THE INFLUENCE OF TOOL GEOMETRY OF FRICTION STIR WELDS ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF 2218-T72 ALUMINUM ALLOY

*** Prof. Dr. Qasim M. Doos.** *** Samer J. Mahmood.**
University of Baghdad, College of Eng.
Kasim_daws@yahoo.com , samerjasem@yahoo.co.uk

1- ABSTRACT

Friction stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt. This process uses a non-consumable tool to generate frictional heat in the abutting surfaces. The welding parameters such as tool rotational speed, welding speed, axial force, etc., and tool pin profile play a major role in deciding the weld quality. In this investigation an attempt has been made to understand the effect of tool pin profile and rotation diameter on microstructure and mechanical properties in aluminum alloy (2218-T72).

Five different tool pin profiles (straight cylindrical, threaded cylindrical, triangular, square, and threaded cylindrical with flat), with three different rotation diameter (3, 4, 5) mm. have been used to fabricate the joint.

Effect of tool pin profile on mechanical properties of welded joints were investigated using different mechanical tests including (tensile, bending and microhardness tests). Microstructure characteristic during (FSW) process was studied and different welding joint were investigated using optical microscope. Based on the stir welding experiments conducted in this study the results show that aluminum alloy (2218-T72) can be welded using (FSW) process with maximum welding efficiency (86.95%) and (83.21%) in terms of ultimate tensile strength and bending force respectively using tool pin profile (threaded cylindrical with flat) with rotation diameter (5) mm, rotation speed (900rpm) and (30mm/min) welding speed.

Keywords: Aluminum Alloy, Friction Stir Weld, Tool Geometry.

الخلاصة

اللحام بالاحتكاك والخلط من الطرق التي تضهر الحالة الصلبة لطرق الربط والتي تكون حالة المعدن الملحوم ليست منصهرة.الطريقة تستخدم عدة غير مستهلكة لتوليد حرارة الاحتكاك في السطح المحاذي.أن عناصر اللحام مثل السرعة الدورانية لعدة اللحام وسرعة اللحام والقوة العمودية الخ.. بالأضافة الى شكل رأس العدة يلعب دور مهم بتحديد نوع اللحام. في هذا البحث محاولة لفهم تأثير شكل رأس العدة وقطر الدوران على الخصائص الميكانيكية والميتالورجية لسبيكة الألمنيوم

استخدمت خمس اشكال لرأس العدة(أسطواني عدل،أسطواني مسنن، مثلث، مربع، أسطواني مسنن مع شق منبسط) مع ثلاثة أقطار دورانية مختلفة (٣،٤،٥)ملم لأنشاء الوصلات.

أن تاثير شكل رأس العدة لوصلات اللحام تم دراستها بالأعتماد على الفحوصات الميكانيكية الأتلافية مثل(فحص الشد،فحص الأنحناء،فحص الصلادة المجهرية) كذلك تم دراسة التغيرات الميتالورجية خلال عملية اللحام ودراسة مناطق اللحام المختلفة بأستخدام مجهر ضوئي. من التجارب المختلفة في هذة الدراسة اتضح بأن سبيكة الالمنيوم قابلة للحام بهذة الطريقة مع الحصول على اقصى كفائة لحام وصلت الى (٨٦،٩٥%)و(٨٣،٢١) اعتماد على مقاومة الشد وقوة الانحناء بالتتابع بأستخدام شكل رأس عدة (أسطواني مسنن مع شق منبسط)وقطر دوران (٥ملم).بسرعة دورانية ٩٠٠ دورة بالدقيقة وسرعة لحام ٣٠ ملمتر بالدقيقة.

2- INTRODUCTION

Friction stir welding (FSW) is a solid-state joining process, which uses a cylindrical rotating tool consisting of a concentric tool pin and tool shoulder. The strong metallurgical bonding during FSW is accomplished by (1) the severe plastic deformation caused by the rotation of the tool pin that plunges into the material and travels along the joining line and (2) the frictional heat generated mainly from the pressing tool shoulder. The key roles of the tool pin and the tool shoulder are to deform the material around the tool and to generate the frictional heating during the processing, respectively. Therefore, the tool geometry (i.e., the shapes and sizes of the pin and shoulder) is one of the most important processing parameters that determine the quality of the joint and the microstructure characteristics **[WANCHUCK WOO2006]**.

FSW offers several advantages over conventional fusion welding process because of its low heat input and absence of melting and solidification process. The most important benefits of FSW are its ability to weld the materials that was thought difficult to be welded such as aluminum alloy of 2xxx and 7xxx series. FSW is a solid state joining technology and gives better material properties: fewer weld defects, low residual stresses and improved dimensional stability **[YAN-HUA ZHAU2005]**.Other benefits include generally low defect compared with fusion welding and the ability to join dissimilar metals **[H.LOMBARD2007]**

3- EXPERIMENTAL WORK

The rolled plates of 3.8mm thickness, AA2218 aluminum alloy The chemical composition and mechanical properties of base metal are presented in **Table 1**, were cut into required size is (150mm×75mm×3.8mm) by power hacksaw cutting and grinding the plate edge to insure that there is no gap between the two plates as shown in **Fig. 1** was prepared to fabricate FSW joints. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the joints.

