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A new single-sided blind riveting method for joining dissimilar materials

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ABSTRACT

A new single-sided, one-step, blind riveting method is developed for joining dissimilar materials. The rivet rotates at a high speed when it cuts and penetrates the workpieces. When fabricating lap joints of AA6111 and AA6022, it was observed that both the torque and force increased as feed rate increased during the rivet penetration. Joints produced by the new method exhibited approximately a 20% higher maximum tensile load compared to joints made by conventional blind riveting and a 11% higher maximum tensile load compared to joints made with friction stir blind riveting (FSBR). The new riveting process is compared to the FSBR due to their process similarity and the mechanism for the success of the new method is discussed.

1. Introduction

Driven by the requirements to reduce emissions and increase fuel efficiency, auto manufacturers world-wide are using light-weight materials such as Al alloys, Mg alloys, and polymer composites in automotive body construction to achieve mass reduction. Joining is a critical process in body construction. However, traditional joining methods such as fusion welding are not capable of joining dissimilar materials in multi-material construction. One alternative is the use of mechanical fasteners (e.g., bolting and riveting) for the joining of dissimilar materials. Conventional bolting or riveting requires a pre-drilling process, which is a two-step joining method. One-step mechanical fastenings, e.g., self-pierce riveting [1], clinching [2] and friction stir blind riveting (FSBR) [3], were developed and applied to join similar and dissimilar materials. However, self-pierce riveting and clinching requires a die on the backside of the workpieces. FSBR was reported to be a single-sided joining method, but it still needs a support on the backside of the overlap area of the workpieces due to high penetration forces [4,5]. Two-sided joining methods have limitations on their application and cannot be applied to joining of semi-closed or closed structures. Therefore, single sided mechanical fastening methods are needed to reduce production time and cost.

A new, single-sided, one-step, riveting method which uses a new rivet modified from the current commercial rivet SSPV-08-06 is introduced in this paper. In the new riveting process, the mandrel of the new rivet is held by a spindle fixture and rotates at a high speed ω (e.g. 9000 rpm), and the rivet is fed along the spindle axis at a rate of f. The rotating rivet tip removes material from the workpiece in a cutting action, and the cut chips fill the hollow mandrel head. Holes having a diameter equal to or slightly larger than that of the mandrel head are left on the workpieces after the penetration of the mandrel head. Then the remaining portion of the rivet can be fed at a rate equal to or higher than f until it reaches the destination, e.g., when the shank head touches the surface of the top workpiece. After that, the mandrel is pulled back to a point where it breaks at the location of the notch. During this operation the shank body expands by which the workpieces are locked, producing a tight fitting joint. Fig. 1 provides an illustration of this process.

Since this new riveting method relies on the cutting of the workpieces by the rivet tip, the penetration force can be significantly reduced through proper rivet tip design, and thereby enable true single-sided joining. This new riveting method is a further development of the friction stir blind riveting (FSBR) process, in which the local workpieces are heated by the friction generated between the rotating rivet tip and workpieces. Frictional heat leads to significantly lower force requirements for the rivet to

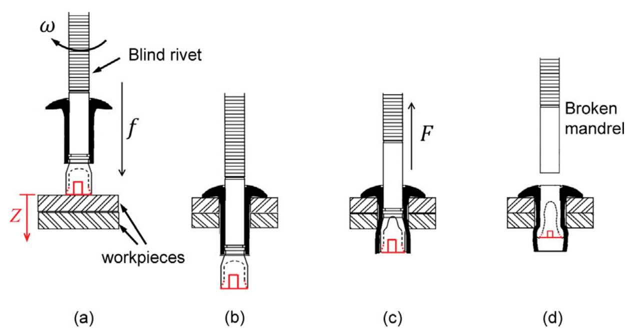

Fig. 1. Illustration of single-sided blind riveting process with rotating rivet: (a) The rivet tip cuts and penetrates the workpieces with a high rotational speed; (b) the blind rivet reaches its destination; (c) the mandrel is pulled back; and (d) the mandrel breaks at its weakened notch, resulting in tightly joined workpieces.

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penetrate the workpieces. In FSBR, the effect of the heating upon the workpiece relies on the frictional heat generation and the heat transfer from the rivet tip to the workpiece, and the penetration force is highly dependent on the feed rate [5].

2. Experimental details

2.1. Rivet designs

Fig. 2a presents the geometric details about the commercial blind rivet, SSPV-08-06. All parts of the rivet are manufactured using mild steel. Based upon prior results using this rivet, three modifications were incorporated as illustrated in Fig. 2b for the new joining method: The 1st modification was that the curved mandrel tip was cut and a new tip was machined to be sharp where the inner slope makes an angle (θ) with the vertical mandrel head wall; the 2nd modification was the introduction of four slots distributed every 90° in the circumferential direction of the mandrel tip with each slot having a width, $2a$, and a height, h; The 3rd modification was slight machining of the shank to reduce its diameter from the original diameter, d_1, to that equal to or slightly smaller (approximately 0.1 mm) than, that of the mandrel head (d_2). The first two modifications aim to reduce the penetration force. The third is to avoid a greater penetration force when the shank penetrates the hole formed by the mandrel tip on the workpieces to reach the destination of the rivet; hence, the shank diameter should not be larger than that of the mandrel head. As summarized in Table 1, the angle of the sharp tip on the modified rivet is set to $\theta = 30°$, and the slot width ($2a$) and the slot height (h) are 2.5 and 4.0 mm, respectively. It is acknowledged that θ, a and h have effects on the penetration force during the penetration of the rivet, but they are not studied and optimized in this work. The comparison of the conventional SSPV-08-06 rivets to the modified rivets can be seen in the insets on the top right of Fig. 2b, with the slot shown on the lower right.

