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JOINING OF HOT-DIP COATED STEEL SHEETS BY MECHANICAL CLINCHING

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ABSTRACT: The joinability of hot-dip coated steel sheets using a mechanical clinching was investigated by an experiment. The distributions of the layer thickness of Zn alloy coating of the joined sheets were examined. Although the sheets were joined, the layer of coating on the side wall of the punch was scratched and the layer thickness on the bottom of the die was reduced. In order to increase the layer thickness of coating of the joined sheets, shapes of the punch and die were optimised by controlling of the deforming behaviours of the sheets using means of the finite element simulation. The layer thickness of coating of the joined sheets was improved by the modification of the punch and die shapes.

KEYWORDS: joining, mechanical clinching, hot-dip coated steel sheet, tool design, finite element simulation

1 INTRODUCTION

The reduction in weight of automobiles is strongly needed in order to improve fuel efficiency. For the reduction, mild steel automobile parts tend to be replaced by high strength steel ones. In addition, to improve the life of automobiles, the use of hot-dip coated steels has attracted owing to their good corrosion resistance.

The zinc-coated steels are generally used for the automobile body panels. Zn-Al-Mg alloy coated steel sheets are recently developed to have longer for the corrosion resistance [1]. The formability in the stamping is high due to the low friction coefficient of the coated surface.

In resistance spot welding of Zn-Al-Mg alloy coated steel sheets, the life of conventional copper electrodes is short by the electro-spark deposition [1]. The electrode wear of Zn-Al-Mg alloy coated steels is caused by its lower electrical resistance, lower melting temperature and accelerated degradation of resistance welding electrode tips. The layer thickness of the coating is reduced by the electrical heating and the pressing of the electrodes. In addition, the performance of the corrosion resistance of the welds is decreased. In the industry, the joining process having low running costs and high qualities is desirable.

The self-pierce riveting [2] and the mechanical clinching [3] have been developed. The self-pierce riveting is applicable for joining of aluminium alloy body panels in the automobile. The riveting is a cold process for joining sheets by driving a rivet through the upper sheet and upsetting the rivet in the lower sheet without penetration into the lower one. The running costs are increased by the use of rivets [4].

In mechanical clinching, sheets are joined by local hemming with a punch and die. Although the strength of joint is not high, the mechanical clinching has the advantage of low running costs [4].

In the present paper, the joinability of hot-dip coated steel sheets using a mechanical clinching was investigated by an experiment. The strength of the joined sheets and the layer thickness of Zn alloy coating of the joined sheets were examined. In order to increase the layer thickness of coating of the joined sheets, a shape of the punch and die was optimised by controlling of the deforming behaviours of the sheets by means of the finite element simulation.

2 CONDITIONS OF MECHANICAL CLINCHING

2.1 MECHANICAL CLINCHING

In the mechanical clinching, the two sheets are mechanically joined by forming an interlock between the lower and the upper sheets with the punch and die as shown in Figure 1. The strength of the joined sheets is determined by the amount of the formed interlock. It is requisite that the joined sheets do not fracture.

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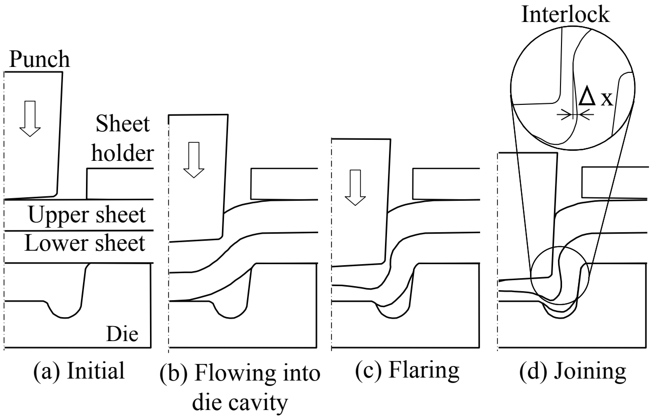


***Figure 1:** Mechanical clinching*

2.2 JOINING CONDITIONS

The apparatus used for an experiment of mechanical clinching of hot-dip coated steel sheets is illustrated in Figure 2. The die has a central flat bottom and ring-shaped groove for the formation of proper interlock. The sheets are pressed with the punch up to 35% of the initial thickness.