Non-consumable tools made of law alloy steel were used to fabricate the joints. The tool dimensions are shown in **table 2.** Five different tools pin profiles (straight cylindrical, threaded cylindrical, triangular, square, and threaded cylindrical with flat), with three different rotations diameter (3, 4, 5) mm were used. Tool shoulder was constant for each tool 18 mm diameter, and used standard pitch screw for the threaded cylindrical, were used to fabricate the joints as shown in **Fig. 2.**

To obtain high quality of (FSW) welded joints with high mechanical properties, i.e. high welding efficiency; the main welding parameters (rotational speed and welding speed) must be carefully selected to balance the effect of each parameter on the amount of heat input during welding.

The rotation speed was chosen according to the self-optimized parameter suggested by **[Mohanad A .Al-Ani2007],** therefore tool rotation speed is kept constant at 900 rpm, and the welding speed was kept constant at 30 mm/min, the aluminum alloy use in Mohanad investigation was (7020-T6) aluminum alloy. The FSW trials are carried out on a vertical milling machine with square butt joint configuration.

Then the joints were visually inspected and X-Ray Photography **Fig. 3**. According to radiography inspection **Fig.4**, eight joints had internal defect in weld line. The type of defect is voids in the middle or root of the weld .from the table we find that, straight cylindrical and threaded cylindrical pin profile with (3,4,5 mm)rotation diameter containing void defect in weld line. The reason of this defect is insufficient heat input and flow of the plasticized metal. Triangular and square pin profile with (3 mm) rotation diameter containing void defect in weld due to the along the side of the shape is small and there is no effect on material flow.

4- TENSILE STRESS AND BENDING STRESS TEST RESULTS.

Flat weld specimens, are used to generate tensile and bending data perpendicular to the weld line. It includes the (NZ, TMAZ, HAZ and the base metal) represented along the gage length.

Tensile specimens were machined from the welds according to the American Society for Testing of Materials **[ASTM, 1988].**
Tensile test and bending test were done and until the failure take place and the result has been divided according to the tool pin profile. It should be noted that the values of the parent metal is (320**N/mm**^{2}, 915N) respectively.

A- Straight Cylindrical Pin Profile (T1-series):

T1-series are characterized by a change in pin diameter from 3mm to 5mm in steps of 1mm. The plastic metal flows around the pin, and there is no pulsating action in this series. The pin with 3mm, pin diameter produce welds with the lowest tensile strength **Fig. 5**. The increase in weld strength with 4mm rotation diameter is small compared to 5mm it is attributed to increasing heat Generation and plastic flow of metal. Bending stress reaches maximum value in this series with 5mm pin diameter. **Table 3** shows that the tensile strength, bending stress, and efficiency of weld joint increase with increasing pin diameter of the tool.

B- THREADED CYLINDRICAL PIN PROFILE (T2-SERIES):

T2-series explore the effect of thread and change in pin diameter on mechanical property, the screw thread will be beneficial to the heat generation under the same welding parameters, more heat input can improve the flow of the plastic material. There is no pulsating action. The Pitch on The pin is (o.5M, 0.7M, 0.8M). The thread on each pin was machined opposite to that of the spindle rotational direction to assist in plastic flow. The lowest values of tensile strength in this series were found with 3mm, and 4mm pin diameter tools. The highest tensile strength occurred with 5mm pin diameter **Fig 6** .The results of bending stress of welded joint also increased with increasing in pin diameter **Table 4**.

Comparing this series with (T1-series) it is found a small increasing in mechanical property due to the effect of thread.

C- Triangular Pin Profile (T3-series)

The triangular pin profiles produce a pulsating stirring action in the flowing material due to flat face. It produces 45 pulse/s when the rotates speed is 900 RPM. The tool with 3mm rotation diameter produces welds with the lowest tensile strength, increases across tool with 4mm rotation diameter to reach maximum value on tool with 5mm rotation diameter **Fig 7.** The results of bending stress of welded joint also increases with increasing in pin diameter **Table 5** compared this series with previous series noted increas the mechanical properties (excepting the tool with 3mm rotation diameter) result from the impacted caused by the pulse during mixing the metal.

D- SQUARE PIN PROFILE (T4-SERIES):

Square pin profiles produce a pulsating stirring action in the flowing material due to flat face. it produces 60 pulse/s when the rotates speed is 900 RPM. The results show that tensile strength has been increased with increasing rotation diameter **Fig 8**. The joints fabricated using square pin have shown highest tensile strength compared to the joints fabricated using Triangular pin due to increase the pulse per Sec. Bending stress reaches maximum value in this series with 5mm rotation diameter. **Table 6** shows that the tensile strength, bending stress, and efficiency of weld joint increase with increasing pin diameter of the tool. The mechanical properties increase due to increase the pulses **[K. Elangovan, 2007].**

E- Threaded Cylindrical with Flat Pin Profile (T5-series)

This tool is characterized by flat; this series was designed to produce combined effects of improving the flow of the plastic material by the threaded and producing a pulsating stirring action by the flat side, the threaded cylindrical with flat pin produces 30 pulse/s when the tool rotates at 900 RPM speed. The maximum value of tensile strength in this series was found with 5mm rotation diameter see **Table 7**. Note there is large range in tensile strength between 3mm, and 4mm pin diameter this is due to increase area of the flat side. The maximum joint efficiency in (UTS FSW / UTS BM) is (86.95) for (G3T5) welded joint. The tensile strength, bending stress, and efficiency of weld joint increase with increasing pin diameter of the tool **Fig 9**.

