Effect of Friction Stir Processing (FSP) to the Mechanical Properties of 7075-T73 Aluminum Alloys Plates Welded by Friction Stir Welding.

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Abstract:

Friction stir processing is a new method of changing the properties of a metal through intense, localized plastic deformation ,this process mixes the material without changing the phase (by melting or otherwise) and creates a microstructure with fine, equiaxedgrains , It is used to improve the microstructural properties of metals.

In this paper , the enhancement of mechanical properties of friction stir welding specimens at variable rotation speeds (1500,1700 and 1900 rpm) with constant feed speed(40mm/min) for 7075-T73 aluminum alloy is studied by using the friction stir processing method at the same variable rotation speed and feed speed in order to transform a heterogeneous microstructure to a more homogeneous, refined microstructure.

The best results of the weld gained at the parameter 40 mm/min weld speed and 1700RPM rotation speed for the friction stir welding (FSW) and friction stir processing (FSP) where the efficiency reaches to 83.7% for FSW and 92.99% for FSP of the ultimate tensile strength of the parent metal.

Keywords : friction stir welding (FSW) , friction stir processing(FSP) , rotating speed , microstructure ,efficiency , Micro hardness .

تأثير معالجة للحام الاحتكاكي للمزج (FSP) على الخواص الميكانيكية لسبائك الألمنيوم من نوع 7075-T73 الملحومة بواسطة اللحام الاحتكاكي للمزج

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الخلاصة :

تعتبر طريقة معالجة المزج الاحتكاكي من الطرق الحديثة لتحسين خصائص المعادن في هذه العملية يتم مزج المواد دون اي تغيير في الأطوار (عن طريق انصهار أو غير ذلك) و يتم استخدام تلك الطريقة لتحسين خصائص البنية ألمجهريه للمعادن.

في هذه الدراسة ، تم قياس الخواص الميكانيكية لعينات لحام المزج بالاحتكاك بسرعات متغيرة (1700، 1500 و 1900 دورة في الدقيقة) مع سرعة تغذية مقدارها (40ملم / دقيقة) لسبائك الألمنيوم من نوع 7075-T73 و من ثم تم استخدام طريقة المعالجة بالمزج الاحتكاكي لنفس سرع الدوران وسرعة تغذية المستخدمة في اللحام بالاحتكاك من أجل تحويل البنية ألمجهريه إلى بنية مجهريه أكثر تجانسا.

و كانت أفضل نتائج لخط اللحام عند سرعة خطية مقدارها 40 مم / دقيقة و سرعة دوران 1700دورة / دقيقة بالنسبة للحام المزج بالاحتكاك وكذلك عند المعالجة بالمزج بالاحتكاك حيث كانت الكفا٪ة لـ 83.7 ٪ و 92.99 ٪ على التوالي و قد تم حساب الكفاءة اعتمادا على أقصى مقاومة شد للمعدن الأساسي.

1. Introduction

Friction stir processing (FSP) is a new microstructural modifications technique; recently it FSP has become an efficient tool for homogenizing and refining the grain structure of metal sheet. Friction stir processing is believed to have a great potential in the field of superplasticity in many aluminum alloy (AA)[1].

FSP is a solid-state process which means that at any time of the processing the material is in the solid state. In FSP a specially designed rotating cylindrical tool that comprises of a pin and shoulder that have dimensions proportional to the sheet thickness. The pin of the rotating tool is plunged into the sheet material and the shoulder comes into contact with the surface of the sheet, and then traverses in the desired direction. The contact between the rotating tool and the sheet generate heat which softens the material below the melting point of the sheet and with the mechanical stirring caused by the pin, the material within the processed zone undergoes intense plastic deformation yielding a dynamically-recrystallized fine grain microstructure[2] as show in **Figure (1).**