The mechanical properties of the sheets are shown in Table 1. The hot-dip Zn alloy coated high strength steel sheets used as materials of automobile body panels were chosen. To investigate the effect of the deforming behaviour of the sheets on the coating, steel sheets without the coating are also employed. Two experiments were carried out for each condition.

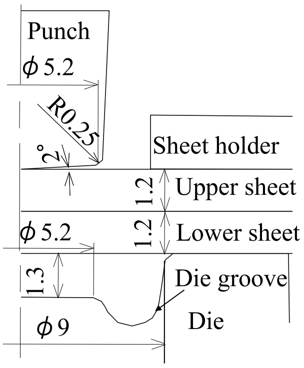


***Figure 2:** Apparatus used for experiment of mechanical clinching*

***Table 1:** Mechanical properties of sheets*

Yield stress /MPa	320
Tensile strength /MPa	377
Elongation /%	29
n-value	0.2
Coating	Zn-Al-Mg alloy
Initial layer thickness of coating /μm	12.5

The mechanical clinching process was simulated by means of the commercial finite element code LS-DYNA. Axi-symmetric deformation was assumed by limiting the calculation to the vicinity undergoing plastic deformation. The cross-sections of the sheets were divided into quadrilateral solid elements and the no layers of coating of the sheets were assumed. The die, punch and sheet holder were assumed to be rigid.

3 JOINING OF HOT-Dip COATED STEEL SHEETS

3.1 DEFORMING BEHAVIOUR OF SHEETS

The deforming shapes of the sheets obtained from the experiment and calculation are shown in Figure 3. In the experiment, defects such as the sheet fracture are prevented, the sheets are joined. The effect of the coating on the deforming behaviour of the sheets is small, the calculated shape agrees well with the experimental ones.

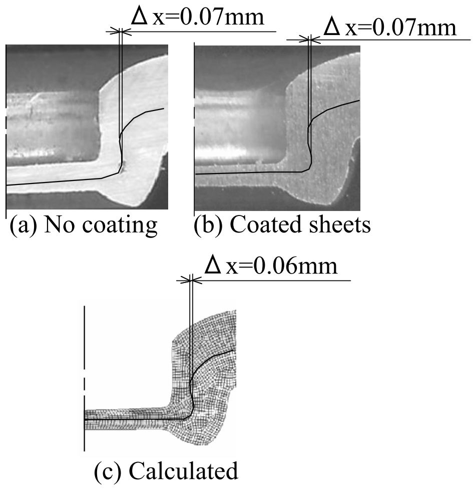


***Figure 3:** Deforming shapes of sheets obtained from experiment and calculation*

The variations in the punch loads with the punch stroke obtained from the experiment and calculation are shown in Figure 4. The effect of the coating on the punch load is also small, the calculated shape agrees with the experimental one.