4- MICROHARDNESS RESULTS.

Microhardness results show that small increase in hardness values toward the weld center **Fig 10**. The increased values found at the center of the weld are retained by the weld nugget and are probably related to the small grain size.

Another observation of the microhardness results is the hardness on one side of weld center differs from the other side (unsymmetrical weld). This difference can be explained as follows: In the leading side (advancing side) for the rotating tool where the rotational velocity vector and the forward motion vector are in the same direction and due to this there is higher heating on one side of the weld center and hence higher the hardness.

Of the 15 joints **Figs 11, 12, and 13**, the highest hardness value of 178 Hv has been recorded in the joint fabricated using threaded cylindrical with flat and rotation diameter (5mm) pin profiled tool and the lowest hardness value of 135Hv has been recorded in the joint fabricated using straight cylindrical rotation diameter (3mm) pin profiled tool, and the hardness increasing as the rotation diameter increased.

All the set of experiment joints increase in the hardness a cross the weld compared to the value of the base metal (HV_{500}=130) was due to equated structure or reprecipitation of the solid solution.

5- MICROSTRUCTURE.

The transition between the weld nugget and (TMAZ) is observed for all the joints fabricated using the tools with 5mm rotation diameter for comparison purpose.

Fig14 shows the sample of the joint produce by straight cylindrical pin profiled tool, it contains void formation on the root of the due to a sufficient heat generation and metal flow. **Fig15** shows the sample of the joint produce by threaded cylindrical pin profiled tool, it contains porous void formation on nugget zone and small cracks on the thermo-mechanically affected zone. **Fig 16** shows the sample of the joint produce by triangular pin profiled tool, it contains effects of pulse intervals and non-clear. **Fig 17** shows the sample of the joint produce by square pin profiled tool, it contains effects of clear and close due to the shape of square.

Fig 18 shows the sample of the joint produce by threaded cylindrical with flat pin profiled tool, it seen homogeneous structure of three regain (NZ,TMAZ,HAZ) are clearly.

6- CONCLUSIONS:

According to results of the present study of (FSW) process on selected Al-alloy, several conclusions can be written regarding alloy weldability, mechanical, microstructure.

1- Aluminum alloy (2218-T72) is wieldable using different (FSW) tool geometry giving different welding efficiencies. The shape of the pin with (3) mm rotation diameter has small effect on the mechanical properties (tensile, bending, hardness) , the shape of the pin with (4, 5) mm rotation diameter has a significant effect on the mechanical properties.

2- The maximum weld strength obtained in this study was (278.24 (N/mm2)) or (86.95 %) weld efficiency with (11.9 %) elongation is recorded in the weld using threaded cylindrical with flat pin profiled tool and 5mm rotation diameter.

3- In the stirred zone, fine equi-axed grains of size ranging are transformed from the parent metal grain structure.

4- Increasing tool pin diameter from (3mm to 5mm) step 1mm for a fixed other parameter causes increasing in mechanical properties of the welds joint.

7- REFRINCE

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Yan-hua Zhao, San-bao Lin, Lin Wu, Fu-xing Qu "The Influence of Pin Geometry on Bonding and Mechanical Properties in Friction Stir Weld 2014 Al Alloy", Materials Letters, Vol. 59, No.5, PP.2948-2952, 2005

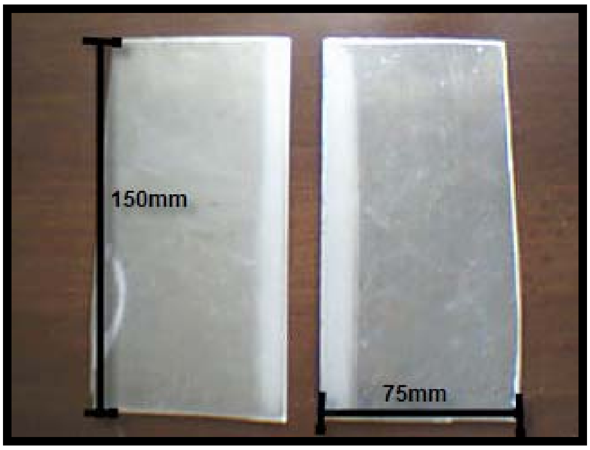

Fig. 1 Plates Preparation for welding.

Table 1 Chemical and Mechanical properties of Al alloy used in this study.

Material type and temper condition	2218-T72 Aluminum alloy (Measured)	2218-T72 Aluminum alloy (Standard)[ASTM]
Chemical Composition	Cu = 4.1% Ni = 2.0% Mg = 1.5%, Si = 0.8% Al=Rem	Cu = (3.5-4.5)% Ni = (1.7-2.3)% Mg = (1.2-1.8)%, Fe = 1.0%, Si = 0.9% Zn = 0.25%, Mn=0.2% Cr = 0.10%, Al=Rem
Mechanical properties	Ultimate strength = 320(N/mm^2) Yield strength =242 (N/mm^2) Elongation =14%	Ultimate strength = 330(N/mm^2) Yield strength = 255(N/mm^2) Elongation =11%

Fig. 2 Image of friction stir tools.

