



# Effect of Different Friction Stir Spot Welding Techniques on the Mechanical Properties and Microstructure of Aluminum AA2024-T3

Akeel Z. Mahdi<sup>1\*</sup>, Samir A. Amin<sup>2</sup>, Sadeq H. Bakhy<sup>3</sup>

## Authors affiliations:

1\*) Mechanical Eng. Dep.,-  
University of Technology,  
Baghdad, Iraq  
akeelzeki@gmail.com

2) Mechanical Eng. Dep.,-  
University of Technology,  
Baghdad, Iraq  
alrabiee2002@yahoo.com

3\*) Mechanical Eng. Dep.,-  
University of Technology,  
Baghdad, Iraq  
sadeqbakhy@yahoo.com

## Paper History:

Received: 11<sup>th</sup> Mar. 2019

Revised: 24<sup>th</sup> Mar. 2019

Accepted: 19<sup>th</sup> June 2019

## Abstract

This paper presents a comparison of using different techniques for stir spot welding of Aluminum 2024-T3, which are refill friction stir spot welding (RFSSW), edited (RFSSW-pin) and conventional friction stir spot welding (FSSW), depending on the obtained tensile shear strength property. Specimens were prepared from AA2024-T3 sheet for chemical analysis and mechanical tests. Workpieces were stir spot welded utilizing the above mentioned techniques at four rotational speeds (2000, 2500, 3000 and 4000 rpm) using tool pin diameters (5 and 7 mm) for conducting the tensile shear tests. The microhardness along the cross section of the welded specimens was conducted at the best conditions as well as the microstructure examination. The comparison results revealed that at the rotational speeds (2000 and 4000 rpm) in both cases of tool pin (5 and 7 mm), the ultimate tensile shear force was slightly higher than that for other speeds. However, the ultimate tensile shear force was found higher at 3000 rpm speed with a tool pin 7 mm. The microhardness results manifested a W-shape at the best conditions. Finally, the microstructure examination depicted the morphology of the main zones of the weld joint.

**Keywords:** FSSW, RFSSW, Tensile shear strength, Microhardness, Microstructure..

تأثير استخدام تقنيات لحام الاحتكاك الخلطي النقطي المختلفة على الخواص الميكانيكية والبنية المجهرية لسبيكة الألمنيوم AA2024-T3

عقيل زكي محمدي ، سمير علي أمين ، صادق حسين باحي

## الخلاصة:

يقدم هذا البحث مقارنة بين استخدام تقنيات مختلفة للحام الاحتكاك الخلطي النقطي لسبيكة الألمنيوم 2024-T3، التي تشمل لحام الاحتكاك الخلطي النقطي المعدل (RFSSW)، لحام الاحتكاك الخلطي النقطي مع المعدل المعدل (RFSSW-pin) و لحام الاحتكاك الخلطي النقطي التقليدي (FSSW) اعتماداً على قوى القص الناتجة من اختبار الشد. تم تحضير العينات من صفيحة من الألمنيوم AA2024-T3 للتحليل الكيميائي والاختبارات الميكانيكية. تم لحام هذه العينات باستخدام التقنيات المذكورة أعلاه بأربعة سرعات دورانية (2000 و 2500 و 3000 و 4000 دورة في الدقيقة) باستخدام أقطار لأداة اللحام (5 و 7 ملم) لإجراء اختبارات القص الشدي. أجري فحص الصلادة الدقيقة على طول المقطع العرضي للعينات الملحومة في أفضل الظروف وكذلك الفحوصات المجهرية. أظهرت نتائج المقارنة أنه في سرعات الدوران (2000 و 4000 دورة في الدقيقة) في كلتا حالتنا أداة اللحام (5 و 7 ملم)، كانت قوة القص الشدي القصوى أعلى قليلاً من تلك السرعة الأخرى. كذلك، كانت قوة القص الشدي النهائي أعلى عند سرعة 3000 دورة في الدقيقة لأداة اللحام 7ملم. أظهرت نتائج الصلادة الدقيقة شكل W في أفضل ظروف لحام. وأخيراً، أظهر الفحص المجهرى المناطق الرئيسية لوصلة اللحام.

