THERMOGRAPHICAL ANALYSIS OF FRICTION STIR WELDING AND LASER ASSISTED FRICTION STIR WELDING

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Summary: *Friction Stir Welding (FSW), developed at The Welding Institute (TWI) in 1991, is a new solid-state welding process. In this technique, the material does not reach the fusion but the joint is the consequence of the plasticization resulting from the generation of heat by friction and the stirring action of the pin on the material due to the rotation and the displacement of a non-consumable tool. Thus, the FSW reaches temperatures lower than those reached by conventional fusion welds. Laser Assisted Friction Stir Welding (LAFSW) is a combined welding technique in which the FSW is assisted, during the weld, by the pre-heating of a de-focalized laser. This technique leads higher welding speeds, lower clamping force and it has some benefits for tool wear. Nevertheless the control of the temperature field is fundamental to guarantee a high quality joint. In this work FSW and LAFSW bead on plate tests were conducted on 6 mm thick 5754 H111 aluminum alloy plates with constant tool rotation and welding speed. Thermographic images were acquired to compare the effect on the temperature field of laser source distance from the tool and laser power.*

Keywords: *friction stir welding, laser assisted friction stir welding, thermography*

1 Introduction

Friction stir welding (FSW) is a new welding technique, developed in 1991 by The Welding Institute (TWI), with potential application in bridge construction, shipbuilding, offshore platforms, aerospace, railway and automotive industry [1]. The process consists in a rotating tool that is driven into the material and, after a period of stationary rotation to heat the material (dwell time), it is translated along the welding line to carry out the weld. This one is the combined result of the plasticization of material due to the generation of heat by friction and the stirring action of the pin due to the rotation and the displacement of the tool [2]. Initially, FSW has been used for aluminum alloys due to their low weldability by conventional welding techniques [1]. In recent years, in order to use FSW on materials with higher melting point than aluminum or light alloys in general (e.g. titanium, steel [3]), laser assisted friction stir welding (LAFSW) has been developed and studied. In this technique (Figure 1), a defocused laser beam precedes the FSW tool during welding, increasing the temperatures reached in front of the tool and allowing an easier advancement of the same. Furthermore, LAFSW can reduce the residual stress in materials where FSW technique is already commonly used [4]. The temperature distributions and the thermal histories have an important role in FSW. It determines whether the welding process will produce a good weld influencing the residual stress, the microstructure and the strength of welds. Xu et al. [5] found that temperatures rise with the rotational speed and decrease with the traverse speed. They also noted that the tensile and yield strength of the weld joints increase with the rotational speed while the percentage of elongation decreases. Several studies have measured temperatures in FSW using thermocouples [5, 6] but only a few have been involved in experimental analysis using thermography [7] and

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still less on laser assisted friction stir welding. The objective of this study is to investigate the influence of the distance between laser spot and FSW tool and of the laser source power on the temperature reached in the front zone tool. To this purpose, one FSW and three LAFSW bead on plate tests have been carried out by a 4 kW Ytterbium fiber laser coupled with a 4 kW power FSW machine. The tests have been conducted on 6 mm thick 5754 H111 aluminum alloy plates with constanttool rotation, dwell time and traverse speed. During the tests, the temperature fields and thermal histories have been recorded by an infrared camera.