Table2 Different pin geometry of friction stir tools.

Description Of the pin	Rotation Diameter (mm)	Shoulder Diameter (mm)	Pitch on The pin (mm)	Pin length (mm)
straight cylindrical	3	18	non	3.5
	4	18	non	3.5
	5	18	non	3.5
threaded cylindrical (V –Thread)	3	18	0.5	3.5
	4	18	0.7	3.5
	5	18	0.8	3.5
triangular	3	18	non	3.5
	4	18	non	3.5
	5	18	non	3.5
square	3	18	non	3.5
	4	18	non	3.5
	5	18	non	3.5
threaded cylindrical (V –Thread) with flat	3	18	0.5	3.5
	4	18	0.7	3.5
	5	18	0.8	3.5

Fig (3) Samples of weld specimens.

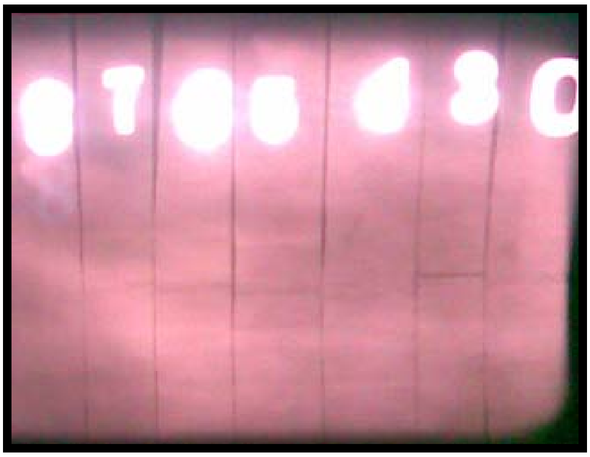

Fig (4) Samples of Radiography film.

Table 3 Results of Tensile and Bending Test of (T1-series).

FSW Exp.	Tensile Strength (N/mm^2)	Elongation (%)	Joint Efficiency in terms of tensile strength (%)	Maximum Bending Force (N).	Joint Efficiency in terms of Bending Force (%)
G1T1	144.24	5.5	45.07	337.8	35.52
G2T1	145.94	6.7	45.60	405.36	42.62
G3T1	244.6	8.8	76.43	511.53	53.78

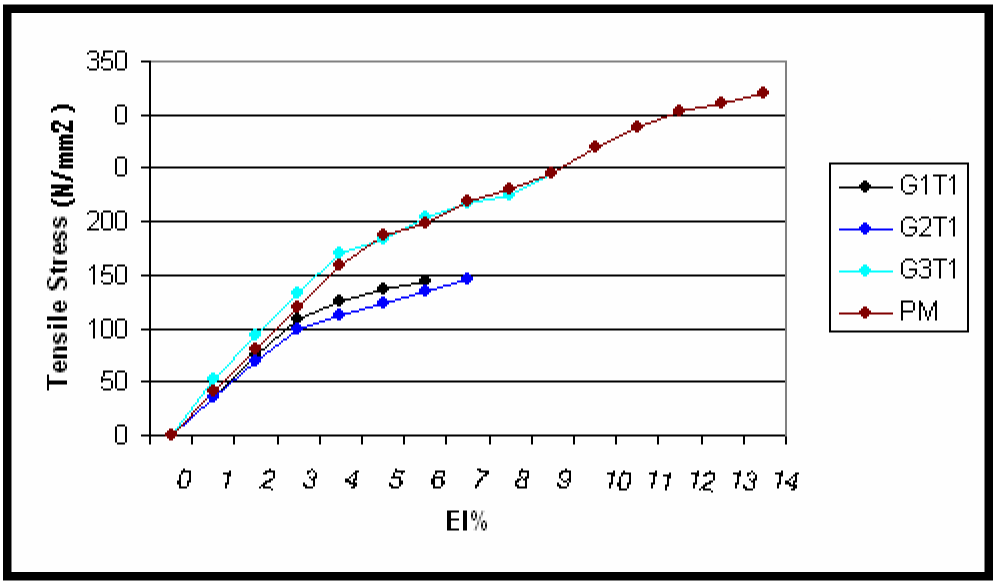

Fig. 5 Tensile strength change with rotation diameter for (T1-series).

Table 4 Results of Tensile and Bending Test of (T2-series).

FSW Exp.	Tensile Strength (N/mm^2)	Elongation (%)	Joint Efficiency in terms of tensile strength (%)	Maximum Bending Force (N).	Joint Efficiency in terms of Bending Force (%)
G1T2	152.06	5.7	47.51	550	57.83
G2T2	158.87	5.7	49.64	579.09	60.08
G3T2	258.09	10.8	80.65	685.25	72.05