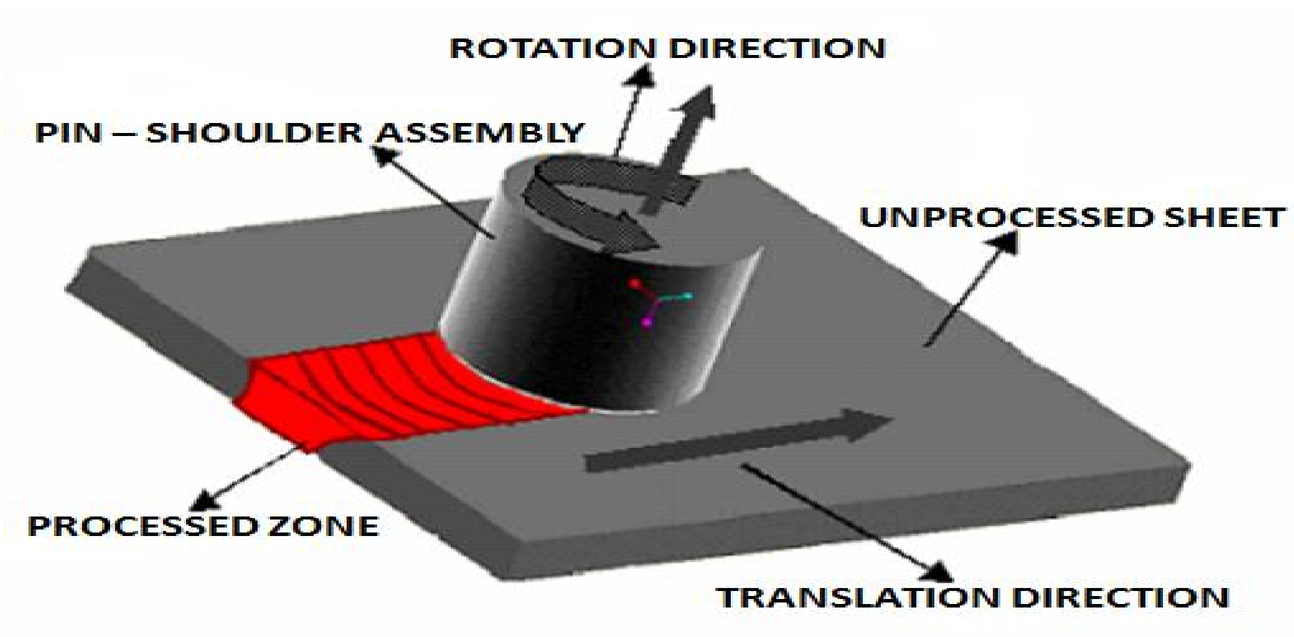


Fig .(1) Schematic of friction stir processing(FSP)[3]

The FSW and FSP zones are (a) Base metal , No material deformation has occurred; such remote material has not been affected by the heat flux in terms of microstructure or mechanical properties.

(b) Heat affected zone (HAZ). In this region the material has undergone a thermal cycle which has modified the microstructure and/or the mechanical properties. However, no plastic deformation occurred in this area.

(c) Thermo-mechanically affected zone (TMAZ). In this area, the material has been plastically deformed by the tool, and the heat flux has also exerted some influence on the material. In the case of aluminum, no recrystallization is observed in this zone; on the contrary, extensive deformation is present.

(d) Nugget. The recrystallised area in the TMAZ in aluminum alloys is generally called the nugget. In such zone, the original grain and subgrain boundaries appear to be replaced with fine, equiaxed recrystallized grains characterized by a nominal dimension of few micrometers.[4]

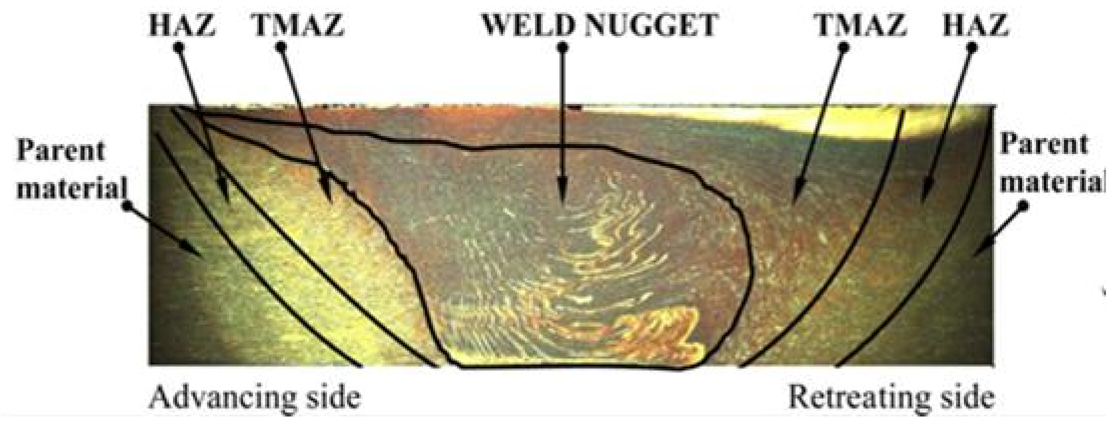


Fig .(2) FSW and FSP zones[5]

In this study 7075-T73 AA was selected , and it is selected because have high characteristics and widely applications Characteristics and applications of 7075 are: Very high strength material used for highly stressed structural parts. The T7351 temper offers improved stress-corrosion cracking resistance[6] , and T73 is means solution heat treated and then specially artificial aged . applies to 7075 AA which have been specially aged to make material resistant to stress-corrosion [7] .and applications: Aircraft fittings, gears and shafts, fuse parts, meter shafts and gears, missile parts, regulating valve parts, worm gears, keys, aircraft, aerospace and defense applications; bike frames, all terrain vehicle (ATV) sprockets[8].Study the mechanical properties of FSW and FSP and explain the enhancement of this properties by using FSP was clarified in detail for this alloy in present study.

2. Experimental work

2.1 Procedure of FSW and FSP

FSW and FSP were made on the 7075-T73aluminum alloy plates 3 mm thickness, 200 mm length, and 75 mm width as show in **Figure (3),** a clamping fixture was utilized in order to fix the specimens to be welded on a MITSUBISHI CNC M70V milling machine **Figure.(4).** And the standard mechanical properties and chemical composition of 7075-T73 AA of the present work and standard are given in (**Table 1)** and (**Table 2**) respectively.