## 1- Introduction

(FSSW) is a solid-state joining technique having the capability to be a replacement for processes, such as resistance spot welding (RSW) and rivet technique in specific uses. Aluminum alloys are used in engineering design due to their high ratio of strength-to-weight, light weight, relatively low cost and well resistance to corrosion. Sergio T. Amancio-Filho et

al. (2011) [1] investigated the microstructure and mechanical behavior of 2024 aluminum alloy friction spot welds. They used the AA2024-T3 alloy (rolled sheets) for the welding procedure. S. Venukumar et al. (2013) [2], determined the mechanical characteristics and microstructure of the welded pure Al. they used a new technique developed to refill the probe hole using an additional filler plate called



“Refill Friction Stir Spot welding” (RFSSW). Four various rotational tool speed values were used (900, 1120, 1400 and 1800 rpm). Also, identification of mechanical characteristics and microstructure of traditional and (RFSS) welds in AA 6061-T6 employing filler plate were studied by S. Venukumar et al. (2013) [3]. (FSSW) with refilling by ‘friction forming process’ (FSSW-FFP) was modified adequately employing filler plate. Both of these new refilling techniques and traditional (FSSW) procedure were utilized for welding Al 6061-T6 lap shear samples, and the comparison of the outputs were conducted. The tool rotational speeds influence on the metallurgical and mechanical characteristics in both cases were investigated. Shear strength, in the static condition, of the refilled welded specimens was obtained exceed those welded by the conventional friction stir spot welding operation for the whole rotational speeds of tools. Damjan Klobcar et al. (2013) [4], presented a comparison among the joint strengths fabricated by (FSW), (FSSW), and a novel method of friction stir linear spot welding (FSLSW) 2 mm sheets of EN AW 5754 in a lap joint. The optimal welding parameters obtained based on the maximum joint strengths at FSW. The rotational speeds influence and the geometry of the tool pin on the mechanical characteristics and microstructure of the (RFSS) welds of similar sheets of AA2024-T3 were investigated by Haidar Kamal and Muhammed Abdul Sattar (2017) [5]. In their research, a new technique named ‘friction stir spot welding with refilling by friction forming process (FSSW-FFP)’ was employed for the keyhole removing from the traditional joints. The mechanical properties and Microstructure of FSSW for AA6061-T4 were presented by Zhikang Shen et. al. (2014) [6]. Muna K. Abbas et al. (2016) [7], studied the optimization of mechanical properties of FSSW joints for dissimilar alloy (AA2024-T3 and AA 5754-H114), and the maximum shear force was obtained at the best welding parameters. The experimental study of mechanical properties and morphological inspections on FSW AA2024 were investigated by H.M. Anil Kumar et.al. (2018) [8]. S. Dourandish et.al. (2018) [9], investigated the microstructure and failure behavior of protrusion FSSW of AA2024 sheets. Finally, in 2018, Kadhim K. Resan et al. [10] investigated the effect of temperature on the fatigue strength and life for friction stir welding joint for aluminum alloy.

There is little work concerned with using different techniques to avoid the common defects that normally occur in conventional friction stir spot welding. Therefore, the aim of the present work is a comparison of using different techniques for (FSSW) of AA2024-T3 Aluminum alloy which are (RFSSW), edited (RFSSW-pin) and traditional (FSSW) that will be conducted. This comparison is based on the mechanical properties (tensile shear test) of the friction spot welded joints.

## 2- Materials and Methods

A sheet with thickness (1.6 mm) of aluminum alloy 2024-T3 (AlCu4Mg1) was used in this work.