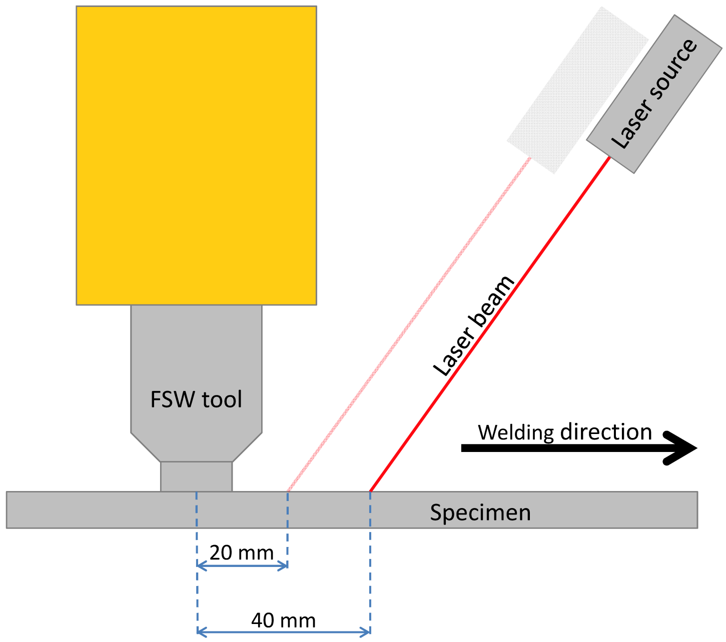


Figure 1: Location diagram of the laser source

2 Material and methods

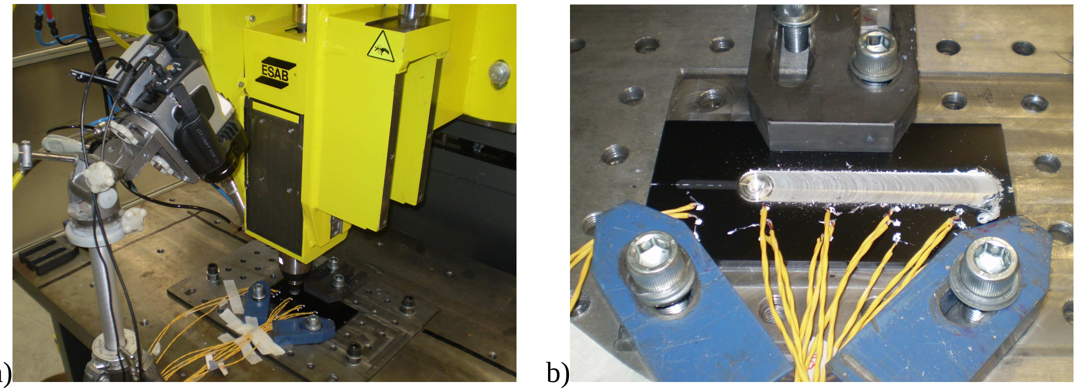
In this work, a FSW and three LAFSW bead on plate tests has been carried out. During the test only laser power or laser spot - FSW tool distance have been changed while tool rotation, dwell time and traverse speed have been kept constant. The trials have been conducted on aluminum 5754 H111 sheets, 200 mm length, 100 mm width and 6 mm thick. Table 1 lists the process parameters used in the experimental tests for the FSW and the LAFSW. The test with laser power 1000 W and 20 mm distance has not been performed because the temperature reached in this case exceeded the temperatures range of the thermo-camera.

Table 1: Process parameters

Designation	Laser power [W]	Dist.laser-FSW tool [mm]	Traverse speed [cm/min]	Dwell time [s]	Rotational speed [rpm]
FSW	-	-	20	3	500
500W/40	500	40	20	3	500
1000W/40	1000	40	20	3	500
500W/20	500	20	20	3	500

The temperature field has been acquired, during the welding process, by the infrared camera NEC H2640 (Range 0-$2000\,^{\circ}\mathrm{C}$; Resolution $0.06\,^{\circ}\mathrm{C}$; Accuracy $\pm 2\,^{\circ}\mathrm{C}$ or $\pm$2%). Figure 2a shows the experimental setup.

The infrared camera has been placed normally to the weld direction, in front of the FSW machine. The optical axis of the camera has been placed with an angle of 60° respect the horizontal direction. To reduce the reflection of the aluminum and increases the emissivity of the surface, the specimen has been painted with matte black acrylic spray paint (Figure 2b). An emissivity of $\epsilon = 0.95$ has been set on the camera.



a) b)

Figure 2: Experimental setup (a) and bead on plate specimen example (b)

3 Results

The Figure 3 shows the thermographic comparison, in four different instants, between the welded specimens. t1 is the end of dwell time, t2 and t3 are intermediate phases and t4 is the instant before extracting the tool.

