

Joining Plastic Sheets by Punch Riveting

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Abstract- In this study, we used punch riveting to join plastic sheets made from polyvinyl chloride. After studying the deformation of these sheets and confirming that their tensile strength depended on the strain rate applied, we joined the sheets and studied their mechanical properties. By varying the pressing speed of the rivet during punch riveting, we studied how the deformation and joint strength of the sheets varied. From these results, we found that increasing the pressing speed increased the strength of the joints, after which we clarified the mechanisms for this increase.

Keywords – Joining, Punch Riveting, Plastic Sheet, Joint Strength, Strain Rate Dependence

I. INTRODUCTION

Punch riveting [1, 2] and impulsive riveting [3, 4] are two riveting methods previously proposed by the authors of this paper. In both methods, a rivet and rivet holder are used to join sheets. In punch riveting, punching and joining of the sheets are performed by pressing the rivet set on the sheets without pre-drilled holes. In contrast, in impulsive riveting, sheet punching and joining are performed simultaneously by colliding a weight, accelerated by an air compressor, with the rivet set on the sheets without pre-drilled holes. These riveting methods enabled the separation of the joints by pushing out the rivet shank from the rivet holder [3].

In punch riveting, sheets are punched at low speeds of 10–1000 mm/min; in impulsive riveting, sheets are punched at high speeds of ~100 m/s or greater. We have shown that impulsive riveting can join aluminum sheets and cold-reduced carbon-steel sheets, producing joined sheets with low deformation and high strength [1, 2].

Using plastics introduces many complications into the joining process. Plastics are viscoelastic [5], causing their deformation to vary significantly at different strain rates; generally, their failure strain decreases as strain rate increases [6]. When plastic sheets are joined using punch riveting, the deformation and strength of the joined sheets may also vary remarkably with punching speed. However, whether plastic sheets can be joined well using punch riveting is still unknown. Because of this knowledge gap, in this study we used punch riveting to join two plastic sheets, and we examined how the deformation and strength of the joined sheets depended on the pressing speed of the rivet.

II. EXPERIMENTS

A. Punch riveting method –

Figure 1 shows the geometry of the lap joint between two plastic sheets; in these experiments we used commercially available 1 mm-thick sheets of polyvinyl chloride (PVC). Figure 2 shows the geometries of the rivet,

rivet holder, and die. We chose to make the rivet and rivet holder from A5052Bd Al alloy; the hardness of the rivet must be higher than that of the sheet, because the rivet shank must penetrate the sheets. The proof stress was 170 MPa. The diameter and length of the rivet shank were 5 mm and 7 mm, respectively. The rivet holder had a height of 3 mm, an outer diameter of 8 mm, and a central hole with a diameter of 4.7 mm.

Table 1 Riveting conditions

No.	Pressing speed (mm/min)	Pressing load (kN)
T1	10	
T2	20	
T3	500	4
T4	1000	

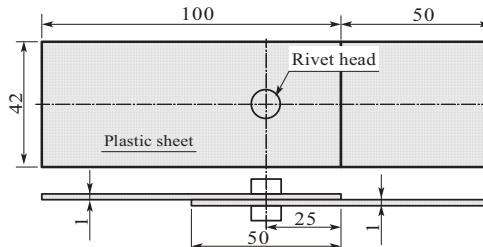


Figure 1. Geometry of the lap joint used

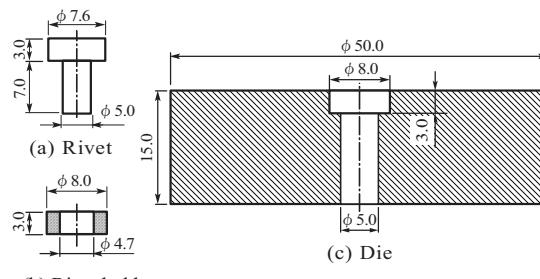


Figure 2. Shape and dimensions of rivet, rivet holder and die

Figure 3 shows schematics of the punch riveting process, which we performed as follows:

- (1) The rivet holder was inserted into the hole of the die shown in Fig. 2. Two sheets without holes were set on the die. Then, the rivet was set on these two sheets, as shown in Fig. 3(a).
- (2) The rivet shank was pushed into the sheets by pressing the rivet.
- (3) The rivet shank punched out the sheets and entered into the hole in the rivet holder. Using an interference fit, the rivet shank was connected with the rivet holder, because the diameter of the rivet shank was larger than that of the hole in the rivet holder. The sheets were tightened by the head of the rivet and the rivet holder, as shown in Fig. 3(b).

The maximum pressing load was 4 kN. Table 1 lists the four pressing speeds we used.

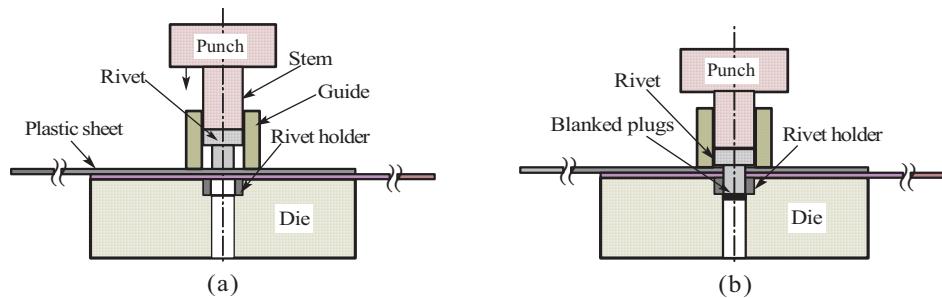


Figure 3. Schematic of the punch riveting method

B. Tension tests of plastic sheet-

To examine how the properties of the sheets depended on strain rate, we performed uniaxial tension tests using a universal tension tester (Shimadz AG-X50kN). Varying the crosshead speed, we examined how the strain rate affected the tensile stress. The specimens were 50 mm long, 20 mm wide, and 1 mm thick. We varied the crosshead speed from 10 mm/min to 1000 mm/min. Five samples were used for each testing condition.

C. Tensile shear test of joints –

To evaluate static joint strength, we performed a tensile shear test on the joint, holding both edges of the joint. The upper chuck and lower chuck were offset to make the two sheets effectively parallel. The joints were pulled at a crosshead speed of 10 mm/min.

III. RESULTS AND DISCUSSION

A. Results of tension test of plastic sheet –

Figure 4 shows an image of a fractured specimen after a uniaxial tension test. Every specimen fractured at $\sim 45^\circ$ to the longitudinal direction. This suggests that they fractured from slip deformation in the direction of maximum shear stress. Figure 5 shows an example of a nominal stress-strain curve obtained from a uniaxial tension test of a plastic sheet; the sheets did not exhibit clear yield points. Figure 6 shows the relationship between the tensile stress of the plastic sheet and the crosshead speed; the points are averages of 5 samples, and the error bars are the standard deviations. The tensile stress of the plastic sheets increased as the crosshead speed increased, exhibiting a clear dependence on strain rate caused by viscoelasticity.