The analysis of base material was analyzed in Central Organization for Standardization and Quality Control by Spectrometer device, Table I, according to [11]. The mechanical properties are defined by test the sample with tensile test, and its samples must be according to ASTM standard [12]. Therefore, The tensile test was done in the University of Technology -Mechanical Department, to specify the mechanical properties by (Tinius Olsen H50KT apparatus), as shown in figure (1). The mechanical properties of aluminum alloy 2024-T3 are tabulated in Table II. The tensile specimen's geometry was fabricated by CNC Milling machine according to standard [13] as shown in the figure (2). Since the mechanical properties were defined by using experimental technique, its propriety can be depended on for future work.

**Table (1):** Standard and Actual Chemical Composition of Aluminum Alloy AA2024-T3

Composition (%)	Standard [12]	Actual
Si	0.5 Max	0.0762
Fe	0.50 Max	0.146
Cu	3.8 - 4.9	4.51
Mn	0.3 - 0.9	0.58
Mg	1.2 - 1.8	1.47
Cr	0.1 Max	0.0025
Zn	0.25 Max	0.0771
Ti	0.15 Max	0.0376
Al	Remainder	Remainder



**Figure (1):** Tensile test machine and specimen (Tinius Olsen H50KT apparatus).

**Table (2):** Standard and actual mechanical properties of AA2024-T3

Al Alloys	Yield Stress (MPa)	Ultimate Stress (MPa)
Actual	375	432
Standard [12]	345	485

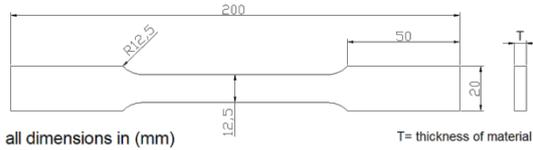
The workpiece dimensions are 30 mm, 30 mm and 100 mm for width, overlapping length and length, respectively, as shown in Figure (3). Four different rotational speeds for a spinning tool, namely 2000, 2500, 3000 and 4000 rpm were selected, and each test was repeatedly done three times at each rotational speed for all welding processes. The (RFSSW) and (FSSW) tools were made from Tool



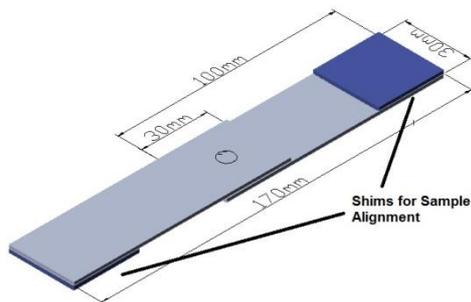
Steel X12M. Tools geometry specifications are shown in Table III and Figure (4).

**Table (3):** Used tools in (RFSSW) and (FSSW) welding experiments.

Tool No.	Type of process	Pin Shape and Dimensions			
		Pin Shape	Pin Details	Pin Length	Shoulder Diameter
Tool 1	RFSSW	Cylindrical	5 mm diameter	6 mm	18 mm
Tool 2			7 mm diameter	6 mm	
Tool 3			Flat with curve 3 degrees (Pinless)		
Tool 4	FSSW	Cylindrical	5 mm diameter	2.5 mm	
Tool 5			7 mm diameter	2.5 mm	



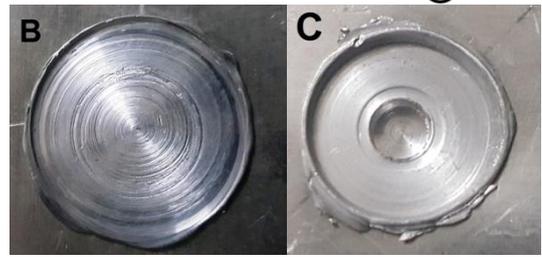
**Figure (2):** The tensile specimen geometry according to standard E 8M-00b [13]



