

Fatigue Behavior of Self-Piercing Rivets and Clinch Joints in Lap-Shear Specimens of Aluminum Sheets

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ABSTRACT

Fatigue behavior of self-piercing rivets (SPRs) and clinch joints in lap-shear specimens of 6111-T4 aluminum sheets is investigated based on experimental observations and a fatigue life estimation model. Lap-shear specimens with SPRs and clinch joints were tested under cyclic loading conditions. Under cyclic loading conditions, fatigue cracks start from the curved interfacial surface of the upper sheet and then grow into the upper sheet thickness for both self-piercing rivets and clinch joints. The self-piercing rivets and clinch joints fail finally through the circumferential/transverse crack growth in the upper sheets and inner button crack growth, respectively. The structural stress solution and the experimental stress-life data for aluminum 6111-T4 sheets are adopted to estimate the fatigue lives of both types of joints. The fatigue life estimations based on the structural stress model show good agreement with the experimental results.

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INTRODUCTION

Resistance spot welding is widely used for joining body-in-white parts made of sheets. However, resistance spot welding of aluminum sheets is likely to produce poor welds due to voids and defects inside the nugget [1, 2]. Recently, several joining processes such as spot friction welding, self-piercing riveting, clinching, and ultrasonic spot welding have been considered to make joints for aluminum sheets in the automotive industry. In contrast to the conventional welding processes, these joining processes make joints without melting the base metals.

Both self-piercing rivets and clinch joints are mechanical fastening joints since they fasten metal sheets mainly by mechanical interlock. As shown Fig. 1, a semi-tubular rivet is punched by a tool into two metal sheets supported by a die. The rivet pierces through the upper sheet and then the tubular tail flares into the bottom sheet. A mechanical interlock is made between the rivet and the two sheets. Unlike the "traditional" riveting process, no pre-process, such as hole drilling and hole alignment, is needed here.

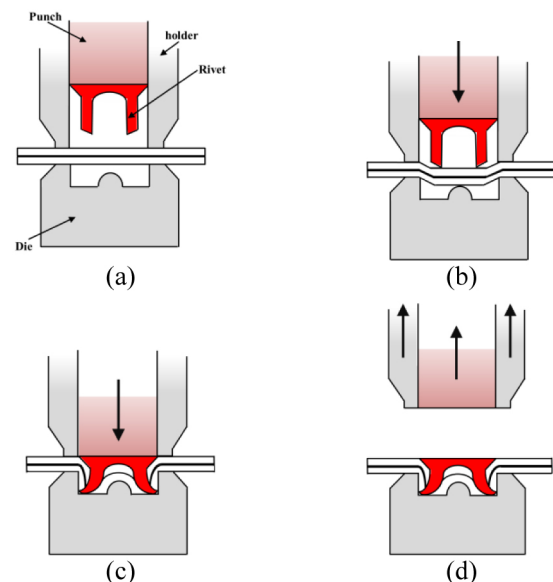


Figure. 1. Schematics of the self-piercing riveting process.

For the clinching process as shown in Fig. 2, two metal sheets are directly punched by a tool into a die. The upper and lower sheets are severely deformed to two button-shaped structures, which provide a mechanical interlock between the two sheets. Compared to the riveting process, no additional joining item is required in this process.

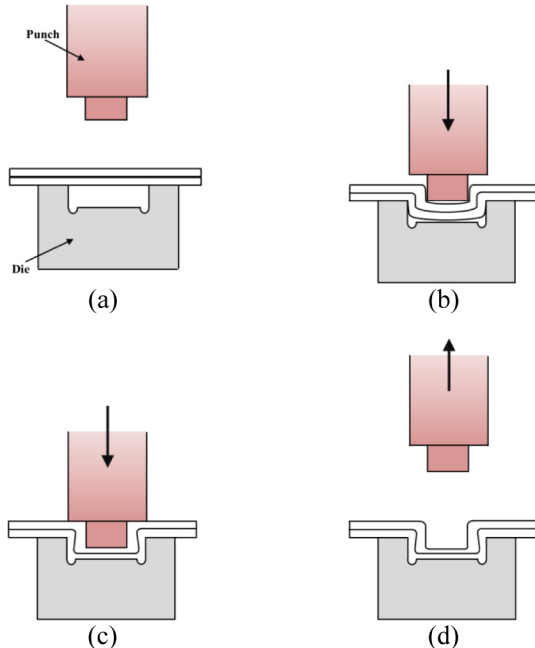


Figure 2. Schematics of the clinching process.

