

Investigation of Failure Mode and Fatigue Behavior of Flow Drill Screw Joints in Lap-Shear Specimens of Aluminum 6082-T6 Sheets

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ABSTRACT

Failure mode and fatigue behavior of flow drill screw (FDS) joints in lap-shear specimens of aluminum 6082-T6 sheets with and without clearance hole are investigated based on experiments and a structural stress fatigue life estimation model. Lap-shear specimens with FDS joints were tested under cyclic loading conditions. Optical micrographs show that the failure modes of the FDS joints in specimens with and without clearance hole are quite similar under cyclic loading conditions. The fatigue lives of the FDS joints in specimens with clearance hole are longer than those of the FDS joints in specimens without clearance hole for the given load ranges under cyclic loading conditions. A structural stress fatigue life estimation model is adopted to estimate the fatigue lives of the FDS joints in lap-shear specimens under high-cycle loading conditions. The closed-form structural stress solutions are based on the analytical solution for a plate with a rigid inclusion under a resultant shear load. The general trends of the fatigue life estimations are in agreement with those of the experimental results.

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INTRODUCTION

Mechanical joining methods such as self-piercing rivets, clinched joints and flow drill screw (FDS) joints have been used to join sheets in the automotive industry recently. FDS joints have the advantage of one-side access for manufacturing flexibility. The advantages of the FDS joining process have been discussed in Claus and Weitzel [1]. The processing parameters of FDS joints have been investigated by Skovron et al. [2, 3]. The mechanical behavior and the failure modes of FDSs have been investigated under combined shear and tension loading conditions by Szlosarek et al. [4]. The failure mode and fatigue behavior of FDS have not been examined in details.

In this paper, FDS joints in lap-shear specimens of aluminum 6082-T6 sheets with and without clearance hole are investigated based on experiments and a structural stress fatigue life estimation model. FDS joints in lap-shear specimens with and without clearance hole were tested under cyclic loading conditions. Optical micrographs were obtained to show the failure modes of the FDS joints in specimens with and without clearance hole. The fatigue lives of the FDS joints in specimens with and without clearance hole under cyclic loading conditions were also obtained. A structural stress fatigue life estimation model is adopted to estimate the fatigue lives of the FDS joints in lap-shear specimens. The closed-form structural stress

solutions are based on the analytical solution for a plate with a rigid inclusion under a resultant shear load. The fatigue life estimations are then compared with those of the experimental results.

EXPERIMENTS

Lap-shear specimens were made by using 25 mm by 100 mm aluminum alloy 6082-T6 sheets with a thickness of 2 mm. The specimen has a 25 mm by 25 mm overlap area. Figures 1 and 2 show the top views of two lap-shear specimens with FDS joints with and without clearance hole, respectively. The type of the screws used is M5×25 EJOT External Torx Plus. Figures 3 and 4 show the micrographs of the cross sections along the symmetry planes of FDS joints in lap-shear specimens with and without clearance hole. As shown in the figures, the upper and lower sheets of the FDS joint with clearance hole has no gap when compared with that without clearance hole. The gap g for the FDS joint without clearance hole due to the extruded material from the FDS drilling process is marked in Figure 4.



Figure 1. A top view of a lap-shear specimen with a FDS joint with clearance hole.

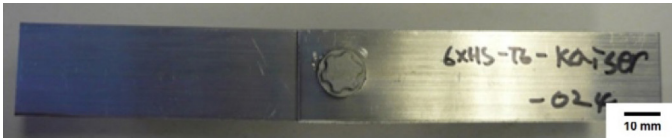


Figure 2. A top view of a lap-shear specimen with a FDS joint without clearance hole.

The lap-shear specimens with doublers were first tested by using a MTS testing machine at a monotonic displacement rate of 7.62 mm/min. The tests were terminated when specimens were separated. The average failure loads were 7.2 kN and 7.3 kN for three lap-shear specimens with FDS joints without and with hole, respectively. The average failure loads were then used as the reference loads to determine the load ranges applied in the fatigue tests. The lap-shear specimens with doublers were then tested with the maximum loads, which are from 80% to 40% of the quasi-static failure loads, by using an Instron servo-hydraulic fatigue testing machine with a load ratio R of 0.1. The test frequency was 10 Hz. The tests were terminated when the specimens were separated or the displacement of two grips exceeded 5 mm.