**Figure (3):** Shear tensile specimen geometry



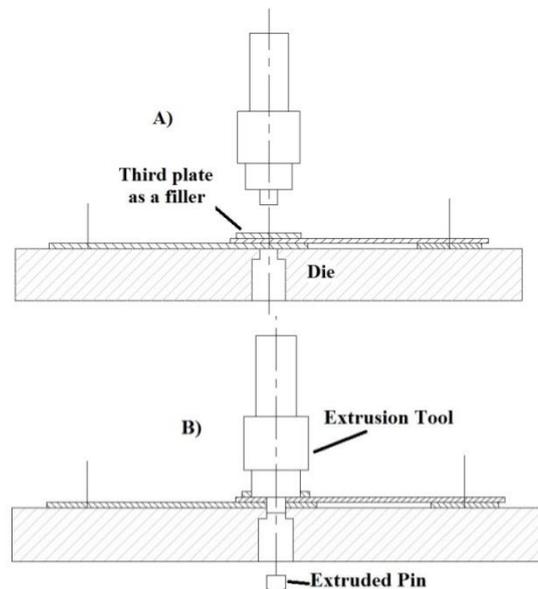
**Figure (4):** Friction Stir Welding Tools.



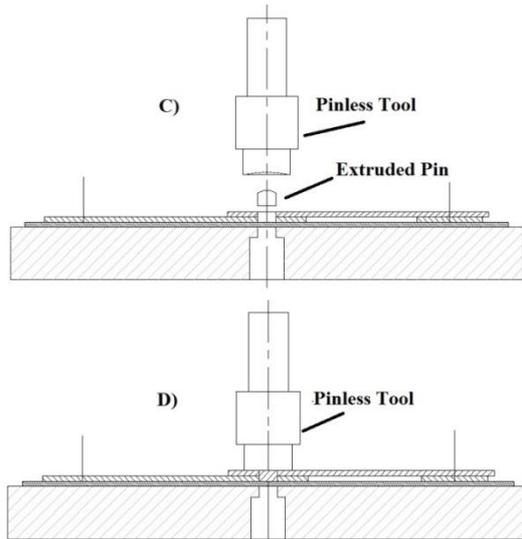
**Figure (5):** A sample of RFSSW specimens, **A)** Front and back of RFSSW specimen, **B)**RFSSW, **C)** FSSW

The macrostructures of the welded specimens are illustrated in the figure (5) for refill friction stir spot welding RFSSW (B) and conventional FSSW (C), while the macrostructures for edited (RFSSW-pin) are similar for RFSSW.

Extrusion and refilling are the main steps of RFSSW technique. The initial stage depends on inserting a spinning tool by force through a workpiece of an aluminum sheet. The friction generates heat at the contact area between the tool and workpiece, and this softens, deforms and displaces the sheet material and makes in the lower plate a bushing projection that leaves at the rear a probe hole in the upper plate, as depicted in Figure (6). Refilling is the second step of RFSSW technique, by taking back the pin that extruded in the first step and plunge it by the pinless tool, as shown in Figure (7). The edited (RFSSW-pin) is the same technique in RFSSW, but the extruded pin will be replaced with a pin that prepared from the base material (AA2024-T3), at the same thickness that is equal to the lap joint thickness part.



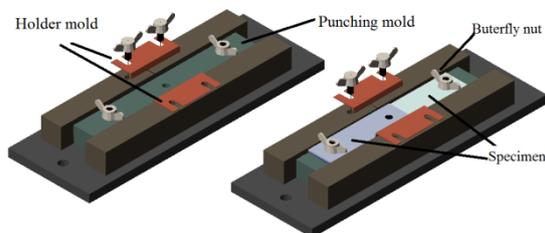
**Figure (6):** Extrusion steps of RFSSW A & B



**Figure (7):** Refilling steps of RFSSW C & D

A mold was fabricated from a rectangular sold bar steel (30 mm x 20 mm) with 200 mm in length. In the middle length, a hole was drilled to be as a punching mold, two molds were fabricated for each tool diameters (5 mm and 7 mm). At 15 mm from each side of the specimen, a stud with diameter 6 mm was fixed to be a guide for keeping the lap joint distance 30 mm, always the same for all welding specimens, as shown in figure (8).