Table .(1) Mechanical properties of 7075-T73 AA

	Ultimate strength(MPa)	Yield strength(MPa)	Modulus of elasticity(GPa)
Standard[9]	462	386	72
Measured	466.366	389.5	72.5

Table .(2) Chemical Composition of 7075-T73 AA

	Zn	Cu	Fe	Mg	Mn	Ti	Si	Cr	Al
Standard[9]	5.1-6.1	1.2-2.0	Max 0.5	2.1-2.9	Max 0.3	Max 0.2	Max 0.4	0.18-0.28	Balance
Measured	5.56	1.85	0.43	2.46	0.27	0.09	0.25	0.192	Balance

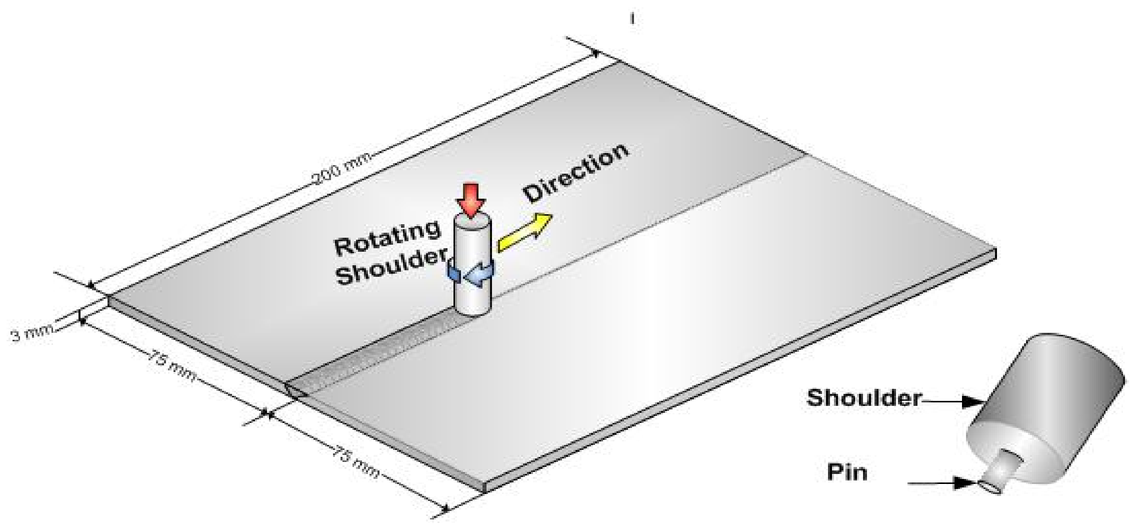


Fig .(3)Schematic of friction stir welding (FSW) for plates

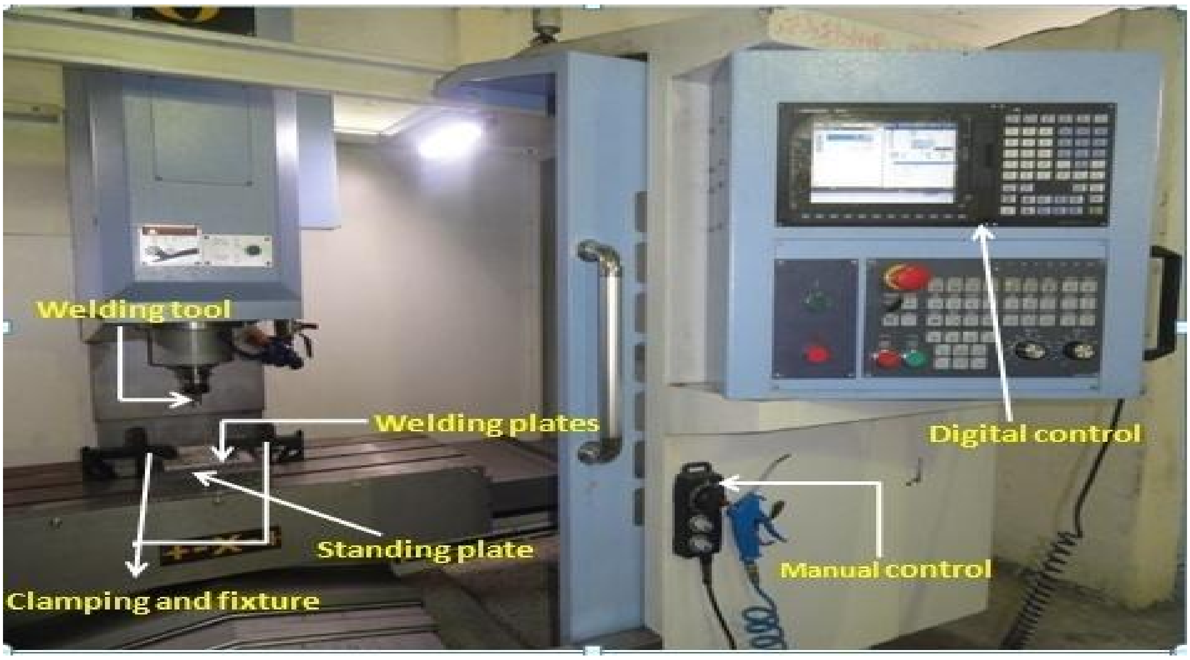


Fig .(4) MITSUBISHI CNC M70V milling machine

The initial FSW&FSP tool designed was a simple cylindrical tool with 16 mm shoulder diameter (SD) and 5 mm pin diameter (PD) [as SD =(3-3.5)PD[10]], height of the pin equal to the distance that plunged in the plate and it was 2.9 mm of the sheets processed the length of the stirrer was same as the required welding depth. The welding process was carried out by rotating the stirrer at different rotational and welding speeds under a constant friction force as show in **Figure (5).**