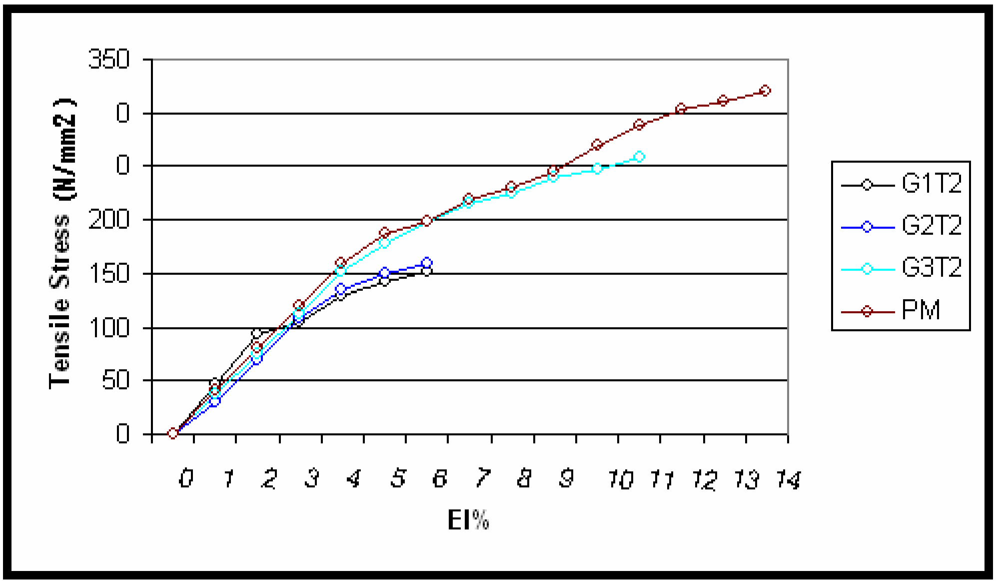

Fig 6 Tensile strength change with rotation diameter for (T2-series).

Table 5 Results of Tensile and Bending Test of (T3-series).

FSW Exp.	Tensile Strength (N/mm^2)	Elongation (%)	Joint Efficiency in terms of tensile strength (%)	Maximum Bending Force (N).	Joint Efficiency in terms of Bending Force (%)
G1T3	153.53	6.7	47.97	550.13	57.84
G2T3	191.19	9.8	59.74	694.09	72.98
G3T3	261.08	10.8	81.58	694.87	73.06

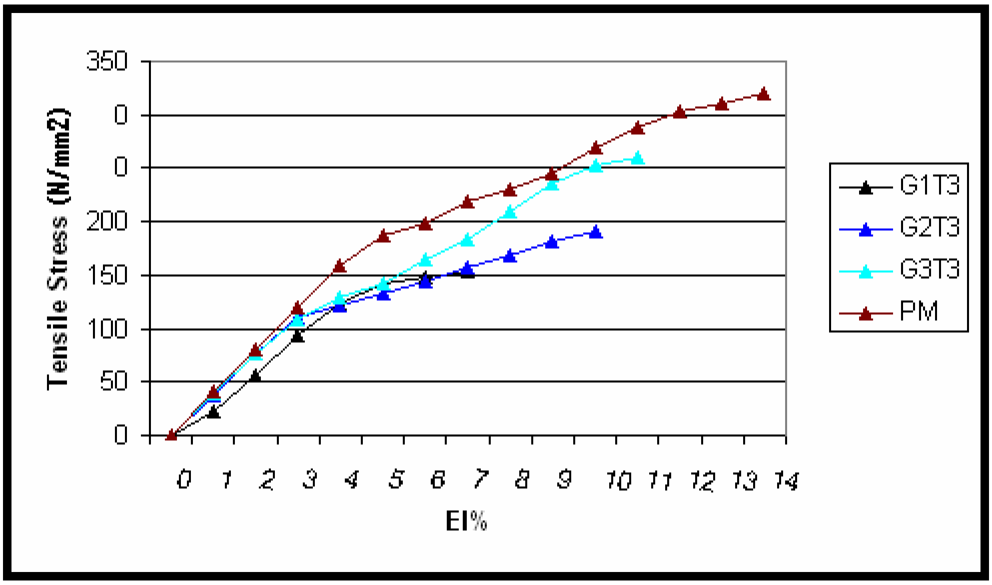

Fig 7 Tensile strength change with rotation diameter for (T3-series)

Table 6 Results of Tensile and Bending test of (T4-series)

FSW Exp.	Tensile Strength (N/mm^2)	Elongation (%)	Joint Efficiency in terms of tensile strength (%)	Maximum Bending Force (N).	Joint Efficiency in terms of Bending Force (%)
G1T4	166.5	7.7	52.03	617.6	64.94
G2T4	218.93	8.9	68.41	704.56	74.08
G3T4	265.05	10.9	82.82	762.46	80.17