The mold was designed to be changeable and similar when using the tools (5 mm and 7 mm). Since too many of specimens are required to be welded in this mold, so the simplification in welding processes (set up and release of the specimen) was taken into account. A holder was fabricated from steel plate with thickness (1 mm) and deformed to be like a spring action with two open slots for quick release the specimen. Also, a butterfly nut was used so that can it be tied by hand instead of a hexagonal common nut. After the extrusion step at the RFSSW, the extruded pin was collected by a simple collector, that placed below the mold to deliver the extruded pin, which will be used again as a filler material in the refill processes, as shown in figure (9).



**Figure (8):** Mold for lap shear test specimen



**Figure (9):** Holder mold and collector of extruded pin

### 3- Results and Discussions

#### 3-1. Tensile shear force

The ultimate tensile shear test was done on AA2024-T3 at four speeds and two tools with different pin diameter (5 mm and 7 mm). This test was repeated for RFSSW, RFSSW-Pin, and FSSW. The comparing results of the ultimate tensile shear test are shown in figure (10) and figure (11) for tool pin diameters (5 and 7 mm), respectively. Generally, ultimate shear force values of RFSSW were higher than FSSW for both (5 mm and 7 mm), these back to the keyhole absence and additional material in the weld owing to plate of filler in (RFSSW) technique. The presence of keyhole in traditional (FSSW) method plays as a notch when the load is applied and leads to stress concentration.

Also, the comparing results between RFSSW and RFSSW-Pin showed that, at speeds (2000 rpm and 4000 rpm) in both cases (5 mm and 7 mm) RFSSW-Pin was slightly higher. While at rotational speeds (2500 rpm and 3000 rpm), the opposite is true. The ultimate values of shear force in figure (11) exhibited those higher values than the results in figure (10) because the area of 7 mm welding joint gives more ability to carry the load than 5 mm. The ultimate value of shear force (4765 N) was obtained at speed 3000 rpm and tool pin diameter 7 mm. Therefore, these optimum conditions were considered for micro hardness and microstructure test.

The main modes of failure observed due to the tensile shear test as; interfacial failure mode as shown in Fig. (12. a), and spot circumferential shear failure mode as exhibited in Fig. (12. b).

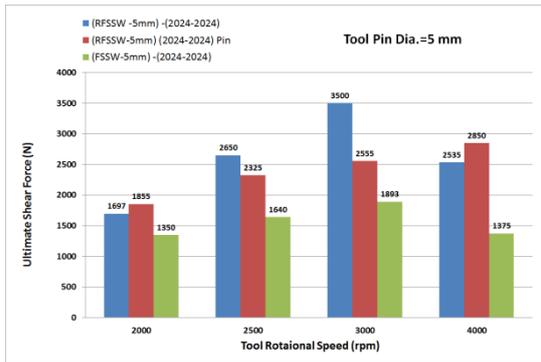


Figure (10): Ultimate shear tensile test for Tool pin diameter (5 mm).

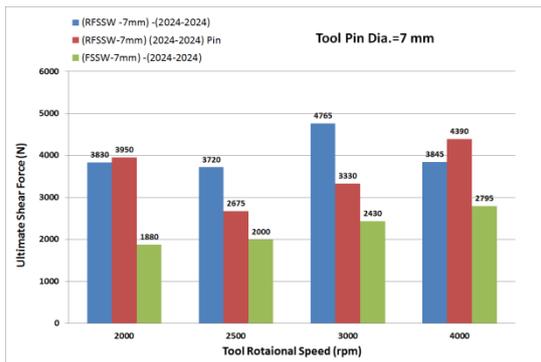


Figure (11): Ultimate tensile shear test for Tool pin diameter (7 mm)

