Studying the Mechanical Properties for 5086 Aluminum Alloy Welded Plates by Friction Stir Welding (FSW)

Ismail Ibrahim Marhoon¹, Ahmed K Al-Kamal² and Mohammed Ali Abdulrehman³*

¹,²,³ Materials Engineering Department/Mustansiriyah University, Baghdad
* Corresponding Author: aljaraah_muhammad@yahoo.com

Abstract: This research emphasizes on friction stir welding (FSW) of 5086 aluminum alloy (AA), welded samples were prepared at different rotating speed 1500, 1700 and 1900 RPM at feeding speed of welding 60 mm/min. the mechanical properties of the joints such as the Micro-hardness and tensile strength of the joints were tested. According to experimental results, the joints mechanical properties were strongly affected by the welding parameter. The optimum results of the weld gained at 1700 RPM rotation speed and 60 mm/min weld speed and where the efficiency reaches up to 84% of the (UTS) ultimate tensile strength of the parent metal.

Keywords: Friction stir welding, AA 5086, Tensile property, Hardness property

1. Introduction
In FSW, the metal at high temperatures below the melting point subjected to plastic deformation as shown as a figure (1). Heat due to the friction is generated when the rotating tool is cast into the metal. Sever plastic deformation produced by rotating speed under high pressure and the interface of the weld mixed together by a probe which stirs to form homogenous structure. [1]

Figure 1. Schematic of FSW [2]

Figure (2) illustrates the FSW zones where the FSW zones are:
(a) Base metal: this region does not have any deformation where microstructure or mechanical properties don't influence by heat flux.
(b) Heat affected zone (HAZ): The microstructure or/and the mechanical properties have changed by a thermal cycle. However, this region does not undergo plastic deformation.
(c) Thermo-mechanically affected zone (TMAZ): The material in the TMAZ zone is subjected to a plastic deformation because of the effect of the tool and the heat flux. The aluminum does not undergo recrystallization in this zone, but only high deformation.
(d) Nugget zone: This region is the recrystallised zone for aluminium in the TMAZ. In this area, the grain boundaries and subgrain boundaries replace with equiaxed, fine recrystallized grains. [3]

![Figure 2. FSW zones](image)

Currently, rivet joints are replaced by FSW joints in order to minimize joint defect and time [4].

A rotational shouldered pin is forced into the interface of the two sheets to make an FSW lap joints, then the tool shouldered touches the upper surface of the sheet and transferring it to an appropriated direction which called the weld line [5].

Temp of sheets and thermal softening is raised at the upper sheet by rotating tool shoulder which happens under the effect of tool shoulder, so the sheet mix up by tool pin and mixed them both without melting.

One of FSW advantage is eliminating the defects of joints like porosities, grain boundary cracks and alloys segregations because of no melting occurs of the joints. Also, that makes FSW very adequate to join dissimilar alloys [6]. Currently, there are many type of research study the FSW dissimilar welding [7-11].

For instance, Saeid et al. [11] produced AA 1060 and copper sheet lap joint of 3 and 4 mm thick respectively using H13 tool of with 15 mm diameter of shoulder and a 15 mm diameter of the cylindrical threaded pin and 6.5 mm length.

Also, to adjust the normal load to the top of the sheet surface, position control was used. The inset depth of tool shoulder 0.2 mm, the speed of rotational altered between (750 to 1500 rpm) while the speed of welding varied between (30 to 375 mm/min).

1.1 *Aim of this work*

Studying the influence of speed of rotational on the mechanical properties of FS-Welded aluminum plates.

2. *Experimental work*

2.1 *Procedure of FSW*
AA 5086 plates of 150 mm length, width 75 mm and thickness 3 mm used as shown in Figure (3). The plate was fixed using a clamping fixture for the welding on a CNC milling machine as shown in Figure (4).

![Figure 3. Schematic of (FSW) for plates](image1)

A 16 mm diameter of shoulder (SD) cylindrical tool and diameter of 5 mm of pin (PD) \([SD = (3-3.5)PD]\) [12] was used as the welding tool of FSW, the height of pin is 2.9 mm as same as the distance of plunged in the plate of the sheets processed. The stirrer length is as same as the welding depth required. The stirrer was rotated at varied welding speeds and rotational with a persistent friction force as shown in figure (5).

![Figure 4. CNC milling machine](image2)
The tool pin is contacted on the surface of the workpiece and the tool rotation is controlled by digit control while the manual spindle is used to control welding speed. FSW process at a various rotation speed (1500, 1700, 1900 rpm) at 60 mm/min feed speed and the specimens to be tested were cut by CNC milling machine.

