

Failure Mode and Fatigue Behavior of Dissimilar Laser Welds in Lap-Shear Specimens of Low Carbon Steel and HSLA Steel Sheets

Zheng-Ming Su and Pai-Chen Lin
National Chung Cheng Univ.

Wei-Jen Lai and Jwo Pan
University of Michigan

ABSTRACT

In this paper, failure modes of dissimilar laser welds in lap-shear specimens of low carbon steel and high strength low alloy (HSLA) steel sheets are investigated based on experimental observations. Micro-hardness tests across the weld zones of dissimilar laser welds were conducted. The hardness values of the fusion zones and heat affected zones are significantly higher than those of the base metals. The fatigue lives and the corresponding failure modes of laser welds as functions of the load ranges are then examined. Optical micrographs of the laser welds before and after failure under quasi-static and cyclic loading conditions are then examined. The failure modes and fatigue behaviors of the laser welds under different loading conditions are different. Under quasi-static loading conditions, a necking failure occurred in the upper low carbon steel sheet far away from the laser weld. Under low-cycle loading conditions, the dominant kinked fatigue crack was initiated from the right crack tip and grew into the upper low carbon steel sheet. Under high-cycle loading conditions, the dominant kinked fatigue crack was initiated from the left crack tip and grew into the lower HSLA steel sheet. The experimental results indicate that the failure modes of the laser welds under cyclic loading conditions strongly depended on the load range amplitude.

CITATION: Su, Z., Lin, P., Lai, W., and Pan, J., "Failure Mode and Fatigue Behavior of Dissimilar Laser Welds in Lap-Shear Specimens of Low Carbon Steel and HSLA Steel Sheets," *SAE Int. J. Mater. Manf.* 8(3):2015, doi:10.4271/2015-01-0706.

INTRODUCTION

Laser welding has many advantages over the conventional welding methods. These advantages include relatively low distortion of the weld, narrow heat affected zone, relatively high welding speed and high penetration. Over the past two decades, extensive research efforts have been spent on studying the fatigue behavior of laser welds for different materials and joint configurations. Lap joints have been commonly used to assess the strength and fatigue behavior of laser welds under shear dominant loading conditions. The geometry of a lap joint provides pre-existing cracks or notches at the edges of the weld bead. Therefore, the fatigue cracks were usually observed to be initiated from these stress concentration sites. Hsu and Albright [1] combined a static stress analysis and Neuber's rule to predict the fatigue lives of laser welded lap joints. Wang and Ewing [2] compared the fatigue strengths of laser welds and resistance spot welds in lap-shear specimens of steel sheets on the basis of equal weld volume. They reported that the fatigue failure in laser welds is dominated by crack propagation in the heat affected zone. Flavenot et al. [3] performed an experimental study to examine the influence of laser beam type, weld bead geometry, gap between the sheets and the input energy on the fatigue behavior of laser welded lap joints. Wang [4] correlated the experimental fatigue lives of laser welds in lap-shear specimens with the values of the J integral obtained from finite element analyses. The results were also used to assess the influence of parameters such as the weld geometry, sheet thickness,

bead width, metal fit-up and bead length. Ono et al. [5] investigated the static and fatigue strengths of laser welded lap joints of thin steel sheets and correlated the fatigue lives of laser welded lap joints with the maximum stress intensity factor ranges.

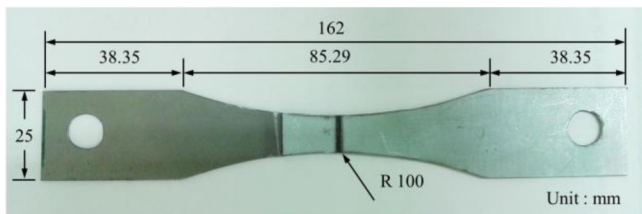
Kaitanov et al. [6] conducted experiments to determine the static and fatigue strengths of laser welded lap joints of steel sheets with different weld widths and penetration depths. They found that the weld width affects the fatigue strength of laser welds. Cho et al. [7] examined the fatigue strength of laser welded lap joints with the consideration of residual stresses obtained from thermo-mechanical finite element analyses. Sripichai et al. [8] and Asim et al. [9] investigated the fatigue behavior of laser welds in lap-shear specimens of high strength low alloy (HSLA) steel sheets based on the closed-form and computational stress intensity factor solutions.

In this paper, the failure mode and fatigue behavior of dissimilar laser welds in lap-shear specimens of low carbon steel and high strength low alloy (HSLA) steel sheets are investigated based on experimental observations. Micro-hardness tests across the weld zones of dissimilar laser welds were conducted. Optical micrographs of the welds before and after failure under quasi-static and cyclic loading conditions are examined to investigate the microstructure and failure mode of the welds. Finally, conclusions are made.

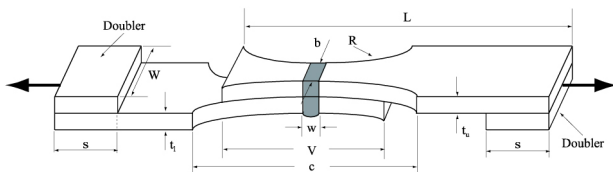
EXPERIMENT

Low carbon steel and SAE J2340 300Y non-galvanized HSLA steel sheets were used for the upper and lower sheets of lap-shear specimens, respectively. The thicknesses of the upper low carbon steel and lower HSLA steel sheets were 0.65 and 0.91 mm, respectively. The arrangement of the low carbon steel and lower HSLA steel sheets follows the convention such that the lower sheet is thicker than the upper sheet. The steel sheets were then sheared into 275 mm by 27 mm strips to make lap-shear specimens. The lap-shear specimens were made by using a 6 kW CO₂ laser shielded by Helium gas at a welding speed of 8 m/min. Note that the laser beam was incident on the HSLA steel sheet and the two sheets were welded together. The specimen geometry followed the guidelines of the ASTM E 466-07 standard for the mechanical testing of welds. The objective of the reduced width for the central portion of the specimen was to investigate the failure mechanism in the vicinity of the laser welds and to avoid the failure of the specimen due to the necking of the specimen sheets far away from the laser welds. Specimens with reduced width for the central portion were used for the study of laser welded joints, for example, see Sripichai et al. [8] and Asim et al. [9].