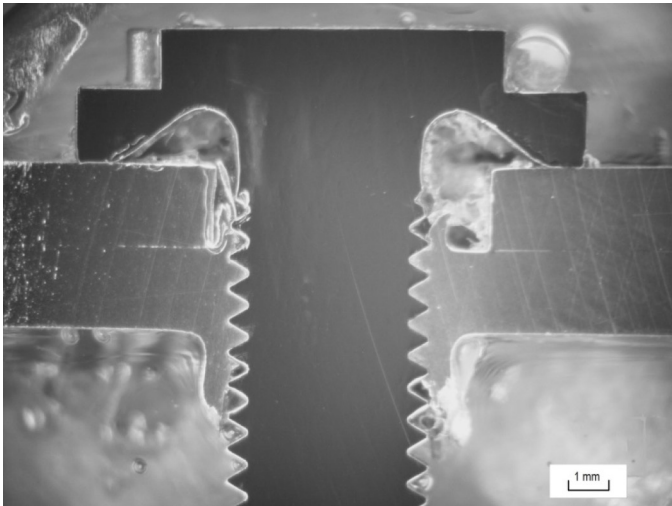


Figure 3. A micrograph of the cross section along the symmetry plane of a FDS joint in a lap-shear specimen with clearance hole.

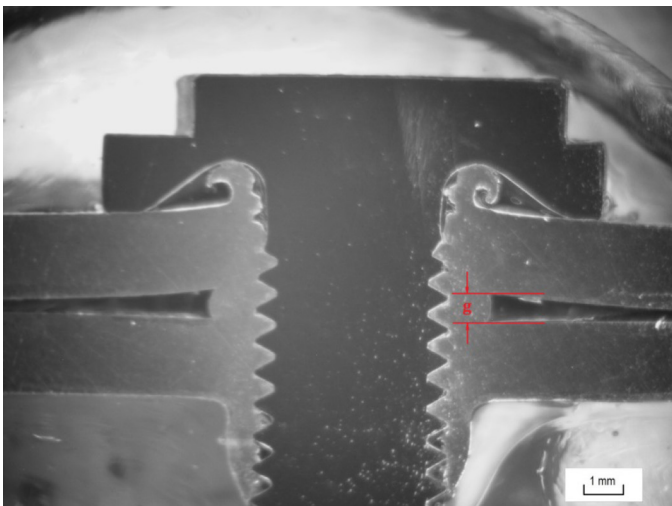


Figure 4. A micrograph of the cross section along the symmetry plane of a FDS joint in a lap-shear specimen without clearance hole.

Figure 5 shows the experimental results for FDS joints in lap-shear specimens with and without clearance hole under cyclic loading conditions. Based on experimental observations, the failure modes of FDS joints in lap-shear specimens under low-cycle and high-cycle loading conditions are different. The low-cycle and high-cycle definitions in this paper are based on the failure modes as discussed in the following.

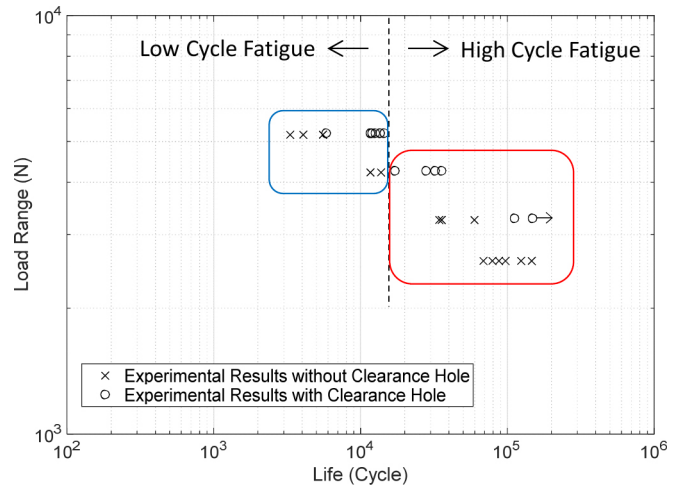


Figure 5. Experimental results for FDS joints in lap-shear specimens with and without clearance hole under cyclic loading conditions.

FATIGUE FAILURE MODES

Figure 6 shows a schematic of a lap-shear specimen with a FDS joint idealized as a rigid cylinder with a radius a under a resultant shear load F . In the figure, t_u and t_l represent the upper and lower sheet thicknesses, respectively, b represents the half specimen width, V represents the overlap length, and L represents the lengths of the upper and lower sheets. The critical locations of points A, B, C and D are 0° , 90° , 180° , and 270° with respect to the x axis, respectively. Two doublers are also shown schematically in the figure. Figure 7 shows a schematic of a top view of the FDS joint with the Cartesian $x-y$ and polar $r-\theta$ coordinate systems centered at the center of the FDS joint. The loading direction is in the x direction at $\theta = 0$.

Figures 8 and 9 show the failed FDS joints with clearance hole in lap-shear specimens under low-cycle and high-cycle loading conditions, respectively. It should be noted that the failures occurred in the lower sheets and Figures 8 and 9 are the bottom views of the failed specimens. The failure modes for the specimens with and without clearance hole are similar and, therefore, the images of the failed FDS joints without clearance hole will not be shown here. As shown in Figure 8 and suggested from the figure, the fatigue cracks grew from the screw at 90° and 270° into the lower sheet under low-cycle loading conditions. As shown in Figure 9 and suggested from the figure, the fatigue crack grew in the lower sheet at about 180° close to the screw and then to the sides of the specimen under high-cycle loading conditions.