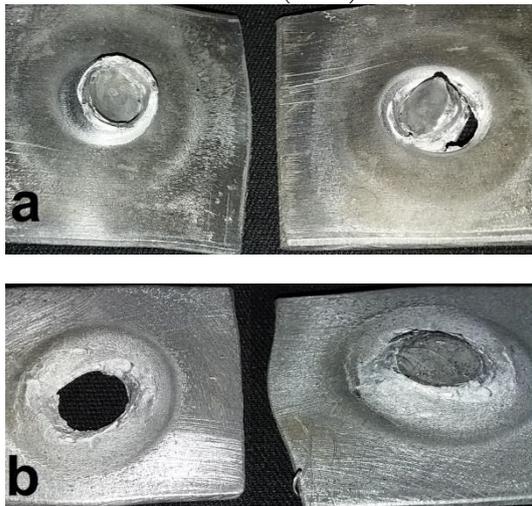


Figure (12): Samples of failure mode for tensile shear test at best conditions for RFSSW joints, right side for upper sheet and left for lower sheet

### 3-2. Microhardness

The results of the microhardness test along the welded specimen cross section via the (RFSSW) method at the best conditions are shown in Figure (13). The general shape of the hardness test results exhibited (W-shape) and this variation caused by the formation of the main zones at the weld joint. The examination of microhardness test for all specimens was found to be approximately in a symmetrical form with respect to the tool pin center as distribution of Vickers hardness.

It is clear from the figure (13), for the microhardness shape along the upper sheet of the refill friction stir spot welding samples, the Vickers

hardness value reached the lowest value in HAZ, and increased progressively in SZ and TMAZ in the direction of the center of the joint. But, it can be noted that the microhardness values in all welding zones were reduced, compared to the microhardness value at the base material zone. This is maybe ascribed to the higher heat input caused by the welding process at the refill step, which produced the dissolution of fine precipitates in the localities that were presented to unusual plastic flow, particularly in the SZ, and further produced softening in the additional regions that were subjected to the influence of thermal cycle due to coarsening of precipitates and grains [14].

