheets by resistance spot welding is high, whereas the fatigue strength is not high because of fast crack propagation. Joining dissimilar sheets such as steel and aluminium sheets is not easy by spot welding.

Mechanical clinching is a cold joining process of two sheets by local hemming with a pair of punch and die, and is a low-cost joining process without a fixture such as a rivet. Mechanical clinching has the advantage of joining dissimilar sheets such as high strength steel and aluminium alloy sheets due to a cold joining process. It is desirable in automobile industry to join the sheets having different materials and thicknesses. Mechanical joining processes by plastic deformation including mechanical clinching have the superior characteristics. Mori et al. indicated that mechanically clinched sheets have superior fatigue strength due to relief of the stress concentration slight allowable slip at the interface between the sheets. Lee et al. controlled material flow of the sheets in mechanical clinching of aluminium alloy sheets by changing tool shapes, and Abe et al. optimised die shapes to increase the joint strength of clinched high strength steel and aluminium alloy sheets. Although the material flow of the high strength steel and aluminium alloy sheets in clinching is improved by the optimised die shape, the improvement may be not enough to join the sheets for the large flow stress difference such as an aluminium and an ultra-high strength steel sheets. The mechanical clinching process with preforming of the lower sheet is developed for joining two ultra-high strength steel sheets. In this process, the material flow was improved by controlling contact between the sheets. Therefore, the material flow for aluminium and ultra-high strength steel sheets in clinching is controllable.

In the study, the material flow in the mechanical clinching process for the aluminium and ultra-high strength steel sheets was improved by preforming of the lower sheet to increase joint strength. The diameter and depth of die were selected without preforming, and then the effect of the punch stroke in preforming was investigated. Finally, the joint strength was measured.

2. Mechanical Clinching Process with Preforming of Lower Sheet and Conditions for Joining Aluminium and Ultra-High Strength Steel Sheets

2.1 Mechanical Clinching Process with Preforming

The conventional mechanical clinching process and the mechanical clinching process with preforming of lower sheet are shown in Fig. 1. In the conventional process in Fig. 1(a), the sheets are formed by the punch and die to generate the interlock $\Delta x$ between the upper and lower sheets without the fracture and cracks. The appropriate strength of the joined sheets is generated by the interlock and the minimum wall thickness $t_{\text{min}}$. However, in joining the sheet having low flow stress as aluminium and the sheet having high flow stress as ultra-high strength steel in Fig. 1(b), the interlock becomes small because of high pressure from the lower sheet. In the mechanical clinching process using preforming of the lower sheet for joining the aluminium and ultra-high strength steel
sheets in Fig. 1(c), the hard lower ultra-high strength steel sheet is formed in preforming. In mechanical clinching, the aluminium alloy sheet is set on the preformed lower sheet. The upper sheet material under the punch bottom flows into the cavity of the preformed lower sheet, and then the material flow to the radius direction in the final compression increases, thus finally the interlock increases.

2.2 Conditions of mechanical clinching

The upper and the lower sheets are an aluminium (A1100-O, A1100-H14, A5052-O, A5052-H32, A6061-T6, A2017-T3 and 1.0 mm in thickness) sheet and an ultra-high strength steel sheet (1.2 mm in thickness), respectively. The tensile strength and elongation of sheets are shown in Table 1. The conditions of the mechanical clinching process are shown in Fig. 2. The punch with 5.2 mm in diameter was used in both preforming and clinching. The diameter $D$ and depth $h_2$ of die were selected without preforming. In preforming, the selected die was used, and then the effect of the punch stroke in preforming was investigated. The punch stroke $s_1 = 0$ to 1.3 mm and the die depth $h_1 = h_2$ were used.

3. Decision of Die Shape

The effect of the die diameter on the interlock without preforming for $h_2 = 1.4$ mm is shown in Fig. 3. Although the interlock is not formed for $D = 9$ mm because of the small reaction force from the die sidewall, the interlock is successfully formed for $D = 8$ and 8.5 mm.