Figs. 1(a) and 1(b) show a top view and a schematic of a laser welded lap-shear specimen. The geometric dimensions of the specimen are shown in the figures. As shown in Fig. 1(a), the average weld width is about 1 mm, which is quite narrow compared with other conventional welding processes. As shown in Fig. 1(b), two doublers with a length of 25 mm were used for aligning the fixtures to avoid the initial realignment of the specimen. The loading direction was indicated by two bold arrows on the right and left sides of the specimen. These bold arrows were also used to indicate the loading directions in the subsequent figures.



(a)

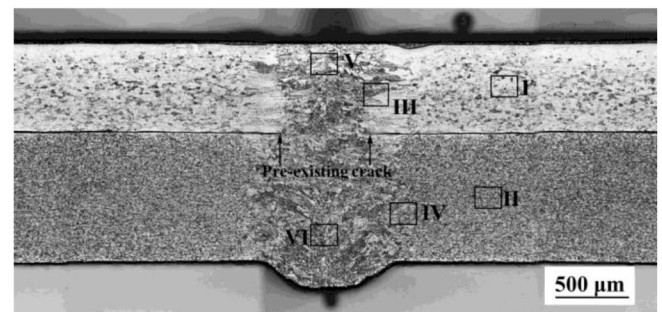


(b)

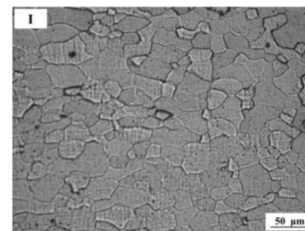
Figure 1. (a) A top view and (b) a schematic of a lap-shear specimen with the loading direction shown as the bold arrows.

Fig. 2(a) shows an optical micrograph of the cross section of a laser weld in a lap-shear specimen. Note that the weld protrusion is located on the bottom of the laser weld since the laser beam is incident on the lower HSLA steel sheet. As shown in the figure, the laser weld appears to be free of porosities and other welding defects, such as cracks and voids. Three different regions can be identified from the micrograph based on their distinct grain structures, namely, the base metal (BM), the heat affected zone (HAZ), and the fusion zone (FZ).

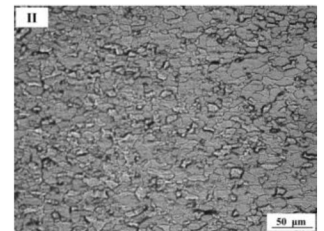
A close-up view of the three regions for both steels can be seen in Figs. 2(b), 2(c), 2(d), 2(e), 2(f), 2(g). In the BM regions, as shown in Figs. 2(b) and 2(c), the grain size of the upper low carbon steel sheet is larger than that of the lower HSLA steel sheet. As shown in Fig. 2(a), the HAZ between the FZ and BM is quite narrow and has a mixture of fine and coarse grains. In the HAZ regions, as shown in Figs. 2(d) and 2(e), the coarse grains indicate the grain growths in these regions due to the welding process. The span of this narrow HAZ varies from 0.05 to 0.17 mm located on both sides of the FZ along the thickness direction. In the FZ regions, as shown in Figs. 2(a), 2(f), and 2(g), long columnar grains with complex dendrite structures can be seen. The width of the FZ is about 0.62 mm along the plane between the pre-existing crack tips.



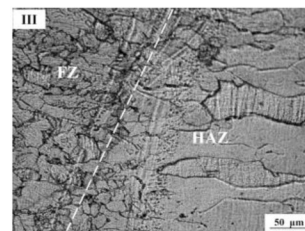
(a)



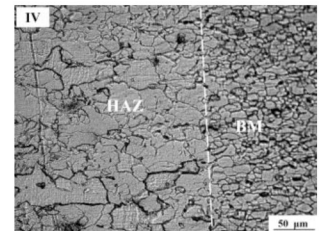
(b)



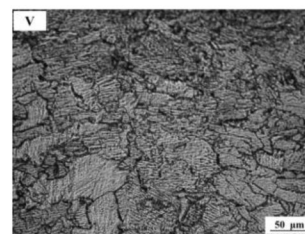
(c)



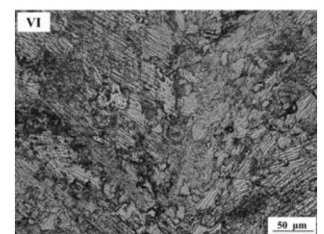
(d)



(e)



(f)



(g)

Figure 2. (a) An optical micrograph of the etched cross section of a laser weld in a lap-shear specimen, and close-up views of (b) the BM of the upper low carbon steel sheet, (c) the BM of the lower HSLA steel sheet, (d) the HAZ of the upper low carbon steel sheet, (e) the HAZ of the lower HSLA steel sheet, (f) the FZ of the upper low carbon steel sheet, and (g) the FZ of the lower HSLA steel sheet.