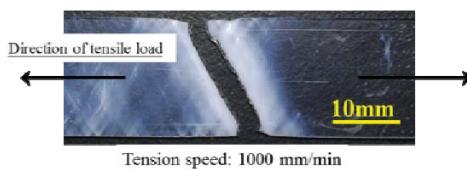


Figure 4. Image of a plastic sheet after tensile fracture

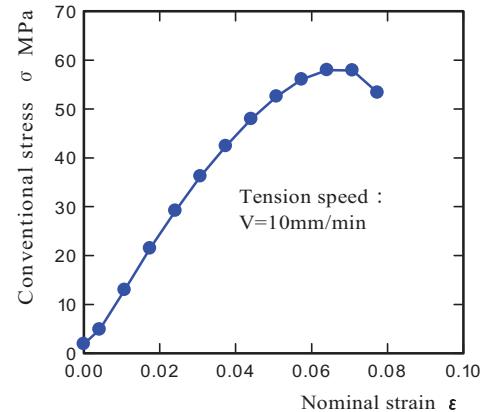


Figure 5. Nominal stress-strain curve of a plastic sheet

B. Aspects of fastening parts of the joint –

Figure 7 shows images of the joint fasteners, verifying that the plastic sheets could be joined by punch riveting without the need for pre-drilling holes in the sheets. The rivet head and rivet holder fastened the sheets uniformly, with little deformation near the fasteners.

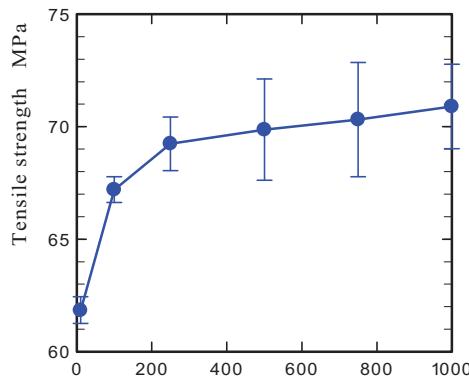


Figure 6. Relationship between tensile stress of a plastic sheet and crosshead speed

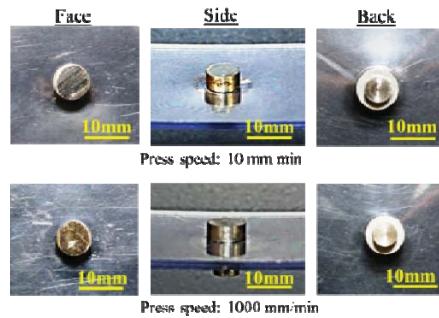


Figure 7. Images of the fastened areas of the joined sheets

C. Pressing load-punch stroke curve –

Figure 8 shows pressing load–punch stroke curves, measured during punch riveting. A punch stroke δ of $\sim 0\text{--}2$ mm corresponds to the rivet shank punching the sheets (because the total thickness of the two sheets is 2 mm, and the length of the rivet shank is 7 mm). A punch stroke of $\sim 2\text{--}7$ mm corresponds to the rivet shank entering the hole of the rivet holder.

The maximum pressing load at a punch stroke of 2 mm is the maximum punching load of the sheet. The pressing speed of the rivet greatly affected the maximum punching load, which varied from ~ 2 to ~ 3.2 kN.

Figure 9(a) compares maximum punching loads. The punching load decreased as the pressing speed of the rivet increased. Figure 9(b) shows the sheared edges and surfaces of the sheets punched by the rivet shanks. At a very slow rivet pressing speed (10 mm/min), the sheared edge was curved and the sheared surface was cracked. In contrast, at a faster rivet pressing speed (1000 mm/min), the sheared surface was flat and the edges of the hole formed right angles. These observations suggest that plastic deformation around the hole decreased as the pressing speed increased, and that the punching load decreased because of a decrease in failure strain.

D. Joint strength –

Figure 10 shows an image of a joint fractured by tensile shear tests. The joints fractured because of extending holes or because of cracks generating around the hole before the rivet shank separated from the rivet holder.

Figure 11 compares the joint strengths of joined sheets; the bar heights are averages of 5 samples, and the error bars are the standard deviations. The joint strength increased as the rivet pressing speed increased, a behavior for which there could be two reasons:

First, increasing the pressing speed led the edges of the punched holes to become right-angled and flattened the sheared surface, causing the stress distribution at the edge of the hole in the direction of the sheet thickness to become uniform. Second, increasing the pressing speed lessened cracking; the strength of the joint punched at 1000 mm/min was $\sim 30\%$ higher than that of the joint punched at 10 mm/min.