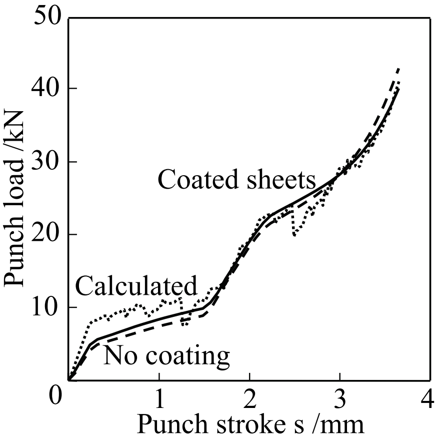


***Figure 4:** Variations in punch loads with punch stroke obtained from experiment and calculation*

3.2 LAYER THICKNESS OF COATING OF JOINED SHEETS

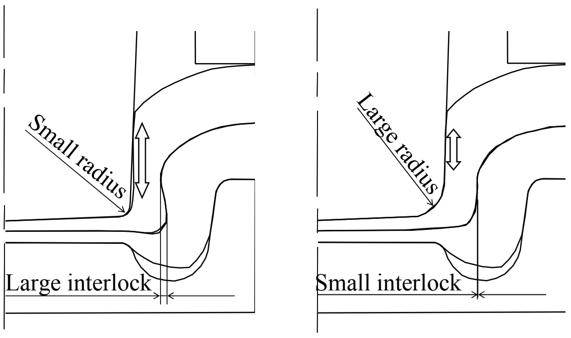
The photographs and layer thicknesses of the coating of the joined sheets in the cross-section are shown in Figure 5. The layer thicknesses are measured along the top and bottom surfaces from the centre of the sheets. The layer thickness in the calculation is estimated from the strain of the surface elements. The layer thicknesses on the side wall of the punch and on the bottom of the die groove were reduced. Although the calculated layer thickness is overestimated due to no consideration of the flaking, the tendency is similar to experimental one.

4 EASING OF REDUCTION IN LAYER THICKNESS

4.1 MODIFICATION OF TOOL SHAPES

To ease the reduction in the layer thickness of coating, tool shapes were modified. The easing of the reduction in the layer of coating on the side wall of the punch is shown in Figure 6. The punch corner radius was increased to ease the concentration of the deformation of the upper sheet.

The effect of the punch corner radius on the interlock and layer thickness of the minimum layer thickness of the top surface obtained from the experiment was shown in Figure 7. As the punch corner radius increases, the minimum layer thickness increases due to small plastic deformation of the upper sheet. In excessive corner radius, the interlock was not formed.



(a) Small corner radius (b) Large corner radius

Figure 6: *Easing of reduction in layer of coating on side wall of punch*

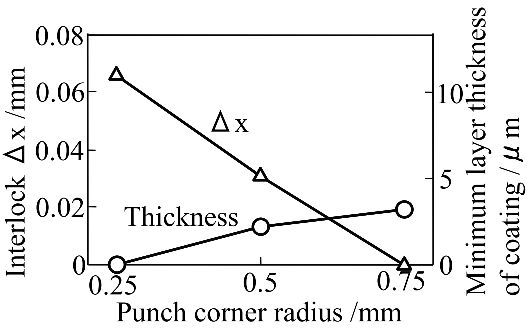
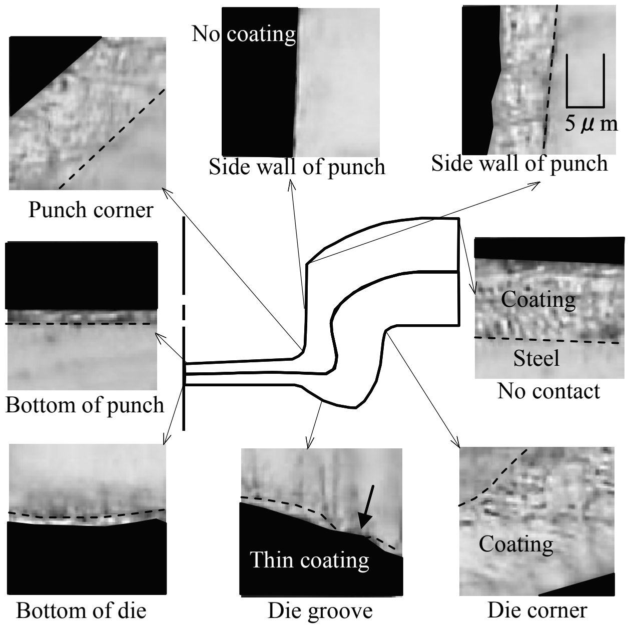
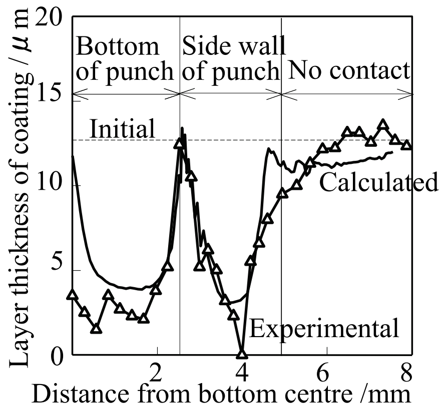