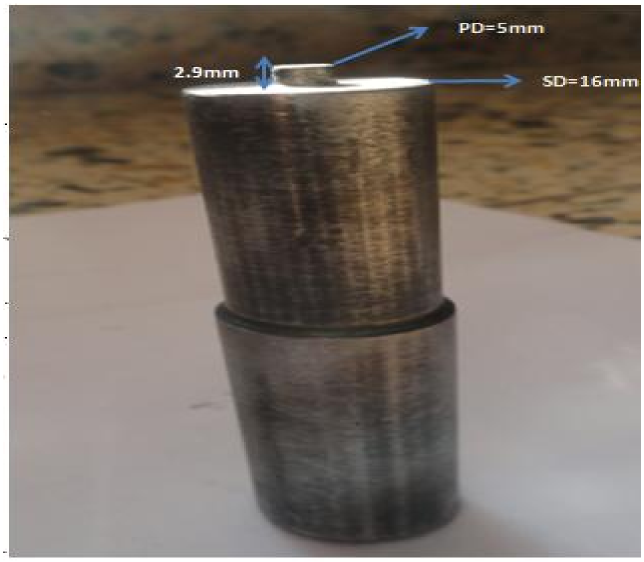


Fig .(5) FSW&FSP tool

The welding tool was made of tool steel X38 as the chemical composition shown in **Table 3.**

Table .(3) Chemical Composition of welding tool

C	Si	Mn	P	Cr	Ni	Mo	Co	Fe
0.88-0.96	0.16	0.40	0.03	0.03	-	4.7-2.0	4.5-5.0	**Balance**

The tool pin is brought in contact with the work piece top surface and the tool is put into rotation using digit control part and the welding speed is controlled by the manual spindle to get the desired welds to complete FSW.

And then at the same rotation and traverse (Feed) speed in **Table (4)** return in reverse direction Until reaching the starting point for welding to produce FSP. As show in **Figure (6)**

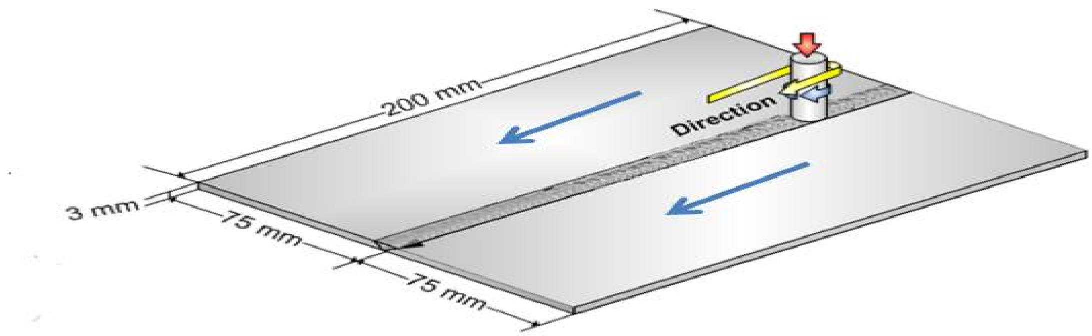


Fig .(6) FSP process for aluminum plates

FSW & FSP is done following the conditions that are shown in **Table 4.**

Table .(4) FSW & FSP process at variable rotation speed at 40 mm/min feed speed

Type of welding	Rotation speed (RPM)
FSW1	1500
FSW2	1700
FSW3	1900
FSP1	1500
FSP2	1700
FSP3	1900

The specimens that needs to be testing for FSW & FSP welded has be cutting by CNC milling machine(CE-TIK milling machine) and **Figure (7)** illustrates the position of the tested samples from each welded plate.

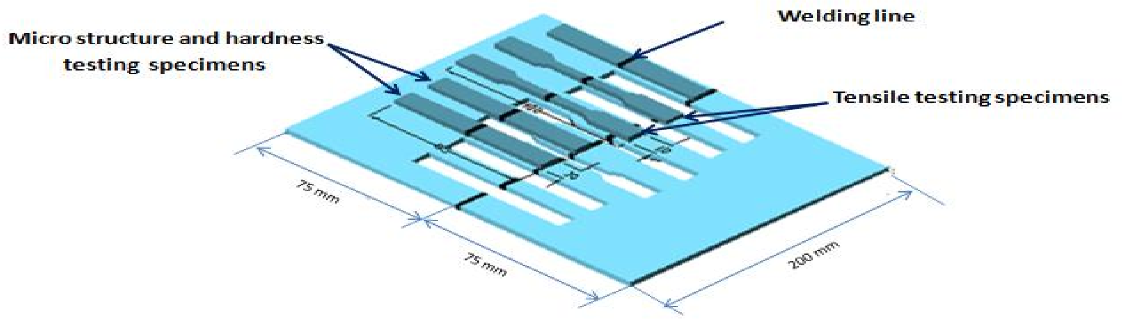


Fig .(7) Dividing welded plate into testing specimens

2.2 Tensile Test

A simple tensile test was carried out using a tensile testing device shown in **Figure (8)**, at a speed of 10 mm /min to the test specimens of 7075-T73aluminum alloy were prepared following the ASTM **E 8M**[11] standard specimen geometry shown in **Figure.(9)**.

