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ScienceDirect
International Journal of Fatigue 29 (2007) 421–434
International Journal of Fatigue
www.elsevier.com/locate/ijfatigue

Laser and shot peening effects on fatigue crack growth in friction stir welded 7075-T7351 aluminum alloy joints

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Received 4 April 2006; received in revised form 12 May 2006; accepted 21 May 2006
Available online 24 July 2006

Abstract

The influence of shot and laser peening on the fatigue crack growth behavior of friction stir welded (FSW) aluminum alloy (AA) 7075-T7351 sheets was investigated. The alterations resulting from this surface modification on the fatigue crack growth of FSW were characterized and evaluated for two different crack configurations. A systematic investigation of the various peening effects indicated a significant decrease in fatigue crack growth rates resulting from using laser peening compared with native welded and unwelded specimens. In contrast, shot peened specimens did not result in a significant reduction in fatigue crack growth. The fatigue striation spacings for the laser peened specimens were assessed and found to be small compared with the unpeened, and shot peened specimens. The reduction in striation spacing indicates a slower fatigue crack growth rate and is partially attributed to the deeper compressive residual stresses induced by the laser peening.
Published by Elsevier Ltd.

Keywords: Friction stir welding; Laser peening; Shot peening; Fatigue crack growth

1. Introduction

Friction stir welding (FSW) (illustrated in Fig. 1) was developed by The Welding Institute in England in 1991 [1]. Since then, this technique has emerged as a promising solid state process for joining materials with encouraging results, especially when used on high strength aerospace aluminum alloys that are usually difficult to weld [2]. The use of FSW is becoming more popular due to the advantages it offers compared with other conventional fusion welding techniques. The capability of FSW to weld high strength aluminum alloys like AA 7000-series has resulted in welded joints being used in critical load bearing structures, and is being used by modern industries for structurally demanding applications [3].

The magnitude of the residual stresses in FSW typically are considerably less than those in fusion welds since FSW takes place at a lower temperature than fusion welding. However, the rigid clamping arrangement used in FSW, along with the heating cycle the material experiences during welding, can still significantly affect residual stresses in FSW [4,5].

These residual stresses can significantly affect the service performance of welded materials by facilitating the fatigue crack growth process [6] and lowering fatigue life by affecting by crack nucleation. Although relatively low, tensile residual stresses do exist after friction stir welding. This has instigated the need for techniques and methods that can alleviate the residual stresses in welded components.

Several studies [7–18] have investigated the fatigue behavior of FSW aluminum alloys, but none of these studies has focused on the effects of laser peening on welded fatigue crack growth specimens. Laser peening (LP) is a technique with the capability to introduce a state of residual

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0142-1123/$ - see front matter. Published by Elsevier Ltd.
doi:10.1016/j.ijfatigue.2006.05.007

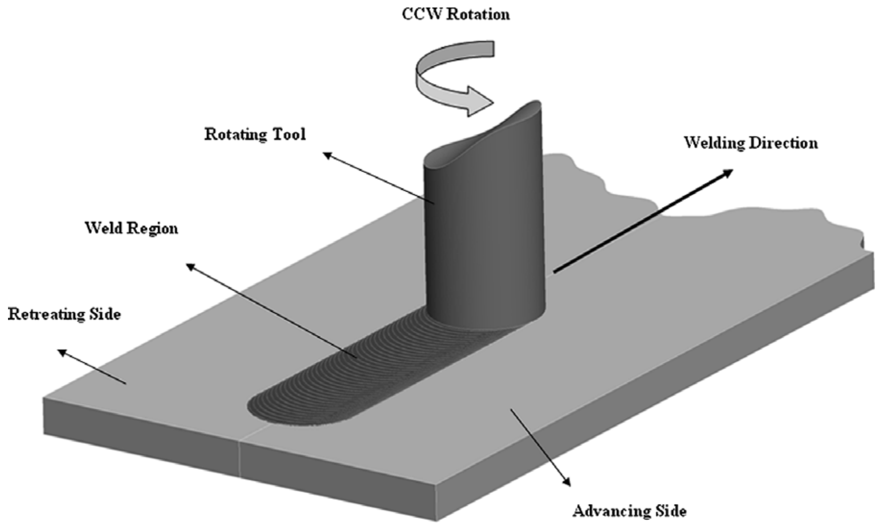

Fig. 1. Principle of the friction stir welding process.

compressive stresses that can significantly increase fatigue properties [19,20]. The depth of the compressive stresses below the surface produced by laser peening can be controlled by using successive shocks. Previous research [21,22] has shown that the residual stress resulting from laser peening can be significantly higher and deeper than for conventional shot peening.

In this study, the surface modification techniques of laser peening and shot peening were used to introduce compressive residual stresses into FSW AA 7075-T7351 specimens. Changes in fatigue crack growth resulting from different peening techniques was assessed and evaluated. The effects of crack orientation with respect to the weld have been explored, and fatigue striations were assessed for various conditions and locations along the crack path.

2. Experimental procedure

The aluminum alloy 7075-T651 was used in this investigation. AA 7075 is a precipitation-hardened aluminum alloy widely used in aerospace applications due to its high strength. The 7075-T651 was supplied as a 0.635 cm plate with mechanical properties as shown in Table 1.

The FSW specimens for this investigation were made using a five axis computer numerically controlled (CNC) milling machine at the NASA Johnson Space Center. The rotational speed used to weld the plates was 350 RPM in the counterclockwise direction, and the translation speed was 2.54 cm/min. The welding direction was aligned with the rolling direction. The FSW panels produced by NASA were $122\ \text{cm} \times 40\ \text{cm} \times 0.635\ \text{cm}$. Following the welding process, the welded plates were aged from the T651 condition to the T7351 condition. The FSW puts the weld nugget microstructure in a supersaturated solid solution condition; therefore, heat treatment is necessary to prevent the welded material from continuing to age at room temperature [23,24].

Table 1
Tensile properties for the as received AA 7075-T651

Material	0.2% Yield stress (MPa)	Ultimate strength (MPa)	Total elongation (%)
7075-T651	534	601	11

Following the heat treatment, the welded plates were inspected using radiographic and penetrant inspections. The inspection results did not reveal any indication of voids or defects in the weld. After that, bending tests using strip specimens with dimensions of $17.8\ \text{cm} \times 2.54\ \text{cm}$ were done. Both the root and the crown sides of the weld were tested to evaluate the quality of the weld. The samples were inspected visually afterward with no crack indications revealed.

Before the peening process was applied, the specimens were milled on the top side of the weld removing about 0.4 mm of material. M(T) specimens with dimensions in accordance with ASTM E647 were then machined using a CNC machine. Two crack orientations were investigated as shown in Fig. 2. In the first configuration, the starter crack was parallel to the weld line. In the second configuration, the crack was perpendicular to the weld line and centered in the weld nugget.

Fatigue crack growth specimens were either shot-peened or laser peened. Unpeened samples were also retained for comparison. Shot peening was accomplished using 0.59 mm glass beads with an Almen intensity of 0.008–0.012 A and a 100% coverage rate. The impinging shots were fired at the surface of the specimens at an angle in order to avoid collision with the rebounding balls.

The laser peening process (shown in Fig. 3) utilizes high energy laser pulses (several GW/cm^2) fired at the surface of a metal coated with an ablative film, and covered with a transparent layer (usually water). As the laser beam passes through the transparent layer and hits the surface of the material, a thin layer of the ablative layer is vaporized. The vapor continues to absorb the remaining laser energy and is heated and ionized into plasma. The rapidly expanding plasma is trapped between the