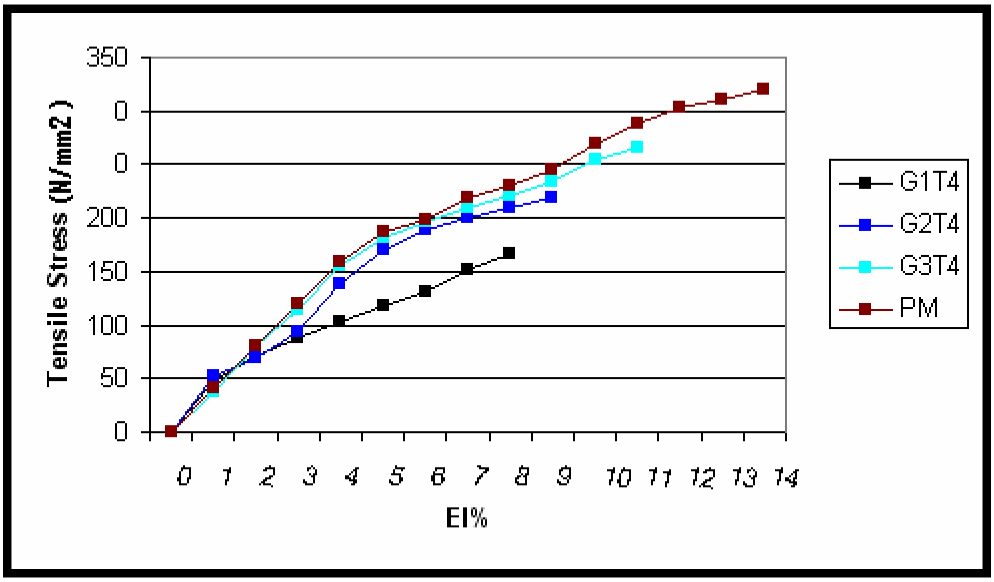

Fig 8 Tensile strength change with rotation diameter for (T4-serie

Table 7 Results of Tensile and Bending Test of (T5-series).

FSW Exp.	Tensile Strength (N/mm^2)	Elongation (%)	Joint Efficiency in terms of tensile strength (%)	Maximum Bending Force (N).	Joint Efficiency in terms of Bending Force (%
G1T5	166.55	5.8	52.04	598.39	62.92
G2T5	224.19	8.7	67.08	762.46	80.17
G3T5	278.24	11.9	86.95	791.42	83.21

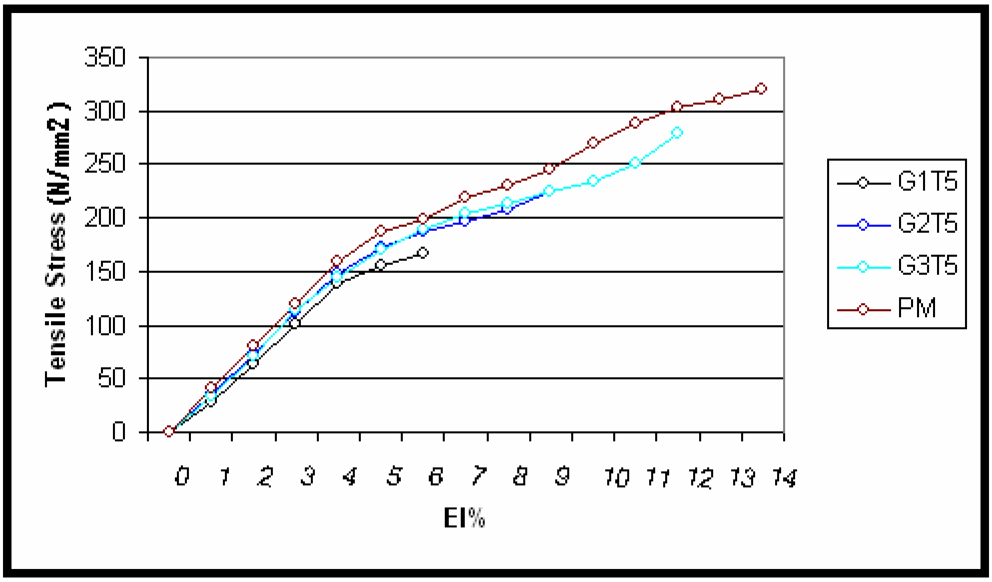

Fig 9 Tensile strength change with rotation diameter for (T5-series)

