INSTANTANEOUS FASTENING OF A CFRP AND STEEL PLATE BY A SELF-PIERCING RIVET

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Abstract

A self-piercing rivet (SPR) has been proposed to mechanically fasten a CFRP laminate and a steel plate at an instant. The SPR consists of a rivet body and two flat washers. The two flat washers were used to suppress damage in the CFRP laminate at the point of piercing. Hole drilling are not required in the fastening process which drastically reduces the processing time. In this study, the viability of the SPR for joining of dissimilar materials was investigated. A quasi-isotropic CFRP laminate and a steel plate was joined by the SPR, and tensile tests of the single lap specimen was performed. Mechanical property of the joint was compared with a bolted joint. Before bolted, a hole was drilled through a CFRP laminate and steel plate. The tensile strength of a SPR joint specimen was almost equal to that of a bolted joint specimen. Experimental results showed the advantages of the SPR for fastening CFRP laminate and a steel plate in terms of process time and cost.

1. Introduction

A self-piercing rivet (SPR) has been used to fasten dissimilar metal sheets [1, 2]. Hole drilling is unnecessary in the fastening process, which drastically reduces processing time. However, SPR utilized plastic deformation of a metal sheet which may easily cause damage in CFRP laminate at the points of piercing.

The SPR was modified to fasten CFRP laminates [3]. In this study, the modified SPR is used to join a CFRP laminate and a steel plate simultaneously. Instantaneous mechanical fastening of quasi-isotropic CFRP laminate and steel plate was performed using the SPR. The viability of the SPR for joining of dissimilar materials was discussed from the experimental results of quasi-static tensile tests on single lap joint specimen.

2. Self-piercing rivet (SPR) for CFRP

2.1. Configuration and materials

The SPR is shown in Figure 1. The SPR consists of a rivet body and two flat washers. Materials of the rivet body and the flat washers are SCM435 and S45C respectively. SCM435 was used because it has been in use for the conventional SPR on metal sheets. The corrosion problem between the rivet body and a CFRP needs to be resolved by surface coating or by changing the material of the rivet body, which is beyond the scope of this study.

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2.2. Fastening process [3]

Since the rivet body pierces the plates in the fastening process, initial hole drilling is not required. However, damage to the CFRP laminate such as delamination due to the piercing process needs to be suppressed because it drastically reduces the acceptable mechanical properties of CFRP laminate. In fastening using the SPR, delamination is suppressed by applying pressure to the CFRP laminate during piercing.

Figures 2a and 2b show cross-sectional drawings of CFRP laminate and steel plate before fastening (before piercing) and after fastening (after piercing). The upper and lower flat washers (1) and (2) are placed on the upper and lower supporting dies (3) and (4). After positioning the supporting dies at a fastening point, the upper and lower supporting dies are pressed against the CFRP laminate and the steel plate. Since the pressure needs to be applied very close to the piercing hole to prevent delamination in the CFRP laminate, two flat washers were used. Therefore, pressure was applied by the two supporting dies through the two flat washers. Maintaining the pressure, the rivet body pierced the CFRP laminate and steel plate simultaneously. Chopped CFRP and steel at the rivet body due to the piercing were discharged through the lower supporting die. After piercing, the cutting tip of the rivet body was curled by the lower supporting die, to complete the fastening process. Fastening using the SPR requires no initial hole drilling which enables instant fastening by means of an automatic riveting machine.