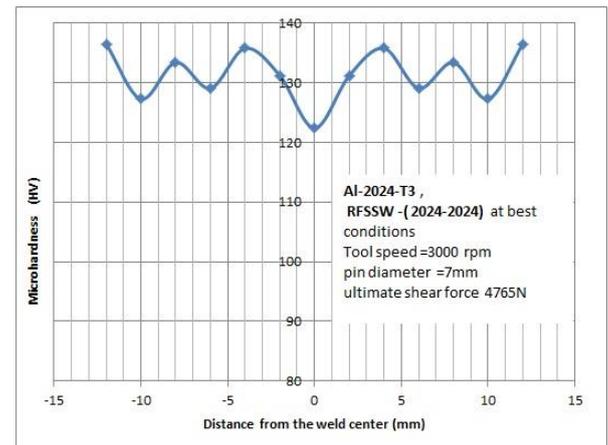


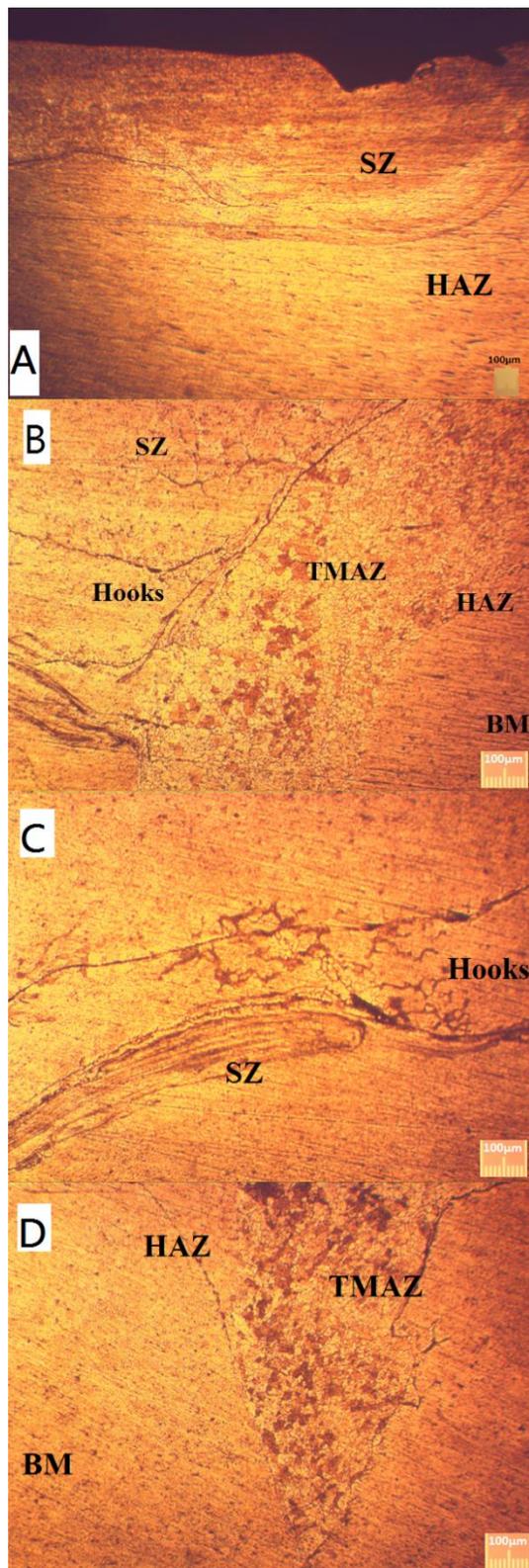
Figure (13): Micro Hardness test for 2024-T3 at the best conditions.

### 3-3. Microstructure

Figure (14) displays the morphology of the main zones at the right and left side of the refilled friction stir spot welded joint at the best conditions. This figure also exhibits the base material microstructure, heat affected zone (HAZ), thermo mechanical affected zone (TMAZ), stir zone (SZ) and nugget zone (NZ) as well as the hook shape that formed during the welding.

As demonstrated in figure (14) for the cross section of the RFSSW specimen for AA2024-T3, it can be seen that there is no keyhole existing at the center of the spot joint, which is the main benefit of the refill friction stir spot welding technique to reduce the concentration stress. Also, some of the material at the top surface is squeezed out and collected along the outer circumference of the tool shoulder boundary which is called 'flash'. The extruded pin filler was squeezed and formed the lower sheet, this process produced many hooks along the parting line between them. This practice ensures that there are oxide-free surfaces meets with each other, followed with high pressure and high temperature, which indicates that the conditions are acceptable to manage the welding.





**Figure (14):** Microstructure of the refilled friction stir spot welded joint at the best conditions (3000 rpm, 7 mm tool pin and 4765 N).

#### 4- Conclusions

Depending on the ultimate tensile shear tests at four speeds, two tools with different pin diameters and using different techniques for stir spot welding of Aluminum 2024-T3, the ultimate shear force values of RFSSW were found higher than those for FSSW and RFSSW technique for both (5 mm and 7 mm pin

diameter). The keyhole and the additional substance in weld owing to plate of filler in RFSSW technique lead to improved ultimate tensile shear force values relative to conventional FSSW and RFSSW-Pin technique, while the keyhole in the conventional FSSW technique plays as notch when the load is applied and leads to stress concentration.

Diameter of pin tools at different techniques effects on the ultimate values of tensile shear force, where the increasing in the diameter of pin tools gives more ability to carry the load. The best conditions were considered for microhardness and microstructure tests. Generally, the microhardness tests of the joint welded at the best conditions by RFSSW technique manifested a (W-shape) behavior. Also, the microstructural examinations of the refilled friction stir spot welded joint at these conditions revealed the morphology of the main zones as well as the hook formation. Eventually, the ultimate value of shear force (4765 N) was obtained at speed 3000 rpm and tool pin diameter 7 mm.