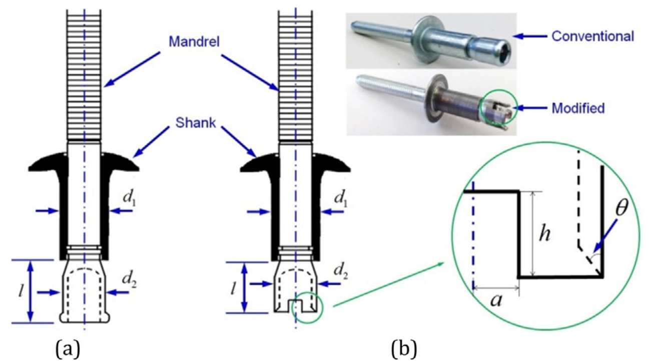

Fig. 2. Illustration for both (a) conventional SSPV-08-06 rivet, as received, and (b) modified rivet.

Table 1
Dimensions of both existing and modified rivets.

Rivets	l (mm)	d_1 (mm)	d_2 (mm)	θ	a (mm]	h (mm)
Existing	9.0	6.4	6.1	–	–	–
Modified	7.5	6.0–6.1	6.1	30°	1.25	4.0

2.2. Riveting tests

The materials used in the riveting tests, which were performed on a Makino machine, are AA6111-T4 and AA6022-T4 with gage thicknesses of 1.0 and 2.0 mm, respectively. The size of the coupons was 38 mm by 127 mm and the overlap area of the lap–shear joints was 38 mm by 38 mm. The fixture used in the riveting tests, shown in Fig. 3, integrated a load cell, and the torque and force were recorded via a data acquisition system at a rate of 100 measurements/sec during the penetration of the rivet. The distance b between the two sliders on the die can be adjusted as shown in the top right inset. To realize single-sided riveting tests, b was adjusted to 38.1 mm, which means that there was no support of the overlap area to represent a single-sided loading condition.

For all the riveting tests in this work as summarized in Table 2, the spindle speed was fixed at 9000 rpm, and the AA6111 and AA6022 were placed on the top and bottom (from the view of penetration), respectively. The feed rates were set to 60, 120, 240 and 480 mm/min for modified rivets. Tests with the conventional SSPV-08-06 rivet were also performed using FSBR at a feed rate of 60 mm/min for comparison (Joint E). These rates were chosen since this setting was also used for the friction stir blind riveting tests as done by Gao et al. [3] and Min et al. [5]. Three sets of coupons were joined for each experimental condition.

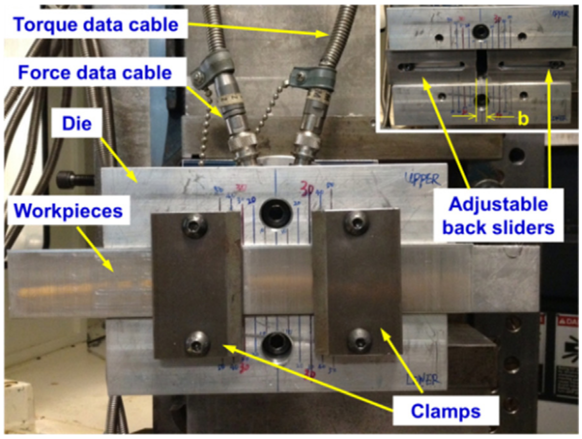

Fig. 3. Fixture used in the riveting tests with data acquisition for force and torque.

Table 2
Riveting tests ("Mod_" and "Con_" indicate modified and conventional rivets, respectively).

Joint	A	B	C	D	E
Rivet Feed rate (mm/min)	Mod_ 60	Mod_ 120	Mod_ 240	Mod_ 480	Con_ 60

3. Results and discussion

Lap–shear joints were successfully fabricated by the new single-sided riveting method. Fig. 4a and b show the semi-finished joints just after penetration by the modified rivets at feed rates of 60 and 480 mm/min (namely, Joints A and D), respectively. For the modified rivet and a feed rate of 60 mm/min, there is no bending on either workpiece in the semi-finished Joint-A, and the gap between both workpieces is uniform and very small (~40 μm) after the mandrel was pulled and broken at the weakened notch, refer to Fig. 4c. Similar results were achieved at 120 and 240 mm/min as well. However, at 480 mm/min with the modified rivet (Fig. 4b), or 60 mm/min using the conventional rivet, the AA6022 workpiece

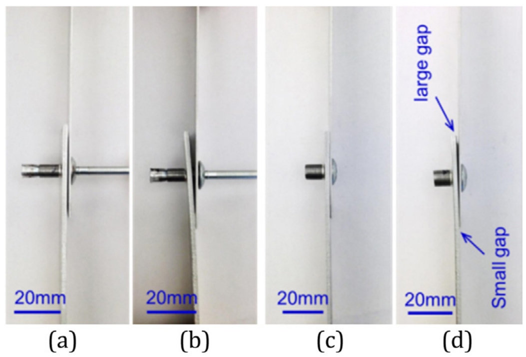

Fig. 4. Semi-finished joints (where the mandrels are not pulled) fabricated with feed rates of (a) 60 mm/min, (b) 480 mm/min, and the respective completed joints (c) and (d).