Self-pierce riveting of three high strength steel and aluminium alloy sheets

Y. Abe[1], T. Kato[2], K. Mori[1]

[1]*Department of Production Systems Engineering, Toyohashi University of Technology, Tempaku-cho, Toyohashi, Aichi 441-8580, Japan*
URL: plast.pse.tut.ac.jp/ e-mail: abe@plast.pse.tut.ac.jp, mori@plast.pse.tut.ac.jp

[2]*Engineering Dept #1, Nippon POP Rivets and Fasteners Ltd, Noyori-cho, Toyohashi, Aichi 441-8540, Japan*
URL:www.popnpr.co.jp/html/english-index.htm e-mail: kato-t@popnpr.co.jp

ABSTRACT: The joinability of the self-pierce riveting process of three high strength steel and aluminium alloy sheets was investigated. The effects of the sheet strength and sheet combination on the deforming behaviour were examined under the fixture of the lower aluminium alloy sheet. Although the joining of three aluminium alloy and mild steel sheets is comparatively easy due to small difference of strength, the joining becomes difficult with the increase in strength of the high strength steel sheet. To improve the joinability with the high strength steel sheets, a shape of the die was optimised by controlling the deforming behaviours of the sheets and rivet by means of the finite element simulation. The joining range of three high strength steel and aluminium alloy sheets was extended by means of the optimised die.

Key words: Joining, Self-piercing rivet, High tensile strength steel, Aluminium alloy, 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 and aluminium alloy ones. Although the spot welding is generally used to join steel sheets, it is difficult to apply this welding to steel and aluminium alloy sheets due to different melting points. It is desirable in industry to develop joining processes of steel and aluminium alloy sheets.

To join steel and aluminium alloy sheets, the mechanical clinching [1], the friction stir welding [2,3] and the self-pierce riveting [4] have been developed. In mechanical clinching, sheets are joined by local hemming with a punch and die. Although the mechanical clinching has the advantage of low running costs, the strength of joint is not high. On the other hand, the friction stir welding is a joining process using frictional heat generated by a rotating tool. The joining speed of the friction stir welding is not enough to join a lot of points in automobile body panels [3].

The self-pierce riveting is applicable for joining automobile body panels. The riveting is a cold process for joining two sheets by driving a rivet through the upper sheet and upsetting the rivet in the lower sheet without penetration into the lower one. The heat damage hardly occurs in the joined sheets due to the cold process. The authors [4-6] have developed a self-pierce riveting process of high strength steel and aluminium alloy sheets by designing a shape of the die. Although the self-pierce riveting is mainly employed to joining of two sheets, this riveting is also applicable to more sheets [7, 8].

In the present paper, the joinability of the self-pierce riveting process of three high strength steel and aluminium alloy sheets was investigated. To improve the joinability of the three sheets, a shape of the die is optimising from finite element simulation in order to control the deforming behaviour of the sheets and rivet.

2 SELF-PIERCE RIVETING OF THREE SHEETS

2.1 *Self-pierce riveting*

In the self-pierce riveting, the sheets are joined by direct piercing with the rivet having a tubular leg as shown in Fig. 1. The requisites for joining the sheets are given by

· Driving of rivet leg through upper and middle sheets
· Flaring of rivet leg in lower sheet
· No rupture of lower sheet.

When the tubular leg of the rivet is not driven through the upper and middle sheets, the sheets are not joined with the lower sheet. Proper strength of the joined sheets is obtained from the interlock formed by the flaring of the rivet leg in the lower sheet, because the lower sheet is hooked on the flared leg. In addition, the rupture of the lower sheet is risky for the corrosion of the sheets.

2.2 Riveting conditions

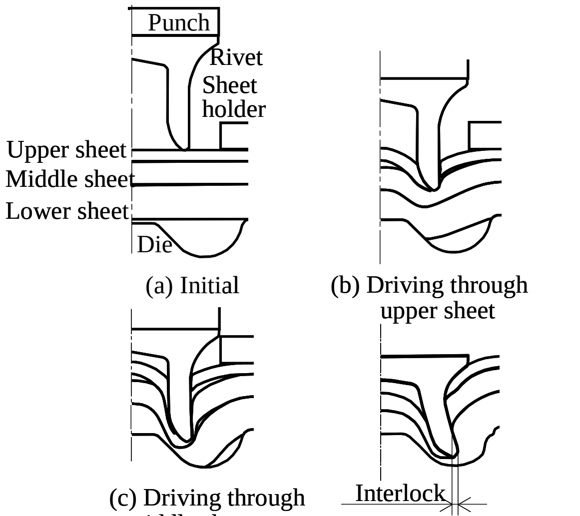
The apparatus used for the experiment of self-pierce riveting is illustrated in Fig. 2. The aluminium alloy sheet A5052-H34 typical of the automobile body panels was chosen, and the steel sheets have different nominal tensile strengths shown in Table 1, where the lower sheet is fixed to the aluminium alloy sheet. The upper, middle and lower sheet thicknesses are 1.0mm, 1.0mm and 2.5mm, respectively. The rivet is made of boron steel and is plated with zinc to prevent corrosion after the riveting. The flow stresses of the sheets and rivet were measured from the uniaxial tensile and compression tests, respectively.