The effect of die diameter on the minimum wall thickness in the upper sheet and the interlock without preforming for $h_2 = 1.4$ mm is shown in Fig. 4. In the all sheet combinations, the minimum wall thickness and the interlock for $D = 8$ mm are large. Because the flow stress difference between the upper and lower sheets is larger as the tensile strength of the aluminium sheet decreases, the minimum wall thickness becomes small. The effect of the die diameter on the interlock is larger than that of the tensile strength of the aluminium alloy sheet.

![Fig. 1 Conventional mechanical clinching and mechanical clinching process with preforming of lower sheet for aluminium alloy and ultra-high strength steel sheets.](image)

![Fig. 2 Conditions of mechanical clinching process.](image)

![Fig. 3 Effect of die diameter on interlock without preforming for $h_2 = 1.4$ mm.](image)

| Sheet      | Tensile strength [MPa] | Elongation [%] |
|------------|------------------------|----------------|
| A1100-O    | 88.0                   | 34.5           |
| A1100-H14  | 137                    | 4.8            |
| A5052-O    | 179                    | 23.7           |
| A5052-H32  | 229                    | 9.2            |
| A6061-T6   | 321                    | 12.2           |
| A2017-T3   | 421                    | 16.0           |
| 1180 MPa steel | 1203                  | 8.5            |
The effect of die depth on the joining defect without preforming for $D = 8$ mm is shown in Fig. 5. In the excessive die depth, the upper sheet is fractured by large deformation in clinching. In small die depth, the interlock is not formed because of small deformation. In the all sheet combinations, sheets are joined without defect for $h_2 = 1.2$ and 1.4 mm.

The minimum wall thickness in the upper sheet and the interlock without preforming for $D = 8$ mm and $h_2 = 1.2$ and 1.4 mm were measured. The effect of the die depth on the minimum wall thickness in the upper sheet and interlock without preforming for $D = 8$ mm is shown in Fig. 6. Although the effect of the die depth on the minimum wall thickness is small, the interlock increases by increased material flow to the deep die. The effect of the die depth on the interlock is larger than that of the tensile strength of the sheet. Thus, the effect of the die shape on the interlock is large in all sheet combinations. Finally, the optimum diameter and depth of die were selected $D = 8$ mm and $h_1 = 1.4$ mm, respectively.

### 4. Increased Interlock and Joint Load

The effect of the stroke in preforming on fracture in the lower sheet is shown in Fig. 7. In the excessive stroke in preforming, fracture on the bottom surface in the lower sheet appears due to large deformation, and the maximum stroke without fracture in preforming is 1.1 mm.

The minimum wall thickness and the interlock are shown in Fig. 8. In all sheet combinations, the interlock is increased by the mechanical clinching process using preforming of the lower sheet due to the increased material flow, whereas the minimum wall thickness slightly decreases. The minimum wall thickness decreases with increasing tensile strength of aluminium sheet due to the flow stress difference between the upper and lower sheets.

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**Fig. 4** Effect of die diameter on minimum wall thickness in upper sheet and interlock without preforming for $h_2 = 1.4$ mm.

**Fig. 5** Effect of die depth on joining defect without preforming for $D = 8$ mm.

**Fig. 6** Effect of die depth on minimum wall thickness in upper sheet and interlock without preforming for $D = 8$ mm.

**Fig. 7** Effect of stroke in preforming on lower sheet fracture.
Figure 9 shows the maximum joint load of the clinched sheets. The joint load was measured by the cross-tension\(^9\) and tension shearing\(^{10}\) tests. The maximum load increases with increasing the tensile strength of aluminium sheet. By the increased interlock with preforming of the lower sheet, the load is successfully increased, and especially the cross-tension load increment for the aluminium sheet with low tensile strength is large.

5. Conclusions

The control of material flow in the mechanical clinching process is important to increase the joining range and joint load. The mechanical clinching process using preforming of the lower sheet was applied to join the sheets having large difference of flow stress as the aluminium and ultra-high strength steel sheets. The interlock was increased by mechanical clinching with preforming due to the increased material flow. Finally, the mechanical clinching process using preforming of the lower sheet was effective for increasing the joint load for the aluminium and ultra-high strength steel sheets.

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