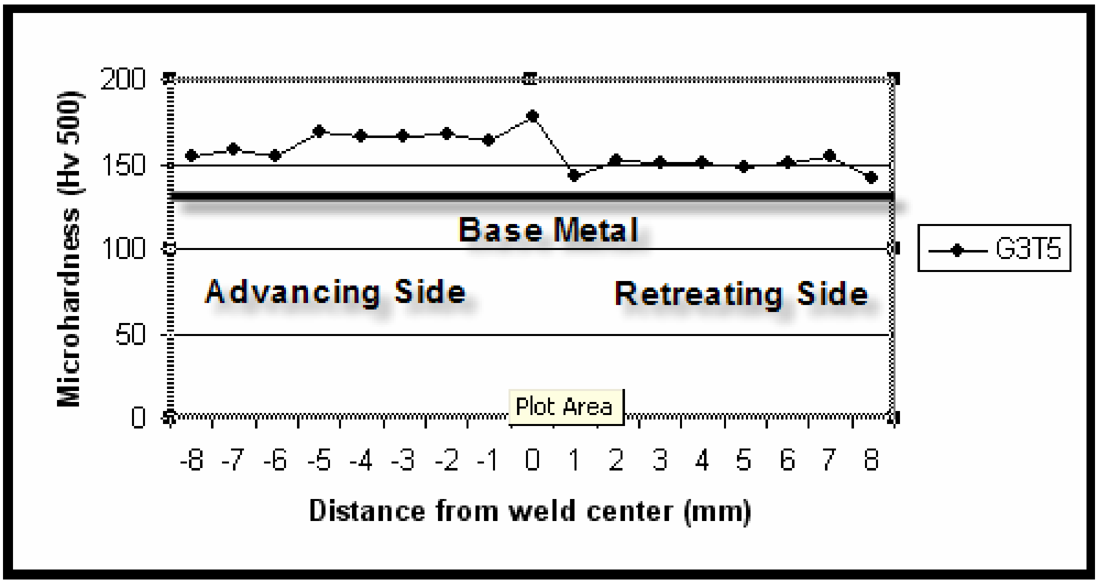

Fig 10 .Hardness distribution along (FSW) zone**.**

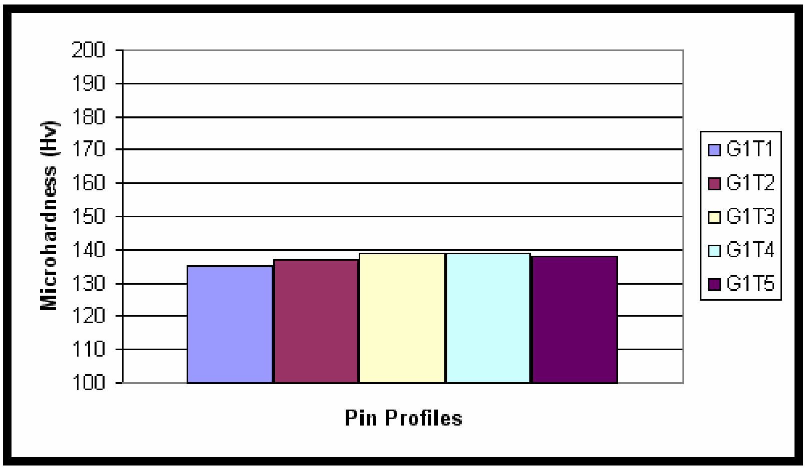

Fig 11 Effect of pin profiles with 3mm rotation diameter on (FSW) Zone Hardness.

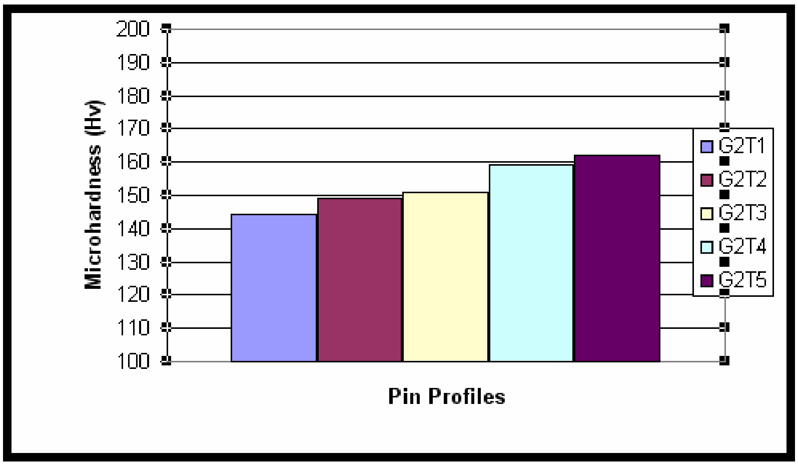

Fig 12 Effect of pin profiles with 4mm rotation diameter on (FSW) Zone Hardness.

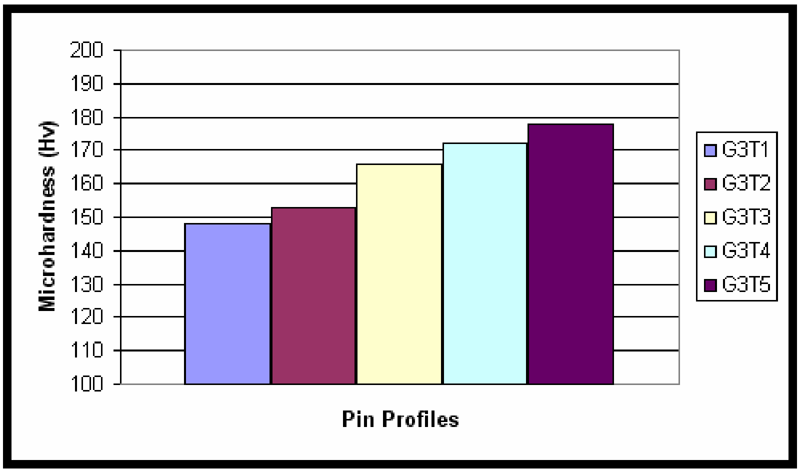

Fig 13 Effect of pin profiles with 5mm rotation diameter on (FSW) Zone Hardness.

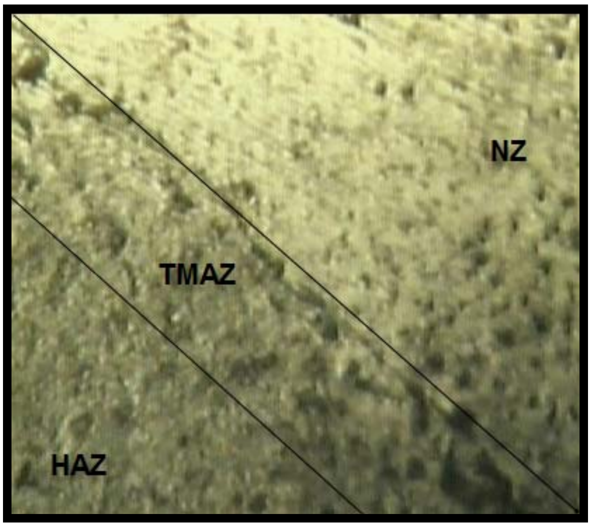

Fig (14) Microstructure observation of the joints fabricated by straight cylindrical pin profiled tool X125.