2.3 Joining of mild steel and aluminium alloy sheets

The cross-sectional shapes of the rivet and sheets obtained from the joining experiment for the mild steel and aluminium alloy sheets are shown in Fig. 3, where A5052-SPCC represents the upper aluminium alloy and middle mild steel sheets. Since the difference of the strength between the aluminium alloy and mild steel sheets is small, the joining is comparatively easy.

3 JOINING WITH HIGH STRENGH STEEEL SHEETS

The effect of the strength of the upper and middle steel sheets on the joinability is examined under the fixture of the lower aluminium alloy sheet. The cross-sectional shapes of the rivet and sheets obtained from the experiment are shown in Fig. 4. The joining for the upper mild and middle high strength steel sheets SPCC-SPFC980 is attained, whereas no interlock for SPFC980-SPCC is observed.



(a) Initial (b) Driving through upper sheet (c) Driving through middle sheet (d) Formation of interlock

Fig. 1. Self-pierce riveting of three sheets

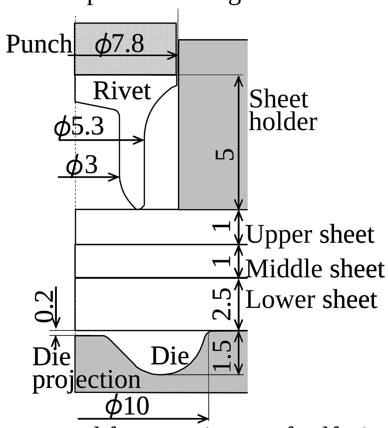


Fig. 2. Apparatus used for experiment of self-pierce riveting

Table 1. Material properties of rivet and sheets

	Material	Thickness / mm	Tensile strength / MPa	Elongation / %	Vickers hardness
Upper and middle sheets	SPFC980	1.0	976	16.8	339
	SPFC780		764	20.3	228
	SPFC590		623	18.2	170
	SPFC440		473	25.0	138
	SPCC		334	33.2	105
	A5052-H34		205	8.2	81
Lower sheets	A5052-H34	2.5	244	9.3	75
Rivet	Boron steel rivet	-	1995	-	505

(a) A5052-SPCC (b) SPCC-A5052

Fig. 3. Cross-sectional shapes of rivet and sheets obtained from joining experiment for mild steel and aluminium alloy sheets

The effect of the tensile strength of the steel sheets on the amount of interlock obtained from the experiment is illustrated in Fig. 5. As the tensile strength of the high strength steel sheet increases, the amount of interlock becomes small, particularly for the upper high strength steel sheet. The joining with the high strength steel sheets is not easy.

(a) SPCC-SPFC980 (b) SPFC980-SPCC

Fig. 4. Cross-sectional shapes of rivet and sheets obtained from experiment for high strength and mild steel sheets

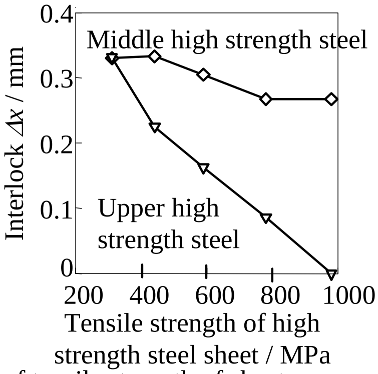
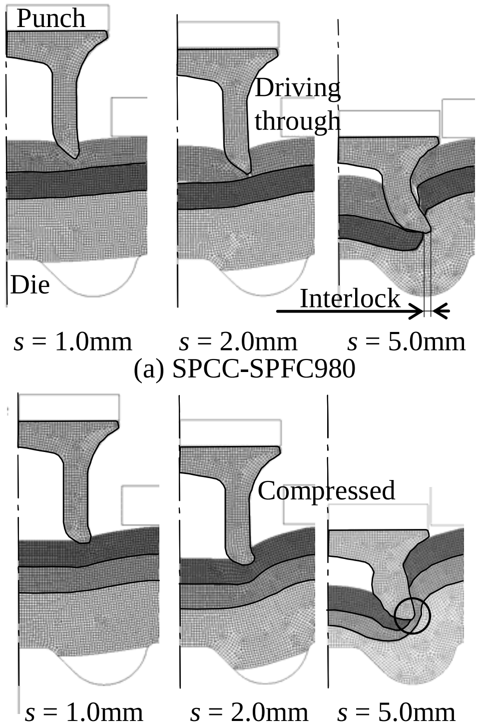