Fig .(8) Tensile Tester

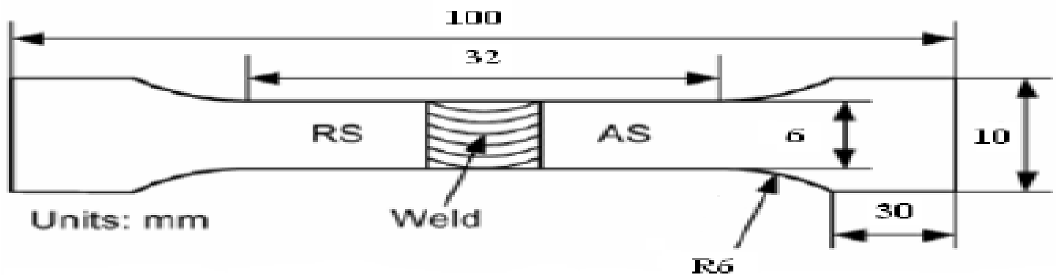


Fig .(9) standard tensile specimen

And **Table (5)** is explain the specimens for tensile test

Table .(5) : specimens the tensile of FSW and FSP

Name of specimens	Type of welding
B1,B2	FSW1
B3,B4	FSW2
B5,B6	FSW3
B7,B8	FSP1
B9,B10	FSP2
B11,B12	FSP3

and **Figure(10)** shows the tensile test specimens at different parameters before test.

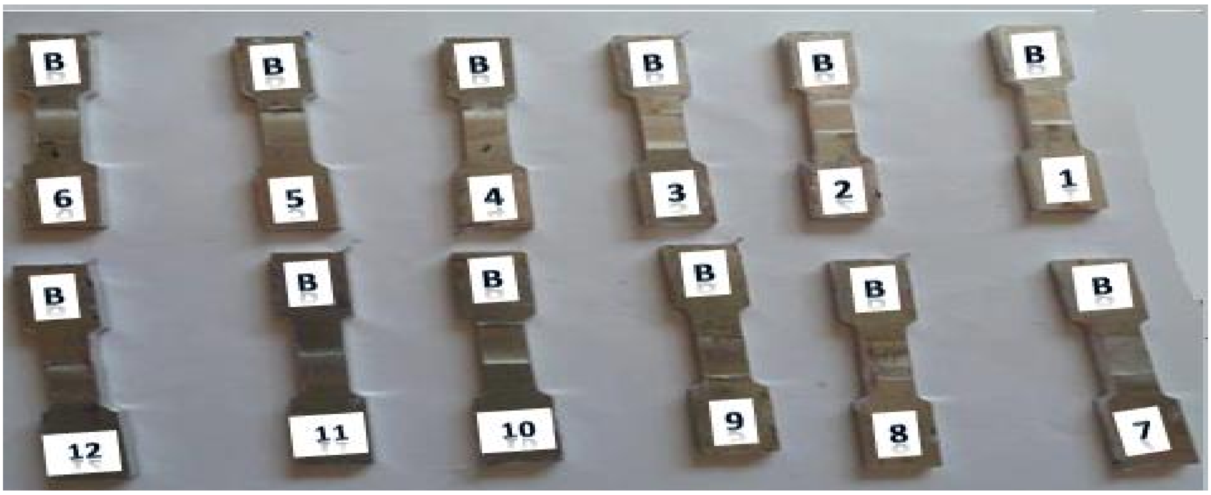


Fig .(10) the tensile test specimens

Tensile specimens had been examined at room conditions as weld **Figure (11)**

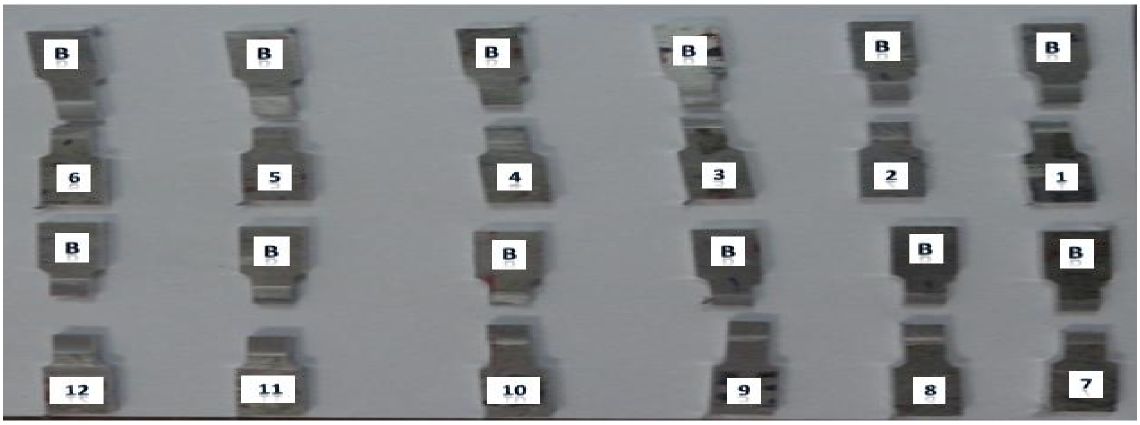


Fig .(11) Tensile Test Specimen after testing

2.3 Microstructure test

Metallographic tests were carried out using an optical microscopic at (500X) for the zooming power. The tests involved the analysis of the central area of the weld (the so-called nugget zone), the area deformed thermo-mechanically affected zone (TMAZ), and the heat affected zone (HAZ). Etching was carried out using Keller's etchant. It is involved (2 ml HF , 3 ml HCL , 5ml HNO3 , 190 ml H2O) according to ASTM E407-76 [12] .