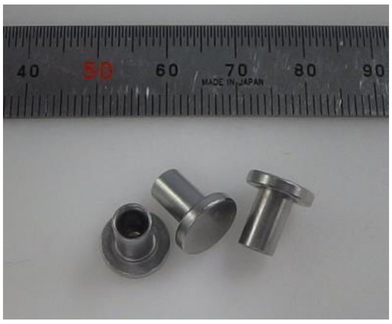
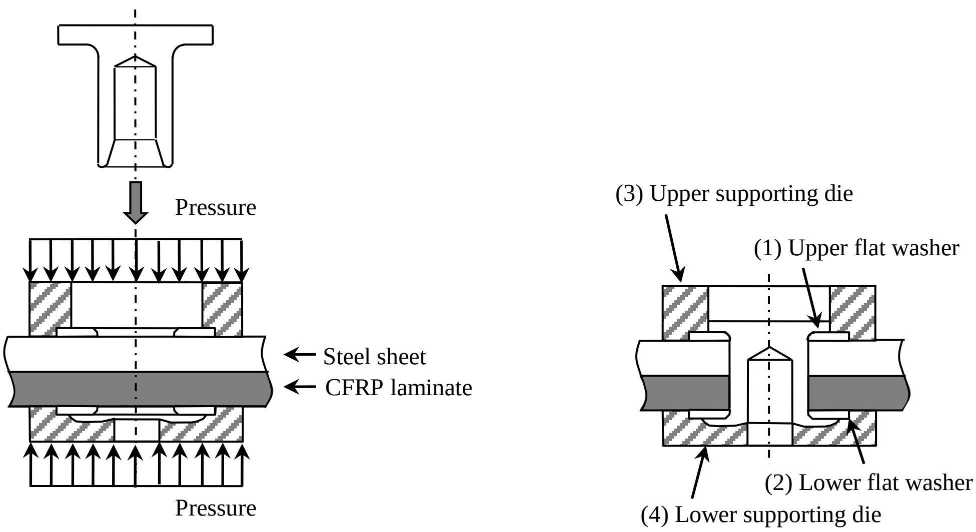


Figure 1. Self-piercing rivets



(a) Before fastening (b) After fastening

Figure 2. Fastening process [3]: A CFRP laminate and a steel plate are pierced simultaneously.

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The clearance between the outer diameter of the rivet body and inner diameter of the washers affects the suppression of delamination in the piercing process. There is a curvature at the neck part of the rivet body to reduce stress concentration. For the upper flat washer, the chamfer was machined at the inner corner (see Figure 2a). The chamfered length is slightly larger than the curvature radius on the rivet, by which the clearance between the outer diameter of the rivet body and the inner diameter of the upper flat washers was minimized. For the lower flat washer, the inner diameter should be almost the same as the outer diameter of the rivet body although this depends on the positioning accuracy and stiffness of the rivet body. In this study, 5.0 mm for the outer diameter of the rivet body and 5.1 mm for the inner diameter of the flat washers were selected. The diameter and thickness of the rivet body should be properly selected according to CFRP laminate and steel plate to prevent bucking of the rivet body in the piercing process.

In this study, the fastening process was divided into two steps. First step was a piercing process of the CFRP laminates by the rivet body. Second step was a swaging process of the cutting tip. Both processes were performed using a riveting machine under control of displacement. No visible damage was observed from the external appearance of the CFRP laminate after fastening.

3. Experimental

3.1 Materials

Quasi-isotropic CFRP laminate was made using a unidirectional prepreg tape in the oven under vacuumed condition. The prepreg tape used in this study was T800SC/#2592 (P2255S-12) produced by Toray Industries. The stacking sequence was $[45_2/0_2/\text{-}45_2/90_2]_s$. After curing the CFRP laminate, it was cut into a rectangular shape of 135 mm long and 36 mm wide using a diamond cutting machine. The thickness of the laminate was 1.6 mm. Cold-rolled steel plate of 1.45 mm in thick was also cut into a rectangular shape of 135 mm long and 36 mm wide, and joined to the CFRP laminate. The thickness of steel plate was selected to be approximately equal flexure stiffness with the CFRP laminate.

3.2. Single lap joint specimens

The configuration of a single lap joint specimen for quasi-static tensile test was followed by ASTM D5961 except the thickness. The CFRP laminate and steel plate were joined by the SPR. A bolted joint with the same configuration was also prepared to compare the joint strengths. For the bolted joint, initially a 5.1 mm hole was drilled and the CFRP laminate and steel plate were then jointed using an M5 bolt and nut. The bolt had a smoothed circular cylinder part which was in contact with the hole through the CFRP laminate and steel plate. The bolt and nut were tightened using only fingers so that pressure was not applied to the CFRP laminate and steel plate. The SPR jointed single lap specimen was shown in Figure 3.

