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Effect of Rotating Speed of Probe on Micro-Hardness, Tensile Strength, Fatigue Behavior and Failure Modes of Friction Stir Spot Weld of Al 6061-T6 of Lap-shear Specimens

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ABSTRACT: The friction stir spot welding of Al 6061-T6 alloy is experimentally studied to determine the behavior of micro-hardness, static strength and fatigue behavior of the lap shear specimens by changing of the rotational speed at three different values. Micro-hardness results show similarity in the regions far from the shoulder indentation region. By the static strength and fatigue results, the optimal behavior of the rotational speed is determined. Therefore, the speed of 1000 rpm shows much better mechanical behavior than the other conditions of this study. The fatigue results of different welding conditions demonstrate, in the same cycles, more divergences in the lower cycles than, the higher ones. Two different failure modes have been observed at different load levels. At high load levels, final failure was nugget pull out. At low load levels, the final failure was the crack growth transverse to the loading direction and separation from the plate. At medium load levels, although the final failure was similar to high load levels, the growth of the crack in the sheet outside the stir zone, just like low load levels, was also observed.

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1- Introduction

Mazda Company introduced the Friction Stir Spot Welding (FSSW) in 2003. In the displacement control FSSW system, different kinds of parameters such as rotational speed, holding time in the stirring step and depth of indentation have some effects on the quality and consequently on the mechanical behavior of FSSW [1, 2].

The rotational speed has been investigated as one of the parameters which can affect the mechanical behavior of the FSSW. In some previous studies, researchers claimed the increasing of speed decreased the static strength [2, 3]. Also, the researchers investigated the fatigue behavior of one specific welding condition and determined the other parameters such as life predictions, the geometry of pin and shoulder and comparison with other bonding methods [4-6].

In the previous studies, the rotational speed has not been investigated on static strength and fatigue behavior to determine the effect of speed on FSSW. So in this study, the micro-hardness, static strength and fatigue behavior of the three rotational speeds have been investigated and the fatigue failure has been discussed to extract the optimum welding condition.

2- Material & Specimen Preparation

sIn this investigation, Al 6061-T6 aluminum alloy in the form of a sheet with 2mm thickness has been used which has the yield stress of 276MPa and the ultimate tensile strength of 310MPa [7]. Lap-shear configuration has been utilized which was made by two 40 mm by 160 mm sheets. Also, a 40 mm by 40 mm area has been used for overlap. Two spacers with 40 mm by 40 mm have been attached to the end of samples (Fig. 1) to eliminate misalignment and the torsional moments. The welding tool was made from hot-work tool steel of H13. The apparatus had 6-degree concave shoulder and conventional pin with 14 mm and 6 mm diameters, respectively, also the pin length was 2.5 mm. Vertical CNC automated machining system is used for the welding process. In order to investigate the effect of rotational speed, three different speed of 500, 750 and 1000 rpm have been chosen. Although, the other parameters were taken constant values in all specimens with 4 seconds of stirring time and 3 mm of plunge depth.

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3- Experimental Procedures

Micro-hardness experiments have been performed with the indentation conditions of the 100gr force and 10s time. Tensile and fatigue experiments have been performed with a Zwick/Roell fatigue testing system. Static strength has been determined by 2 mm/min rate of loading at room temperature.

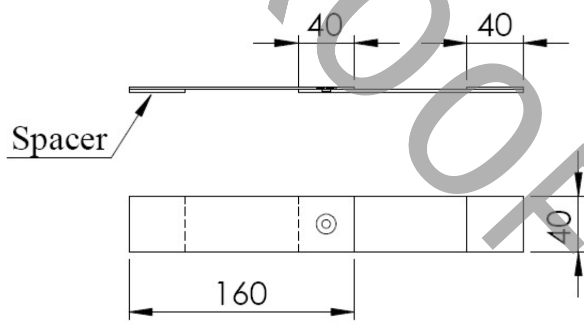

Figure 1. The geometry of lap-shear specimens.

The loading procedure has been continued until separation of the joint. Fatigue experiments have been performed at six different load levels with a sinusoidal stress ratio of 0.1 and a frequency of 10 Hz.

4- Results

The static shear strength has been determined by the average of three tested specimens for each welding condition. Fig. 2 compares the static strength of different welding conditions. It is clear that the speed of 1000 rpm causes the best static strength.

Fatigue tests have been performed at six various load levels considering the static strength of similar welding conditions. The life of each load level of different welding conditions is illustrated in Fig. 3. The fatigue results reveal that 1000 rpm welding condition can be introduced as the best welding condition.

According to the symmetry of the process around the tool axis, micro-hardness distributions on two sides of cross-section would be similar so, micro-hardness results have been obtained on the half side of the welding. Fig. 4 illustrates the distributions of micro-hardness in the different welding conditions.

5- Discussion

Results of the static experiments show that the speed of 1000rpm has the highest strength. Also, the percentage of increase strength between 1000 and 750rpm is more than 750 and 500rpm welding conditions.