2.2 Tensile Test
Tensile strength was measured by using tensile test under 10 mm/min speed. Tensile test samples were prepared according to ASTM E 8M [13] specimen geometry standard as shown in Figure (6).

2.3 Hardness Test
Micro-hardness test was used to measure different regions of the FSW plate. The measurement took place at the center of the welds cross section at nine points (four points to the right of the weld, four points to the left of weld region and the ninth point at the center of the welded zone) for each sample with different rotation speeds by using micro-hardness device as shown in fig 7.
2.4 Bending Test
Bending test of Aluminum is done by TESTOMETRIC instrument as shown as in Figure (9). A milling machine was used to produce the specimen. Ductility and toughness were studied by using Face and Root end tests which passed 90°bend test.

2.5 Radiographic Test
X-ray is used to detect the discontinuities using the recording medium. X-Ray result is shown in Figure (10).
3. Results and Discussion
Tensile and microhardness tests were used to measure the quality of FSW welding

3.1 FSW Results
Figure (10) shows the upper appearance for FSW joints for different samples at various rotation speed and the whole welding lines have a very good appearance by visual examination.

3.2 Tensile Results
UTS values of the welded specimens and the base metal are shown in figure (11) and the efficiency of each case was compared with the base metal are shown in figure (12).
The optimum value was obtained at 60 mm/min welding speed and 1700 rpm rotating speed for both FSW, it was 260 MPa for ultimate tensile strength and the efficiency was 84% of welding line as compared with base metal. Therefore, FSW is considered an effective method and it gives long life welds due to the modification of microstructure which leads to the improvement of mechanical properties, Note from the above results that the role of the FSW is in the welding and connect
between the two pieces with the softening of the granules in the welding area, resulting in a
great convergence of results with the original alloy.

3.3 Micro hardness results
The relation between the microstructure and the mechanical properties of the weld can be determined
by hardness profiles. Each specimen is divided by dividing for testing, and the duration of each point
was 10 seconds in hardness Vickers (HV). The values are recorded and the other points are measured
respectively and. The distance between each two points is 2 mm. The results for FSW at 1700 RPM
and 60 mm/min for AA 5086 were presented in Figure (13)

![Figure 13. Hardness profiles of FSW](image)

For figure (13) the hardness results at different positions of the processed area varied. The
hardness values at the nugget zone are higher than other zones and NZ at (-1-1 mm) and thermal
mechanical affected zone (TMAZ) at (1.1-5 mm) and heat effected zone (HAZ) at (5.1-8 mm), and
the hardness decreases as going farther from nugget zone till it reaches its minimum at heat affected
zone and then increases again The results of hardness show the differences in the values depend
on the size of granules, which depends on the difference in temperature [14]

Micro-hardness is decreased by FSW due to the decreasing of the displacement density. Dynamic recrystallization is caused by total rotation and feed rate and leads to form new grain giant. [14]

3.4 Bending Results
FSW mold of 5068 aluminum alloy at the 1700 rpm and 60 mm/min was showed the best results
regarding the ductility. Many of FS Al alloys can be formalized because they did not fail in the bent
test.

The results are shown in fig 14, 15, and 16 for the base sample, face FSW, and root FSW
respectively.
Fig 17 shows the results for the samples which failed in bend test due to inappropriate mixing and insufficient downward face which leads to the lack of the tool face and/or position of the feedback system.

**Figure 14.** Face base metal bending sample

**Figure 15.** Face bending FSW sample (1700 rpm, 60 mm/min)

**Figure 16.** Root bending FRW sample (1900 rpm, 60 mm/min)
3.5 X-Ray Radiographic Results

X-ray result of FSW sheets is shown in Figure (18).

Figure 18. Radiographic sample welded by FSW on 1700 rpm, 60 mm/min.

The radiation test of the welding area shows that there are no areas of weakness or cracks in the welding area, which enhances the mechanical results indicating the high welding efficiency.

4. Conclusions

1- The highest strength of AA 5086 for FSW at (1700 RPM and 60 mm/min) with the values of 260 MPa for FSW and 84 % the percentage of efficiency improvement by using FSW.

2- The highest Vickers hardness values of 5086 AA are 135.7 for FSW.
3- The FSW is enhanced by the microstructural properties at zones of welding especially nugget zone which it produced grain refined of the microstructure.

5. References

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