2.4 Micro Hardness Test

Hardness is a quantifiable mechanical property of a material. At the microscopic level, it is a measure of resistance of the material to indentation and cracking [13].Micro hardness testing using a hardness tester is capable of providing useful information on hardness variation through different regions of the FSW & FSP plate. The hardness profiles were measured along the centerline of the cross section of the welds at about nine points (five points at the left of the weld and five points at the right of the weld and another point in the center of the weld) with various welding rotational and translational speeds using micro hardness apparatus. (**Figure.12)** shows the micro hardness apparatus: The specimens are presented in (**Figure. 13).**

Fig .(12) Microhardness tester

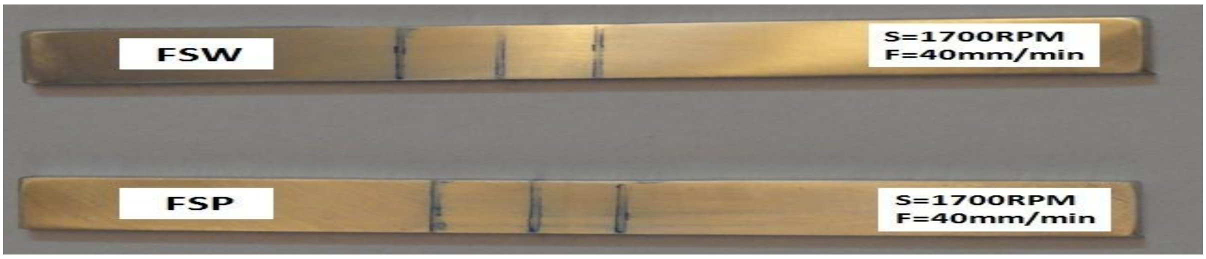


Fig .(13) Hardness test specimens

3. Results and Discussions

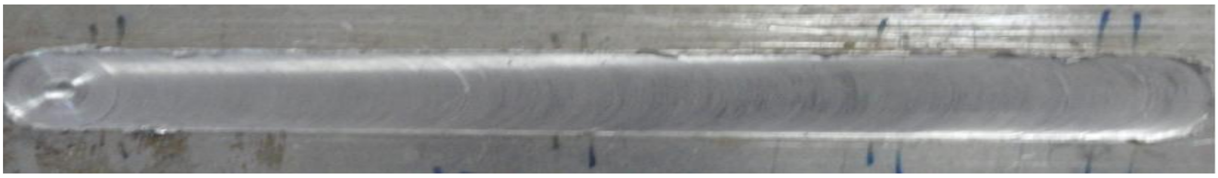
Experimental results for 7075-T73 aluminum alloys are welding by FSW and FSP in this chapter. The most common measure of FSW and FSP quality after welding were done in (tensile, Micro hardness, and microstructure) tests.

3.1 FSW Results

The friction stir welding (FSW) joints are shown in **(Figure.14)**

FSW at 1500RPM,40mm/min

FSW at 1700RPM,40mm/min



FSW at 1900RPM,40mm/min

Fig .(14) The appearance of upper surface of welding beads of 7075-T73 AA plates produced by FSW.

And the appearance of upper surface of welding beads of 7075-T73 AA plates produced by FSP as show in **Figure (15)**

FSP at 1500RPM,40mm/min

FSP at 1700RPM,40mm/min

FSP at 1500RPM,60mm/min

Fig .(15) The appearance of upper surface of welding beads of 7075-T73 AA plates produced by FSP.

For these **Figures(14 & 15)** all welding lines are have good appearance by visual inspection .

3.2 Tensile Results

the results for tensile specimens are explain in **Table (6)**

Table .(6) Results for tensile specimens

Name of specimens	Type of welding	Average of ultimate tensile strength (MPa)
B1,B2	FSW1	367.4
B3,B4	FSW2	390.35
B5,B6	FSW3	383.2
B7,B8	FSP1	384.55
B9,B10	FSP2	433.72
B11,B12	FSP3	405.72

And **Figure (16)** show the values of ultimate tensile strength of welded specimens and ultimate tensile strength of base metal

