

Closed-Form Structural Stress Solutions for Fatigue Life Estimations of Flow Drill Screw Joints in Lap-Shear Specimens of Aluminum 6082-T6 Sheets

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ABSTRACT

Closed-form structural stress solutions are investigated for fatigue life estimations of flow drill screw (FDS) joints in lap-shear specimens of aluminum 6082-T6 sheets with and without clearance hole based on three-dimensional finite element analyses. The closed-form structural stress solutions for rigid inclusions under counter bending, central bending, in-plane shear and in-plane tension are first presented. Three-dimensional finite element analyses of the lap-shear specimens with FDS joints without and with gap (with and without clearance hole) are then presented. The results of the finite element analyses indicate that the closed-form structural stress solutions are quite accurate at the critical locations near the FDS joints in lap-shear specimens without and with gap (with and without clearance hole) for fatigue life predictions. The fatigue life predictions based on the closed-form and computational structural stress solutions are in agreement with the experimental results for FDS joints in lap-shear specimens without and with gap (with and without clearance hole) under high-cycle fatigue loading conditions.

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INTRODUCTION

Claus and Weitzel [1] recently discussed the advantage of the one-side access of using flow drill screw (FDS) joints for lightweight aluminum sheets for automotive applications. The processing parameters of FDS joints were discussed in details in Skovron et al. [2, 3]. The failure modes of flow drill screw (FDS) joints in lap-shear specimens with and without clearance holes under cyclic loading conditions were investigated by Hong et al. [4]. The fatigue failures under low-cycle and high-cycle loading conditions were initiated at different locations near the screws in the lower aluminum sheets of lap-shear specimens under cyclic loading conditions. Based on the closed-form structural stress solution presented in Lin et al. [5] and Su et al. [6], Hong et al. [4] correlated quite well the fatigue lives of FDS joints with and without clearance hole with the experimental results under high-cycle fatigue loading conditions.

In this paper, the accuracies of the closed-form structural stress solutions used in Hong et al. [4] are investigated by conducting three-dimensional finite element analyses of lap-shear specimens with FDS joints with and without clearance hole. The closed-form structural stress solutions for rigid inclusions under counter bending, central bending, in-plane shear and in-plane tension are first reviewed. The structural stress solutions near the FDS joints along the symmetry planes of lap-shear specimens with and without clearance hole are then obtained from the finite element analyses and compared with the corresponding closed-form structural stress solutions. Based

on the closed-form and computational structural stress solutions, fatigue lives are predicted and compared with the experimental results. Finally, some conclusions are made.

LAP-SHEAR SPECIMEN

Lap-shear specimens were made by using 25 mm by 100 mm aluminum alloy 6082-T6 sheets with a thickness of 2 mm as discussed in Hong et al. [4]. The type of the screws used is M5×25 EJOT External Torx Plus. The specimen has a 25 mm by 25 mm overlap area. Figure 1 shows a lap-shear specimen with a FDS joint with clearance hole. The picture of the lap-shear specimen with a FDS joint without clearance hole is very similar to the one with clearance hole and will not be shown here. Figures 2 and 3 show the micrographs of the cross sections along the symmetry planes near the FDS joints in lap-shear specimens with and without clearance hole, respectively. 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, as marked in Figure 3, is due to the extruded material from the FDS drilling process. The critical locations in the lower sheets for initiation of high-cycle fatigue failure are marked by "HCF Fracture" in the figures. Both the upper sheet and lower sheets are subjected to the equivalent tensile resultant forces and bending moments which are also marked in the figures.

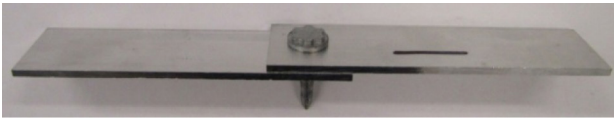


Figure 1. A lap-shear specimen with a FDS joint with clearance hole.

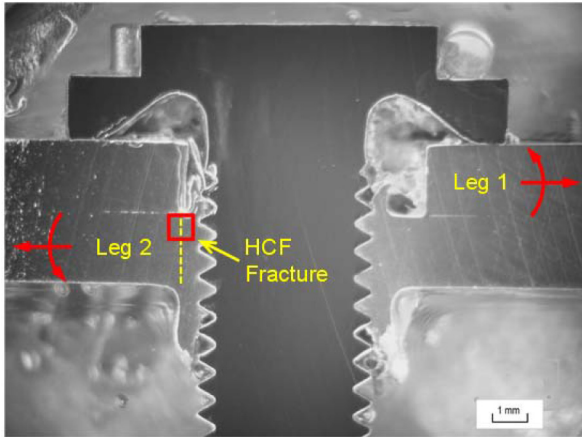


Figure 2. A micrograph of the cross section along the symmetry plane of a FDS joint in a lap-shear specimen with clearance hole.