#### 5- References

- [1] S. T. Amancio-filho, A. P. C. Camillo, L. Bergmann, E. Kury, N. G. A. Machado, J. F. Santos "Preliminary Investigation of the Microstructure and Mechanical Behaviour of 2024 Aluminium Alloy Friction Spot Welds" *Materials Transactions, Special Issue on Aluminium Alloys 2010*, The Japan Institute of Light Metals. Vol. 52, No. 5, pp. 985–991, 2011.
- [2] S. Venukumar, S. Muthukumar, Y. Swaroop "Microstructure and Mechanical Properties of Refilled Friction Stir Spot Welding of Commercial Pure Aluminium" *Materials Science Forum*, Vol. 765, pp. 776–780, 2013.
- [3] S. Venukumar, S. Yalagi, S. Muthukumar "Comparison of microstructure and mechanical properties of conventional and refilled friction stir spot welds in AA 6061-T6 using filler plate" *Trans. Nonferrous Met. Soc. China*. Vol. 23, pp. 2833–2842, 2013.
- [4] Damjan Klobčar, Janez Tušek, Aleš Nagode, Matija Bušić and Vladka Lešer, "Comparison of joint strength produced by FSW, FSSW and a novel technique Friction Stir Liner Spot Welding" Paper presented at the Zavarivanje: zbornik radova = Welding: proceedings, Pages 31–40, 2014.
- [5] H. K. Ibrahim "Effects of Rotational Speeds and Tool Pin Geometry on Microstructure and Mechanical Properties of Refilled Friction Stir Spot Welds of Similar AA2024-T3 Aluminum Alloy Sheets" *International Journal of Engineering Research & Technology (IJERT)*. Vol. 6, No. 04, pp. 937–952, 2017.
- [6] Zhikang Shen, Xinqi Yang, Shuo Yang, Zhaohua Zhang and Yuhuan Yin "Microstructure and mechanical properties of friction spot welded 6061-T4 aluminum alloy" *Materials and Design* Vol. 54, pages 766–778, 2014
- [7] Muna Khethier Abbass, Sabah Khamass Hussein, Ahmed Adnan Khudhair "Optimization of Mechanical Properties of Friction Stir Spot Welded Joints for Dissimilar Aluminum Alloys (AA2024-T3



and AA 5754-H114)" Arab J Sci. Eng., Vol. 41, Pages 4563–4572, 2016.

[8] H.M. Anil Kumar, V. Venakata Ramana and S.P. Shanmuganathan "Experimental Investigation of Mechanical Properties And Morphological Studies on Friction Stir Welded Aluminum 2024 Alloy" Science Direct, Materials Today: Proceedings, Vol. 5, Issue 1, Part 1, Pages 700-708, 2018.

[9] S. Dourandish, S. M. Mousavizade, H. R. Ezatpour and G. R. Ebrahimi "Microstructure, mechanical properties and failure behaviour of protrusion friction stir spot welded 2024 aluminium alloy sheets" Science and Technology of Welding and Joining, Vol. 23, No. 4, 2018

[10] Kadhim K. Resan, Abbas A. Alasadi, Muhannad Al-Waily, Muhsin J. Jweeg "Influence of Temperature on Fatigue Life for Friction Stir Welding of Aluminum Alloy Materials" International Journal of

Mechanical & Mechatronics Engineering IJMME-IJENS, Vol. 18, No. 02, 2018.

[11] ASTM E1251–94 "Standard Test Method for Optical Emission Spectrometric Analysis of Aluminum and Aluminum Alloys by the Argon Atmosphere , Point-to-Plane" Vol. 03, 1999.

[12] Klaus M. Zwilsky, Edward L. Langer "Properties and Selection: Nonferrous Alloys and Special-Purpose Materials" American Society for Metals, ASM Handbook, vol. 2, 1997.

[13] ASTM E 8M–00b "Standard Test Methods for Tension Testing of Metallic Materials [ Metric ]" An American National Standard, , vol. 02, 2001.

[14] Y. Sun, H. Fujii, N. Takaki and Y. Okitsu, "Novel spot friction stir welding of 6061 and 5052 Al alloys", Science and Technology of Welding and Joining, Vol. 16, No. 7, Pages 605-612, 2011.