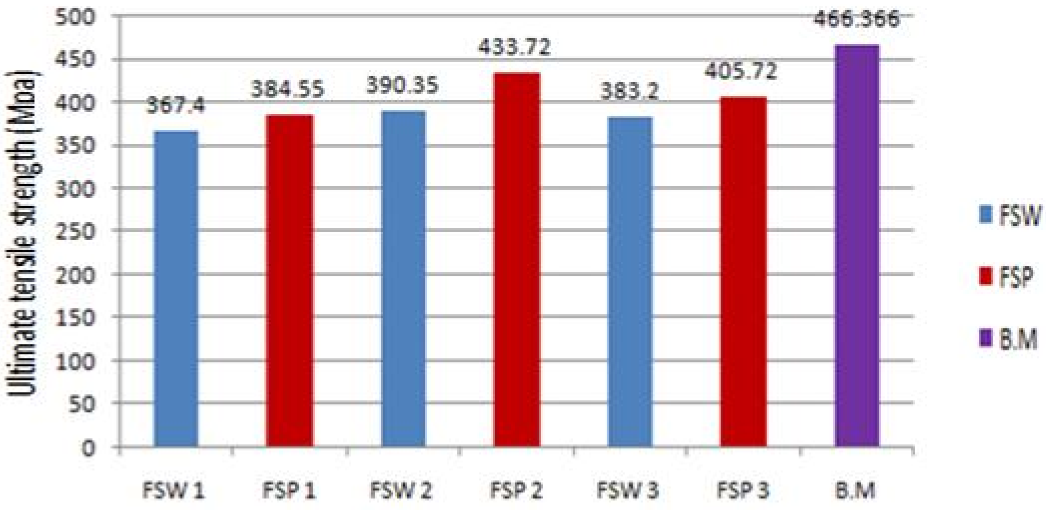


Fig .(16) Tensile test results

Figure (17) shows the efficiency for each case compare with base metal

Fig .(17) results of efficiency for tensile test

The optimum value was obtained at 1700 rpm rotating speed and 40 mm/min welding speed for both FSW & FSP , it was 390.35 MPa for ultimate strength and 83.7% these efficiency of welding line compared with base metal for FSW and 433.72 MPa and the welding efficiency is 92.999% for FSP of the base metal that means FSP method is effective, it will give long life welds because of FSP is enhance the mechanical properties and modification of microstructure is leads to increase the mechanical properties.

3.3 Microstructureresults

The optimum resulted from tensile test are both in FSW & FSP are examined in microstructure test and **Figure (18)** are explain the microstructure of welding zones in both cases

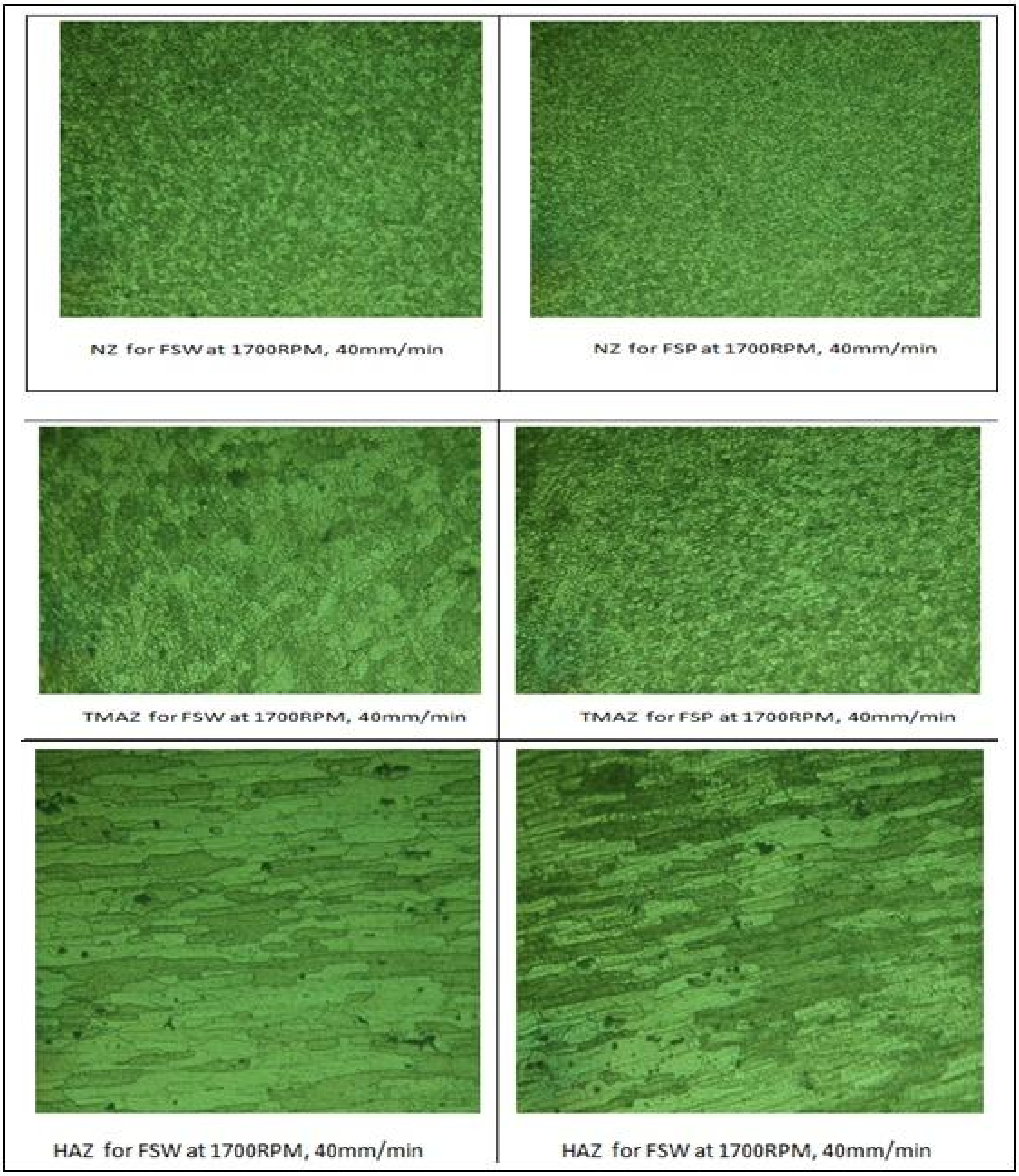


Fig .(18): The microstructure of welding zones in FSW & FSP

According to **Figure (18)** the FSP is ultra fining and modification of microstructure for nugget(welding) zone and other welding zones this refining leads to increase the mechanical properties and this microstructure is proved are no porosity or defect in welding (Nugget) zone in both cases.