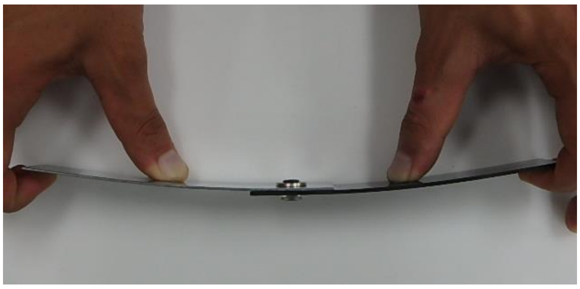

Figure 3. SPR jointed single lap specimen

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3.3. Tensile Test

Quasi-static tensile tests of the single lap specimens were performed using a universal testing machine (AG-IS150kN, Shimadzu). Crosshead speed was 1.0 mm/min.

4. Results and discussion

The load-displacement curves of the two single lap specimens jointed by the SPR and a bolt were shown in Figure 4. The tensile tests were performed several times for each single lap joint specimen, in which almost the same load-displacement curves were obtained. The joint stiffness was relatively higher for the SPR joint than for the bolted joint. Clearance between the fastener and the hole was smaller for the SPR joint than the bolted joint since the SPR pierces into the CFRP laminate and steel plate without drilling. The contact area was, therefore, larger for the SPR joint, which increased the joint stiffness [4]. The maximum loads of the SPR joint and bolted joint were both approximately 9 kN. An almost equal maximum load was observed for the SPR joint and the bolted joint. In the both case, load was progressively dropped after reaching maximum load.

Figure 5 shows the external appearance of the single lap joint specimen after tensile test. The tensile tests were continued until the joints separated. The failure mode was bearing failure for both joints. Since the thickness was relatively thin, the rivet body was pulled out from the CFRP laminate as a result of the bearing failure.

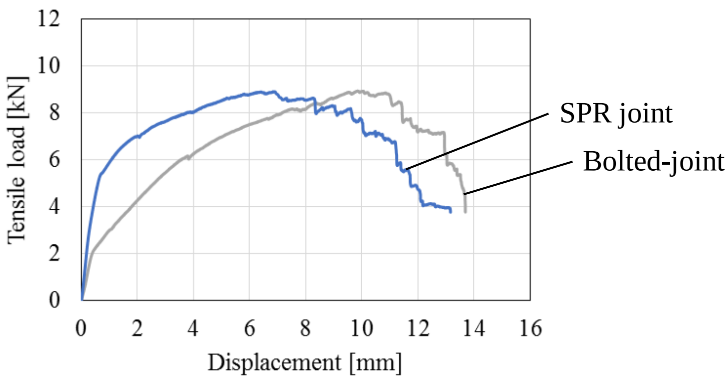

Figure 4. Load-displacement curves of single-lap joint specimens

Figure 5. SPR joint after failure

5. Conclusions

A CFRP laminate and a steel plate were instantly fastened simultaneously using the SPR. Quasi-static tensile tests of the dissimilar material single-lap joint specimen were performed to investigate the viability of the mechanical fastener. The results obtained in this paper are summarized as follows.

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1. Pressure was applied to the CFRP laminate and steel plate by two supporting dies through two flat washers during the piercing process. Then, the CFRP laminate and steel plate were mechanically fastened instantaneously without the need to drill a hole. No visible damage was observed from the external appearance of the CFRP laminate.
2. The joint stiffness was higher for the SPR joint than for the bolted joint. The joint strength of the SPR joint and bolted joint were almost equal. The experimental results showed the advantages of the SPR for fastening CFRP laminate and a steel plate in terms of process time and cost.

Acknowledgments

The SPR rivet was manufactured and the SPR joint specimen was fabricated by Fukui Byora Co., Ltd.

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