

Stress Intensity Factor Solutions for Welds in Lap-Shear Specimens under Clamped Loading Conditions

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ABSTRACT

Analytical stress intensity factor solutions for welds in lap-shear specimens of equal thickness under pinned and clamped loading conditions based on the beam bending theory are presented and examined. Finite element analyses are also employed to obtain the stress intensity factor solutions for welds in lap-shear specimens under both clamped and pinned loading conditions. The computational solutions are compared well with the analytical solutions. The results of the analytical and computational solutions indicate that the bending moments at the clamped edges reduce the mode I and II stress intensity factor solutions by about 7% to 10% for the given specimen geometry. The effects of the clamped grips depend on the ratio of the weld width to the specimen length. Comparisons of the stress intensity factor solutions suggest that the fatigue lives of the welds in lap-shear specimens under clamped loading conditions should be higher than those under pinned loading conditions.

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INTRODUCTION

Lap-shear specimens are most commonly used for examining the fatigue behavior of welds or joints. For example, Asim et al. [1] investigated the fatigue behavior of laser welds in lap-shear specimens of SAE J2340 300Y high strength low alloy (HSLA) steel sheets. As shown in Figure 1 from Asim et al. [1], kinked fatigue crack grew from the main crack for a laser weld in a lap-shear specimen of SAE J2340 300Y HSLA steel sheets. Sripichai et al [2] derived the mode I and II stress intensity factor solutions for the main crack in lap-shear specimens under pinned loading conditions based on the beam bending theory for weld widths much larger than the sheet thickness. Based on the global stress intensity factor solutions for the main crack, the local stress intensity factor solutions for small kinked cracks from the main crack can be estimated based the solutions given by Cotterell and Rice [3]. Although computational stress intensity factor solutions for finite kinked cracks are needed for estimation of fatigue lives for these laser welds [2], the global stress intensity factors of the welds and the local stress intensity factor solutions for small kinked cracks are the necessary fracture mechanics parameters for estimation of fatigue lives of the laser welds in lap-shear specimens.

The fixture for testing these laser welds in lap-shear specimens are made such that the specimens were subjected to pinned loading conditions [1] as schematically shown in Figure 2. As shown in Figure 2, the displacements of the upper surface of the left edge of the lower sheet are constrained. A lap-shear load F is applied at the lower surface of the right edge of the upper sheet. In the figure, r represents the half weld width, t represents the thickness of the upper and lower sheets, and L represents the upper and lower sheet lengths.

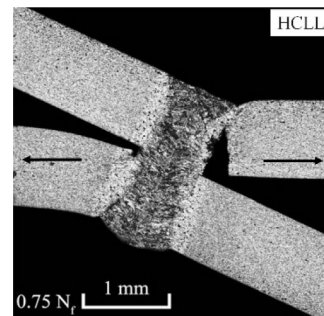


Figure 1. Kinked fatigue crack growth from a main crack for a laser weld in a lap-shear specimen of non-galvanized SAE J2340 300Y HSLA steel sheets in Asim et al. [1].

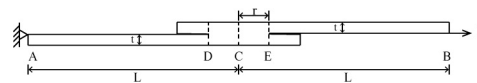


Figure 2. A lap-shear specimen under pinned loading conditions.

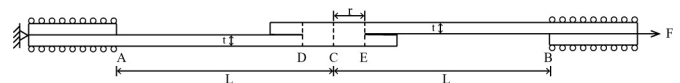


Figure 3. A lap-shear specimen under clamped loading conditions.

However, due to the availability of specimen grips commercially, welds in lap-shear specimens are sometimes tested under clamped loading conditions, as schematically shown in Figure 3. As shown in Figure 3, two doublers are used at both ends of the specimen. The displacements of the middle surface of the left edge are constrained. A lap-shear load F is applied at the middle surface of the right edge. The displacements of the upper and lower surfaces of the clamped

areas in the vertical direction are constrained. When a lap-shear specimen is subjected to clamped loading conditions, the bending moments and transverse shear forces due to the clamped loading grips can have effects on the loading conditions at the weld and consequently on the stress intensity factors for the weld. The effects of these bending moments due to the clamped loading grips have not been investigated in the past.