Fig. 5. Effect of tensile strength of sheet on amount of interlock obtained from experiment



(a) SPCC-SPFC980

(b) SPFC980-SPCC

Fig. 6. Effect of sheet combination on deforming behaviour of sheets and rivet obtained from finite element simulation

The effect of the sheet combination on the deforming behaviour of the rivet and sheets obtained from the finite element simulation is shown in Fig. 6. For SPCC-SPFC980, the tubular leg of the rivet is driven through the upper and middle sheets, whereas the tubular leg for SPFC980-SPCC is not driven through the middle sheet, because the piercing of the rivet leg is delayed by the hard upper sheet.
The joining range obtained from the experiment is shown in Fig. 7. Although the joining with the upper sheet tensile strength sheet below 590MPa is attained, the joining with the ultra high strength steel sheet becomes difficult.

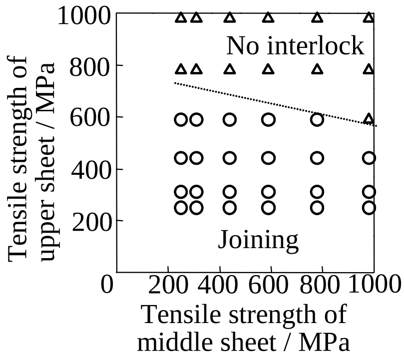


Fig. 7. Joining range obtained from experiment

4 OPTIMISATION OF SHAPE OF DIE

As the diameter of the die cavity and the depth of the central projection of the die increase, the punch load decreases due to the relaxation of constraint of the deformation. The effects of the diameter of the cavity and the depth of the central projection on the deformation behaviour were examined from the finite element simulation, and the die for the riveting with the high strength steel sheet was designed as shown in Fig. 8.

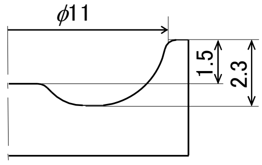


Fig. 8. Die having large diameter of die cavity and large depth of central projection for riveting with high strength steel sheet

The deforming behaviour of sheets and rivet obtained from the finite element simulation of the riveting with the optimised die for SPFC980-SPCC is shown in Fig. 9. By means of the optimised die, the tubular leg of the rivet is driven through the upper and middle sheets, and then the proper interlock is formed. In the experiment, the sheets are joined by the optimised die as shown in Fig. 10.

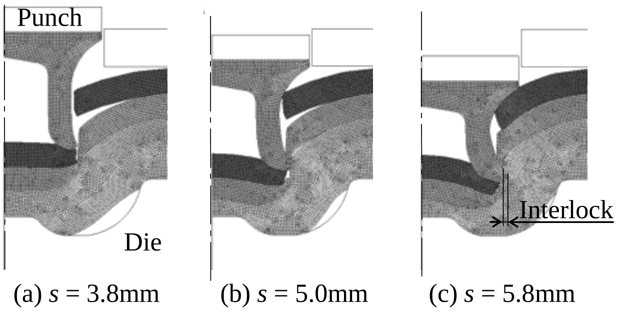


Fig. 9. Deforming behaviour of sheets and rivet obtained from finite element simulation of riveting with optimised die for SPFC980-SPCC

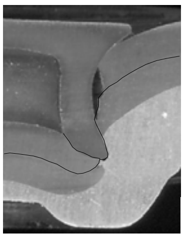


Fig. 10. Cross-sectional shapes of rivet and sheets obtained from experiment with designed die for SPFC980-SPCC

The joining range obtained from the experiment with the optimised die is shown in Fig. 11. The joining range is successfully expanded in comparison with the result for the conventional die shown in Fig. 7.

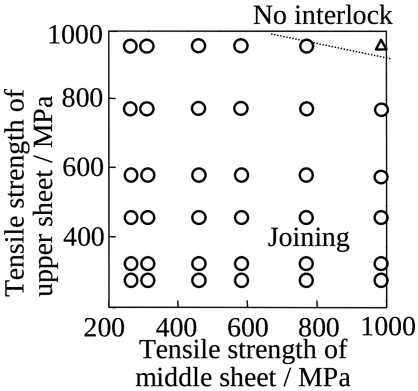


Fig. 11. Joining range obtained from experiment with designed die

5 CONCLUSIONS

A self-pierce riveting process of three high strength steel and aluminium alloy sheets has been developed. In this process, the difference of the melting temperature between the aluminium alloy and steel sheets is not a problem due to the cold joining. Although the joining becomes difficult with the increase in strength of the steel sheet, the joining range was expanded by optimising the shape of the die. The self-pierce riveting is attractive for applying high strength steel and aluminium alloy sheets to automobile parts.

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