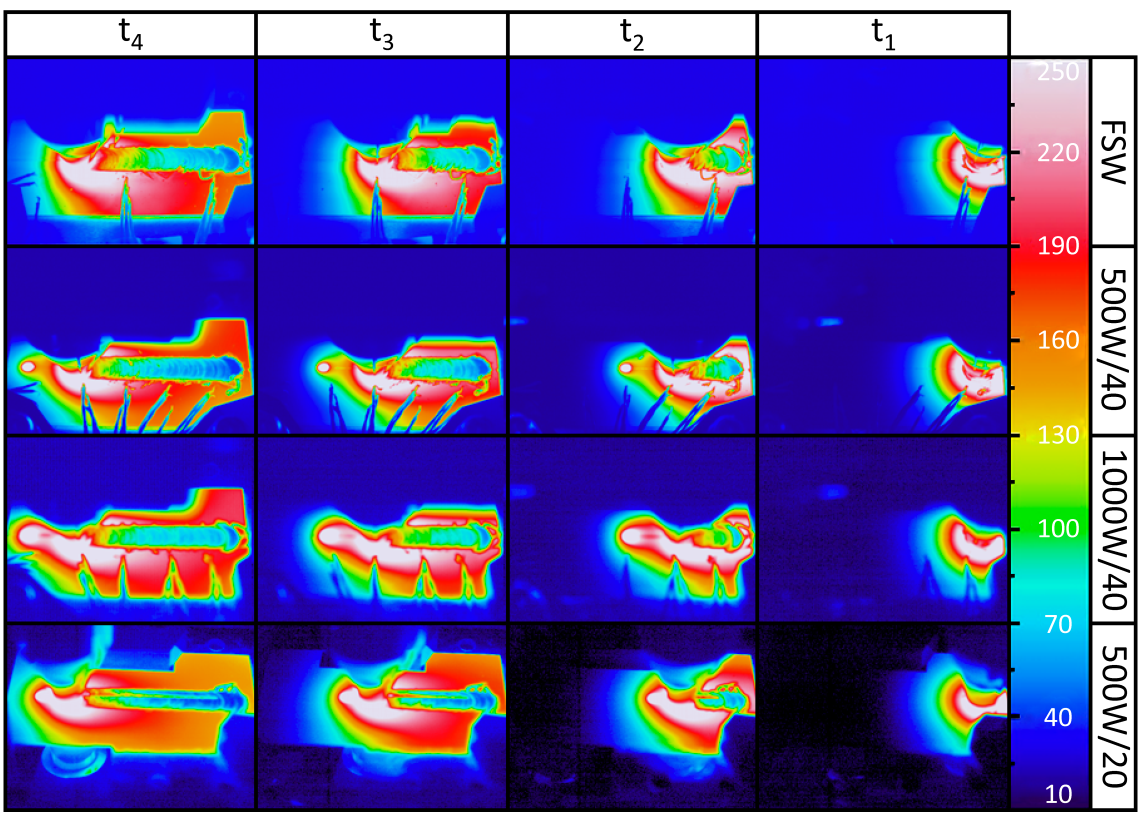


Figure 3: Comparison between the thermography results of the welded specimens in four different instants

The white area in the Figure 3 describes the zone of the specimens where the temperature exceeds $250\,°\mathrm{C}$. This value has been chosen because it is slightly above the temperature ($200\,°\mathrm{C}$) reached by the FSW in the area of the tool (Figure 4). In this way it has been visually identified the area in front of the tool which is influenced by laser. Furthermore, the temperature on the bead is due to the variation of the emissivity after the transit of FSW tool. This is due to the paint removal and change of roughness of the surface of the specimens. The figure shows that for the 500 W/40 and less for 1000 W/40 the temperature between laser spot and FSW tool decreases rapidly at values under $250\,°\mathrm{C}$. This implies that the pre-heating effect of the laser is vanished. This is due to the high conductivity of aluminum and the excessive distance of the FSW tool from the laser spot. The graphic reported in Figure 4 highlights this behavior. Along the welding line, the effect of 500 W and 1000 W laser power at a distance of 40 mm, in the zone near the tool (indicated by A), produces a slight increase of temperature than the traditional FSW. Instead, reducing the distance of the laser spot to 20 mm produces, also with 500 W laser power, a considerable increase of temperature in the front zone of the tool.

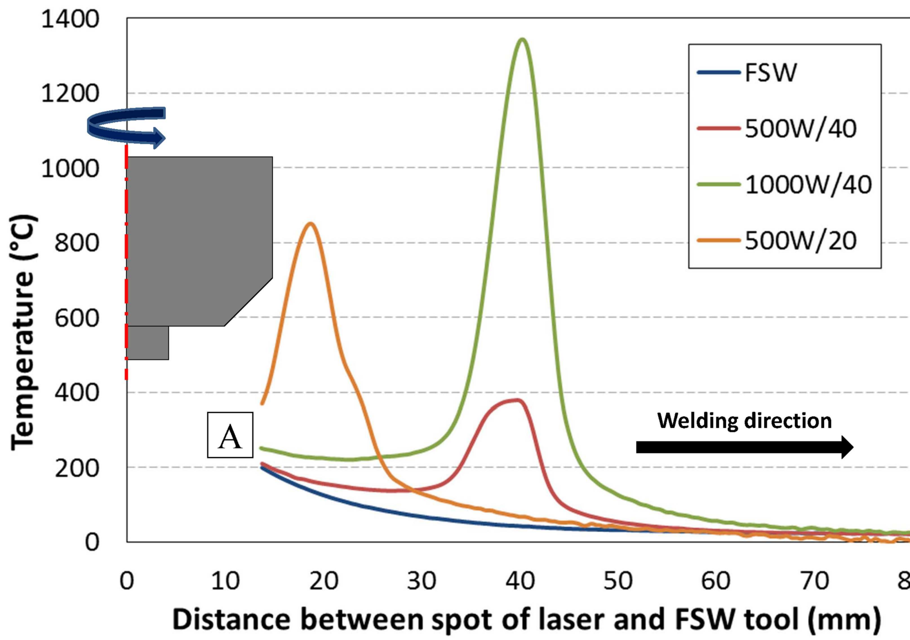


Figure 4: Temperature comparison along welding line in front of FSW tool

4 Conclusion

In this work the influence on the temperature reached in the front zone tool of the distance between laser spot and FSW tool has been studied. It has been shown that, due to the high conductivity of aluminum, the distance of 40 mm is excessive (regardless of laser power) to produce a strong preheating effect on the specimens. Instead, it has been shown that a 20 mm distance is good choice for the aluminum alloy. The higher preheating effect with the 20 mm distance should reduce the residual stress in the welds in a stronger manner than that shown by Campanelli et al. [4].

References

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