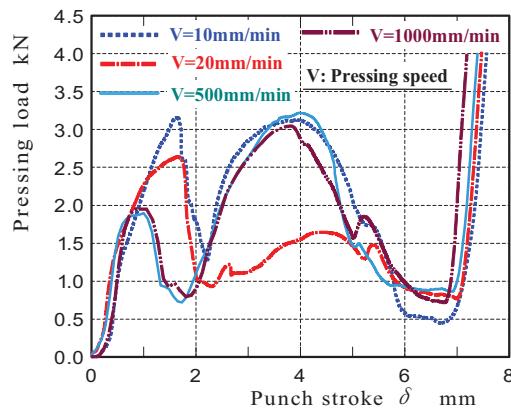


Figure 8. Pressing load–punch stroke curves during punch riveting

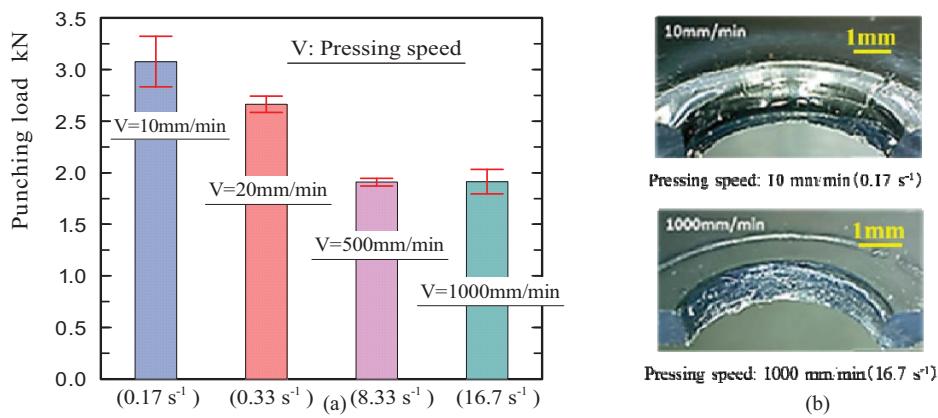


Figure 9.(a) Comparison of maximum punching loads(b)Sheared edges and surfaces of sheets punched by a rivet shank



Figure 10. Image of joint fractured by tensile shear test

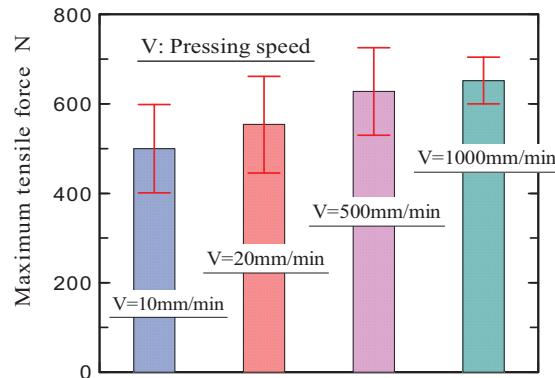


Figure 11. Comparison of the joint strength of joined sheets

IV.CONCLUSIONS

Using punch riveting, we joined PVC plastic sheets and examined how the rivet pressing speed affected the strength of the joined plastic sheets. We found the following results:

- (1) The tensile strength of the PVC sheets depended much on strain rate at tension speeds of 10–1000 mm/min.
- (2) The PVC sheets were well joined by punch riveting at pressing speeds of 10–1000 mm/min.
- (3) The punching load of the PVC sheets decreased as the rivet pressing speed increased. At a very slow pressing speed, the sheared edge was curved and the sheared surface was cracked. In contrast, at a faster pressing speed, the sheared surface was flat and the edge of the hole formed a right angle.
- (4) The joint strength increased as the rivet pressing speed increased. We believe this improvement had two reasons: First, increasing the pressing speed flattened the sheared edges of the punch hole, causing the stress distribution at the edge of the hole in the direction of the sheet thickness to become uniform. Second, increasing the pressing speed made cracks more difficult to form.

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