3.4 Micro hardness results

Hardness profiles are extremely useful, as they can assist in the interpretation of the weld microstructure and mechanical properties. Each specimen was tested by dividing it into regions each point took 10 seconds in hardness Vickers (HV) then the reading has been recorded and measured the other points respectively were measured. when the distance between any two points is 2 mm. The results for FSW and FSP at 1700 RPM and 40 mm/min for 7075-T73 are presented in **Figure (19)**

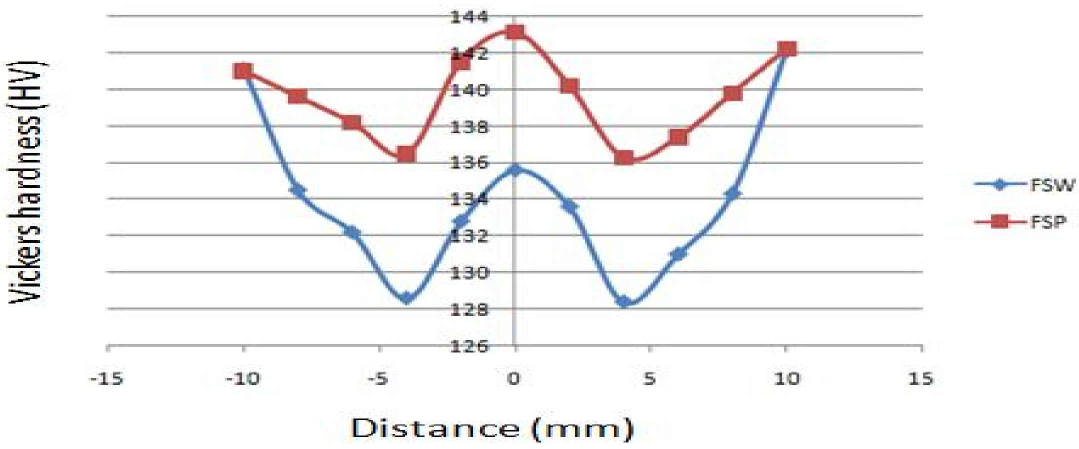


Fig .(19):Hardness profiles of FSW and FSP

For **Figure (19**) the hardness varied at different positions of the processed area. This variation is believed to be caused by the variation of the temperature reached at different positions and the results show that the friction stir processing (FSP) has a higher Vickers hardness value than the FSW . The hardness profile shows that the hardness values at the center of the deformation zone (nugget zone) is higher than the other zones and NZ at (-1_ 1 mm) and thermal mechanical effected zone (TMAZ) at (1.1 - 5 mm) and heat effected zone (HAZ) at (5.1 - 8 mm) .

Friction stir welding is caused to decreasing of the displacement density and de-creasing in that cause to decreasing of the micro hardness. In this process tool rotation and feed rate cause to dynamic recristallization and dynamic recristallization cause to new grain giant [13] The hardness profile shows that the hardness values at the center of the deformation zone (nugget zone) is higher than the other zones as shows in **Figure (20),** and as going farther from the nugget the hardness decreases till it reaches its minimum value at edge of the deformation zone (heat affected zone) and then increases again [13].

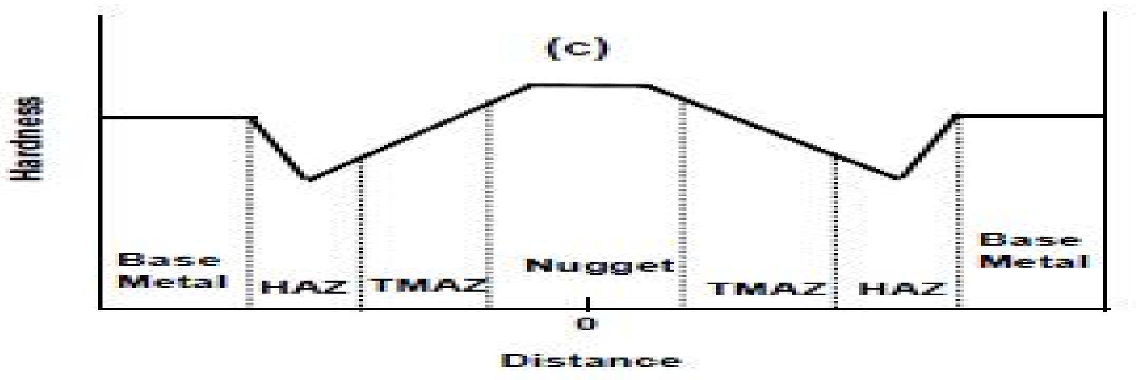


Fig .(20)): Hardness profiles of FSW for 7xxxx [13]

And for **Figure(19)** is explain the values of Vickers hardness for FSW and FSP and this fig distinguished the increase of .hardness in FSP because the FSP is leads to refining of microstructure and enhancement of mechanical properties.

Conclusion :

1- The highest strength of 7075-T73 for FSW and FSP at (1700 RPM and 40 mm/min)with the values of 390.35 MPa and 433.72 MPa for FSW and FSP respectively and 9.299 % the percentage of efficiency improvement by using FSP.

2- The highest Vickers hardness values of 7075-T73 AA are 135.7 and 143.1 for FSW and FSP respectively .

3- The friction stir processing is improved the micro structural properties at welding zones specially nugget zone and it caused grain refined of microstructure respect to friction stir welding .

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