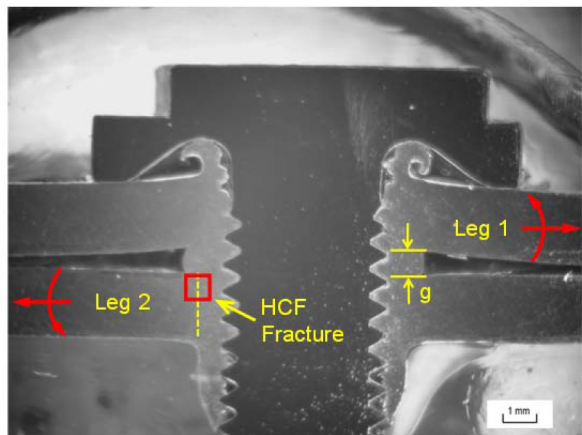


Figure 3. A micrograph of the cross section along the symmetry plane of a FDS joint in a lap-shear specimen without clearance hole.

CLOSED-FORM STRUCTURAL STRESS SOLUTIONS

Figure 4 shows a lap-shear specimen with a FDS joint idealized as a rigid cylinder with the radius a under the applied shear resultant force F . Figure 4 also shows that the displacements of the upper left edge of the lower sheet are fixed and the applied shear resultant force F is uniformly distributed along the lower right edge of the upper sheet. In the figure, t represent the sheet thickness, b represents the half specimen width, V represents the overlap length, and L represents the lengths of the upper and lower sheets. For the lap-shear specimens that we considered, $t = 2$ mm, $V = 25$ mm, $b = 12.5$ mm and $L = 100$ mm. The gap g is estimated to be 0.8 mm from the micrograph from Hong et al. [4]. The rigid inclusion radius a is assumed as 2.3 mm which represents the mean radius of the screw with consideration of the threads. Figure 5 shows a top view of a lap-shear specimen with a FDS joint. The Cartesian $x - y$ and polar $r - \theta$ coordinate systems as shown in the figure are centered at the centers of the rigid inclusion in

the upper and lower sheets when the structural stress solutions are considered for the upper and lower sheets, respectively. The z coordinate is in the downward direction following the right-hand rule. The loading direction is in the x direction at $\theta = 0$ or $\theta = 180^\circ$. Figure 6 shows a schematic of the decomposition process of the shear resultant force of a lap-shear specimen. Model A represents a rigid cylinder under the resultant shear force. Model B represents the rigid cylinder under the equivalent resultant force and moment. The resultant force and moment of Model B can be decomposed into four simple types of loads: counter bending (COB), central bending (CEB), in-plane shear (S), and in-plane tension (T), shown as Models C, D, E, and F, respectively.

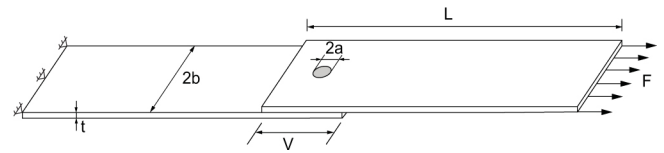


Figure 4. A lap-shear specimen with a FDS joint idealized as a rigid cylinder under the applied shear resultant force F .

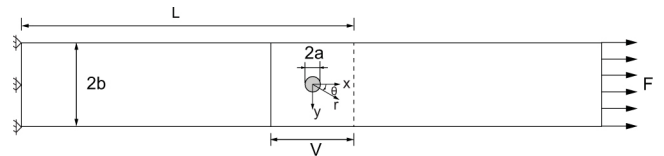


Figure 5. A top view of a lap-shear specimen with a FDS joint modeled as a rigid inclusion with the Cartesian $x - y$ and the polar $r - \theta$ coordinate systems as shown.

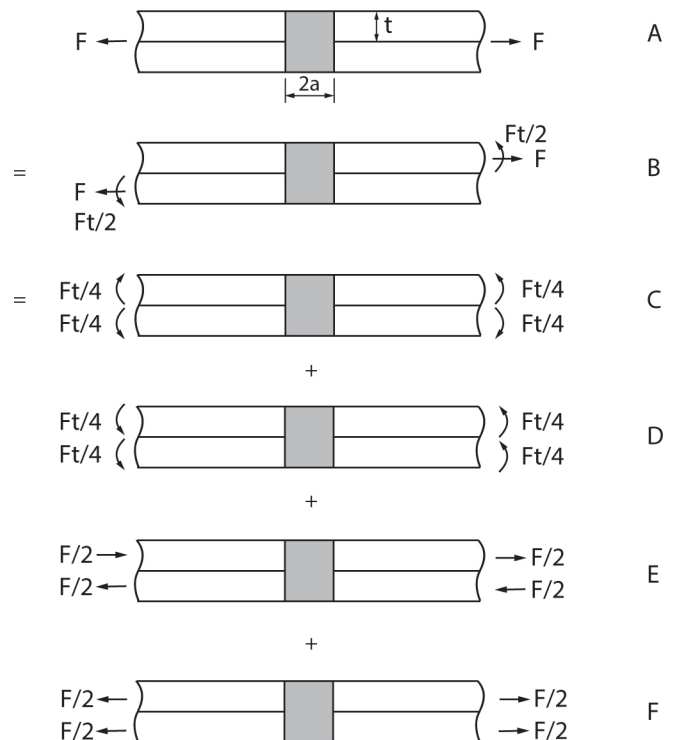


Figure 6. A schematic of the decomposition process of the shear resultant force of a lap-shear specimen.