In this paper, the stress intensity factor solutions for lap-shear specimens under both pinned and clamped loading conditions based on the beam bending theory are presented and examined. The analytical solutions for the clamped loading conditions are compared with those for the pinned loading conditions. Finite element analyses are also employed to obtain the stress intensity factor solutions for welds in lap-shear specimens under both clamped and pinned loading conditions. The computational stress intensity factor solutions are then compared with the corresponding analytical solutions. Finally, the implications of the stress intensity factor solutions for welds in lap-shear specimens under pinned and clamped boundary conditions on fatigue test data are discussed.

ANALYTICAL STRESS INTENSITY FACTOR SOLUTIONS

Hong et al. [4] investigated the failure mode and fatigue behavior of dissimilar friction stir spot welds in lap-shear specimens of transformation-induced plasticity steel and hot-stamped boron steel sheets. The lap-shear specimens with welds were tested under clamped loading conditions. Hong et al. [4] derived the bending moments and the transverse shear force solutions at the grips based on the beam bending theory with the assumption that the displacement and the slope at the welds are continuous for the upper and lower sheets. Figure 4 shows a free body diagram of a welded lap-shear specimen under the force F , the bending moments M_A and M_B , and the transverse shear force V at the grip ends. In the figure, t_u and t_l represent the upper and lower sheet thicknesses, respectively, r represents the half weld width, and L_u and L_l represent the lengths BC and AC for the upper and lower sheets, respectively.

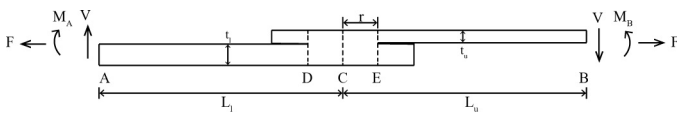


Figure 4. A free body diagram of a lap-shear specimen under the force F , the bending moments M_A and M_B , and the transverse shear force V at the grip ends.

The derivation of the analytical stress intensity factor solutions for the welds in lap-shear specimens is quite lengthy. The derivation will be presented in a future publication [5]. In order to have a closed-form solution to examine the effects of the bending moments due to the clamped grips on the stress intensity factor solutions, we examine the special case where both the upper and lower sheet thicknesses t_u and t_l are set to equal to each other with $t_u = t_l = t$. The upper and lower sheet lengths L_u and L_l are also set to equal to each other with $L_u = L_l = L$. The width of the specimen is denoted by b .

The mode I and II stress intensity factor K_I and K_{II} solutions for a weld in a lap-shear specimen under pinned loading conditions are derived in terms of the force F , the specimen width b , and the sheet thickness t in Sripichai et al. [2] as

$$K_I = \frac{\sqrt{3}}{2} \frac{F}{b\sqrt{t}} \quad (1)$$

$$K_{II} = \frac{F}{b\sqrt{t}} \quad (2)$$

For convenience, the effective stress intensity factor K_e can be defined as

$$K_e = \sqrt{K_I^2 + K_{II}^2} \quad (3)$$

For convenient presentation of the results, Equations (1), (2) and (3) can be expressed in the normalized forms as

$$K_I = f_I^p \frac{F}{b\sqrt{t}} \quad (4)$$

$$K_{II} = f_{II}^p \frac{F}{b\sqrt{t}} \quad (5)$$

$$K_e = f_e^p \frac{F}{b\sqrt{t}} \quad (6)$$

where the superscript “p” represents the pinned loading conditions. Here, f_I^p , f_{II}^p , and f_e^p are the normalized stress intensity factor solutions for the pinned loading conditions. For the pinned loading conditions,

$$f_I^p = \sqrt{3}/2 \quad (7)$$

$$f_{II}^p = 1 \quad (8)$$

$$f_e^p = \sqrt{(f_I^p)^2 + (f_{II}^p)^2} \quad (9)$$

The mode I, II, and effective stress intensity factor K_p , K_{IIp} , and K_e solutions for a weld in a lap-shear specimen under clamped loading conditions can also be expressed in the normalized forms as

$$K_I = f_I^c \frac{F}{b\sqrt{t}} \quad (10)$$