According to the fatigue results, 1000 rpm condition has the optimum behavior at all load levels. Also, the slope of the trend line of 1000rpm gets steeper than the two other conditions and this can be a result of different failure modes in various load levels. At high load levels, the failure is the shear fracture at the stir zone. The stir zones have different mechanical properties due to the different welding process. However, at low load levels, the final failure is the transverse crack growth. Fig. 5 compares the two different failure modes. The micro-hardness profiles show that the differences between different welding conditions from stir zone to shoulder indentation is significant. However, after the indentation shoulder zone, the profiles get close to each other. This behavior can be justified by the heat generated during the welding process which had a different value between various welding conditions.

6- Conclusions

In this paper the micro-hardness, static strength and the fatigue behavior of three different speeds of 500, 750 and 1000 rpm analyzed and the optimum behavior determined. The micro-hardness distributions show that far from the welding zone various welding conditions get close. The static and fatigue results show that the 1000 rpm condition is the optimum

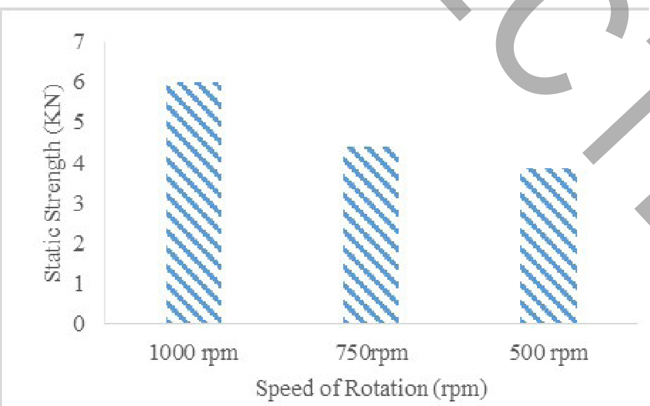

Figure 2. Comparison of the static shear strength of different welding conditions.

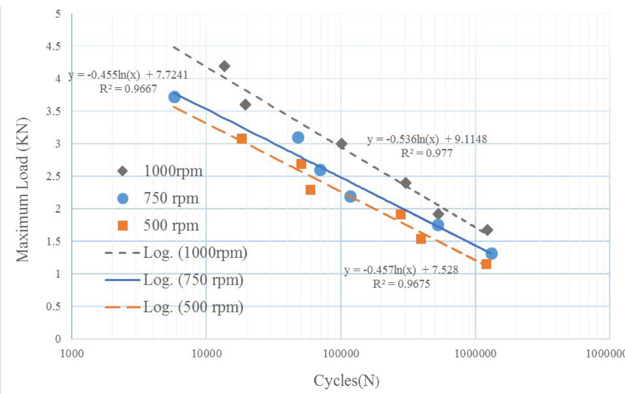

Figure 3. Fatigue results of different conditions.

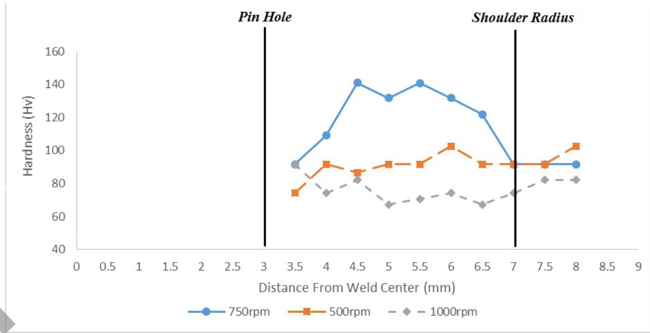

Figure 4. Fatigue failure surfaces of 1000rpm. Top: high load level. Bottom: low load level.

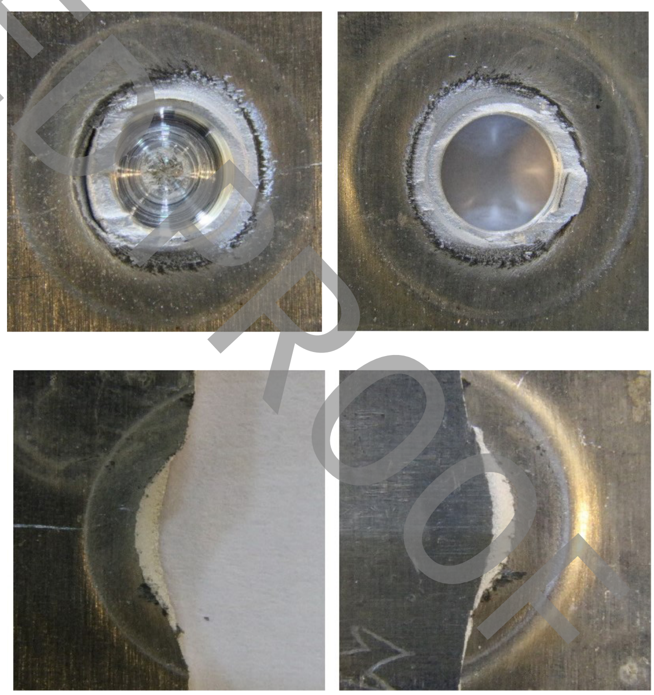

Figure 5. Fatigue failure surfaces of 1000rpm. Top: high load level. Bottom: low load level.

welding condition. Two failure modes were observed in fatigue specimens. At high load levels, the shear fracture is the main kind of failure. However, at low load levels, the final failure is the transverse crack growth.

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