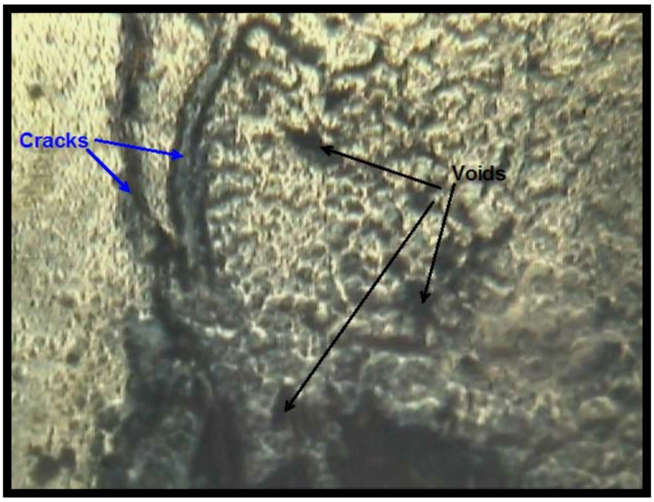

Fig (15) Microstructure observation of the joints fabricated by Threaded cylindrical pin profiled tool X125.

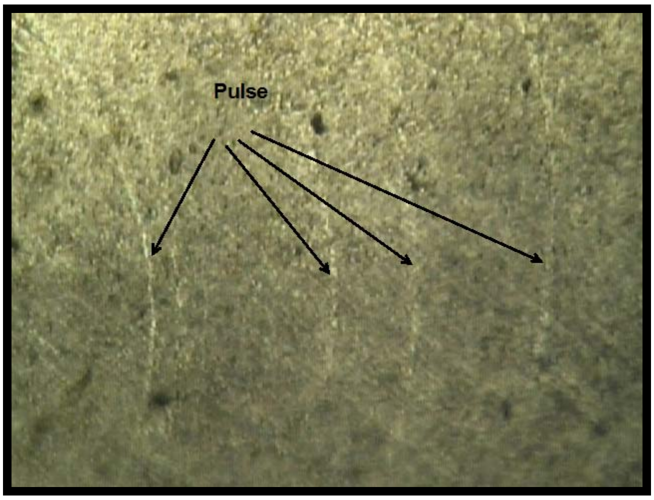

Fig (16) Microstructure observation of the joints fabricated by triangular pin profiled tool X125.

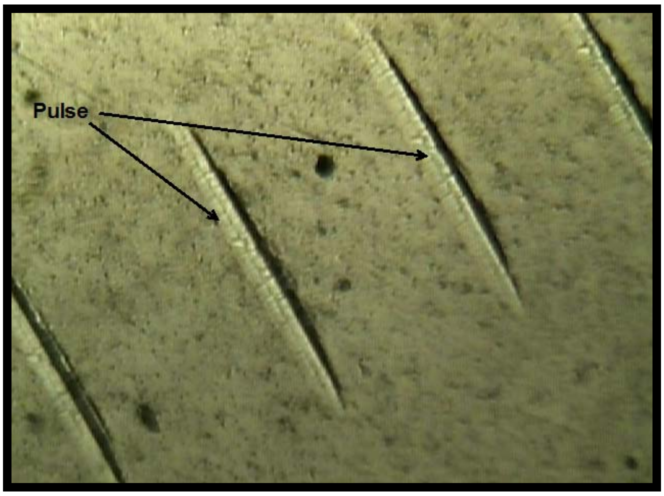

Fig (17) Microstructure observation of the joints fabricated by square pin profiled tool X125.

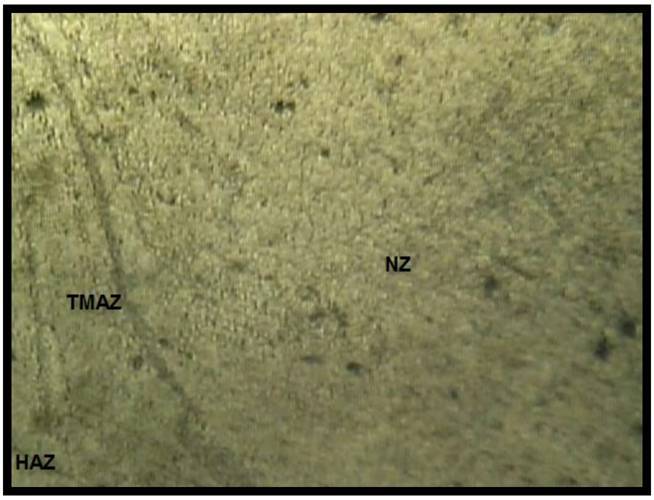

Fig (18) Microstructure observation of the joints fabricated by threaded cylindrical with flat pin profiled tool X125.

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