Recently, the fracture and fatigue behaviors of self-piercing rivets and clinch joints have been investigated by many researchers. However, most of the literature only focuses on their fatigue performance. The fatigue life estimations for both types of joints have not been well studied. Unlike spot welds and spot friction welds, there is no original crack along the circumference of both types of joints. Therefore, the kinked crack growth model of Lin et al. [3, 4, 5] based on the global and local stress intensity factor solutions at the critical locations of spot welds or friction stir spot welds is not applicable here. Kim [6] studied the fatigue crack growth behavior of clinch joints in lap-shear specimens of cold rolled steel sheets and adopted the fatigue crack growth model of Zhang [7] and Lin et al. [3] to estimate the fatigue lives of clinch joints. Unfortunately, significant differences between the experimental results and estimated fatigue lives are shown. In this study, the structural stress model of Tran et al. [8, 9] based on the closed-form structural stress solutions is considered to estimate the fatigue lives of self-piercing rivets and clinch joints.

In this paper, fracture and fatigue behaviors of self-piercing rivets and clinch joints in lap-shear specimens of aluminum 6111-T4 sheets are investigated by experimental observations and a fatigue life estimation model. Optical micrographs of the welds before and after failure under cyclic loading conditions are first examined. Dominant fatigue

cracks and the corresponding crack initiation locations are identified. The structural stress model based on the Kirchhoff plate theory as discussed in Tran et al. [8, 9] is adopted to estimate the fatigue lives of the joints. The closed-form structural stress solutions and the experimental stress-life data for aluminum 6111-T4 sheets are adopted to estimate the fatigue lives. Finally, the fatigue life estimations based on the structural stress model are compared with the experimental results for both types of joints.

SELF-PIERCING RIVETS AND CLINCH JOINTS OF 6111-T4 ALUMINUM SHEETS

In this paper, 6111-T4 aluminum sheets with the thicknesses of 1.6 and 1.4 mm were used. Two different joining processes, self-piercing riveting and clinching, were used to make the joints investigated here. Fig. 3(a) shows an optical micrograph of the cross section along the symmetry plane of a self-piercing rivet before testing. The thicknesses of the upper and lower sheets are 1.4 and 1.6 mm, respectively. As shown in the figure, the rivet pierces through the upper sheet and the tail flares into the lower sheet. The rivet head and deformed tail tightly fasten the upper and lower sheets and provide a mechanical interlock. Under the steel rivet and inside the tail, a small portion of the upper sheet can be seen. The profile of the lower sheet reflects the general shape of the die. Fig. 3(b) shows an optical micrograph of the cross section along the symmetry plane of a clinch joint before testing. The thicknesses of the upper and lower sheets are 1.6 and 1.4 mm, respectively. As shown in the figure, the upper and lower sheets are punched by a tool into a die and deformed to two button-shaped structures. The indentation profile reflects the general shape of the tool and die.

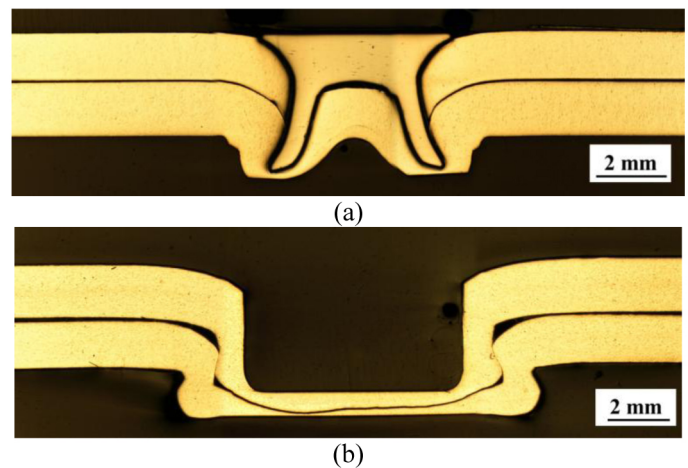


Figure 3. Optical micrographs of the cross sections along the symmetry planes of (a) a self-piercing rivet and (b) a clinch joint in lap-shear specimens.