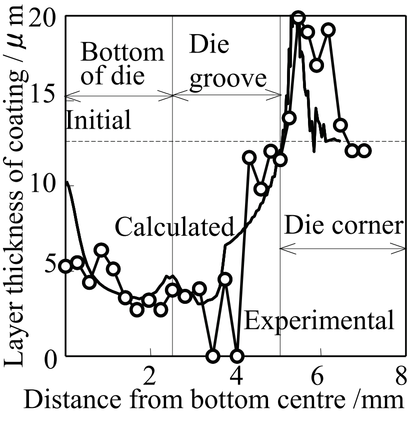
Figure 7: *Effect of punch radius on interlock and layer thickness of minimum layer thickness of top surface obtained from experiment*



(a) Cross-sectional shapes



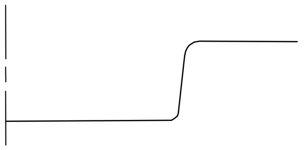
(b) Layer thickness of top surface



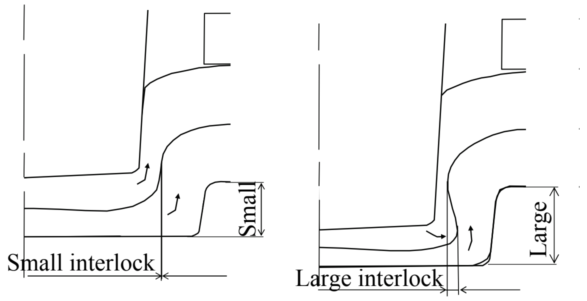
(c) Layer thickness of bottom surface

Figure 5: *Photographs and layer thicknesses of coating of joined sheets*

The easing of the reduction in the layer of coating on the bottom of the die groove and the effect of the die depth on interlock are shown in Figure 8. The flat bottom of die without the groove is introduced to contact with the die bottom and to decrease the plastic deformation of the lower sheet. Because the insufficient die cavity by the elimination of the die groove brings no interlocking, the depth of the die was modified.



(a) Flat bottom of die



(b) Small die depth (c) Large die depth

***Figure 8:** Easing of reduction in layer of coating on bottom of die groove and effect of die depth on interlock*

The effect of the die depth on the interlock and the minimum layer thickness of the bottom surface obtained from the experiment is shown in Figure 9. The use of flat bottom of die, the easing of the reduction in the layer was achieved. The maximum interlock was formed at die depth=2mm.

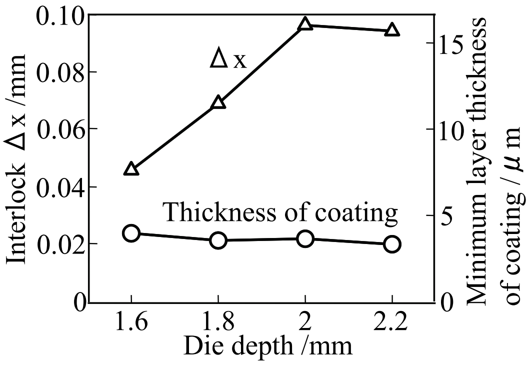


***Figure 9:** Effect of die depth on interlock and minimum layer thickness of bottom surface obtained from experiment*

4.2 LAYER THICKNESS OF COATING BY MODIFIED TOOL

The cross-sectional shape of the joined sheets by the modified tool is shown in Figure 10. The layer thicknesses of coating were improved by the modification of the punch and die shapes.

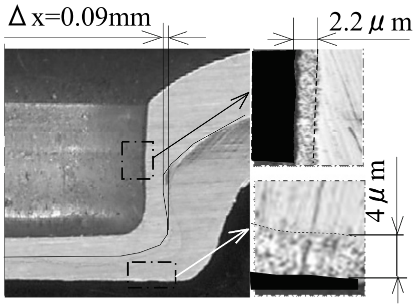


***Figure 10:** Cross-sectional shape of joined sheets by modified tool obtained from experiment*

5 CONCLUSIONS

A mechanical clinching process of hot-dip coated steel sheets was investigated by an experiment and a calculation. The layers of coating on the side wall of the punch and the bottom of the die were reduced. The layer thickness of coating of the joined sheets was increased by the modified shapes of the punch and die. It was found that the mechanical clinching is effective in the joining of hot-dip coated steel sheets in automobile parts.

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