Al-Nahrain Journal for Engineering Sciences (NJES) Vol.21 No.2, 2018, pp.230-237

Effect of Friction Stir Welding and Friction Stir Processing Parameters on The Efficiency of Joints

Mohsin Abdullah Al-Shammari **Worood H. Ibrahim**
Mechanical Eng. Dep., University of Baghdad, Baghdad, IRAQ
dr.alshammari@uobaghdad.edu.iq worod_h@yahoo.com

Received: *09-May-2017* ***Revised:*** *18-Oct.-2017* ***Accepted:*** *18-Jan.-2018*
http://doi.org/10.29194/NJES21020230

Abstract

Friction Stir Welding is one of the most practical welding process at the solid state. Friction Stir Processing is used to enhance the microstructure of FSW welded zone. The present study investigates the effect of welding parameters on the tensile properties of FSW and FSP joining 3 mm AA 5083 - H111 aluminum alloy by means of stress – strain curve with a uniaxial tensile test and by comparing the efficiency between FSW , FSP and base metal .The experiments were conducted with 1000,1500 and 2000 rpm rotation speeds ,and 20,40 and 60 mm/min travel speed. The best result of the welding joint was shown at the 20 mm/min feed speed and 1500 rpm rotational speed for FSW, and 40 mm/min feed speed and 1500 rpm rotation speed for FSP. The efficiency of ultimate tensile strength reaches to 92% for FSW and 94% for FSP.

Keywords: Friction Stir Welding, Friction stir processing, Mechanical Properties, AA5083 - H111.

1 Introduction

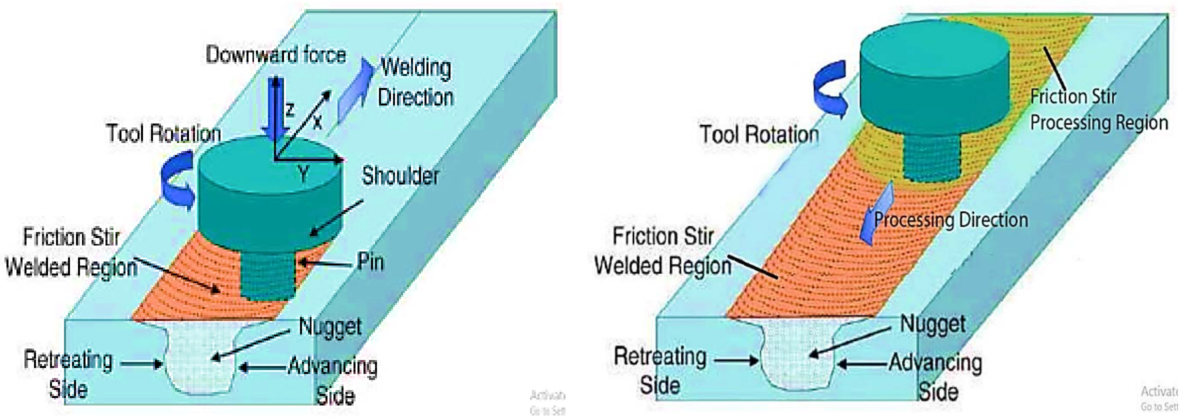
Friction Stir Welding (FSW) was developed by Wayne Thomas at TWI (The Welding Institute) in 1991. At first, the process was seen as a “laboratory” curiosity, but it soon became obvious that FSW very useful in the manufacturing of aluminum products [1]. FSW considered weight savings in lightweight applications due to the high strength of joints as a compared with conventional welding process. The principle of friction stir welding works is depend on the rotating tool consist of a cylindrical shoulder and pin come out from it, the pin plunged through two pieces of sheet to make the sufficient string welded zone and the rotating shoulder provide friction to generate the heat sufficient to elevate the temperature below melting point. Then the tool traveled forward along the butt joint line. particular preparation of the type of joint and filler metal is not required. [2] Mechanism of friction stirs welding with nomenclature shown in Figure (1) - (a) [3].

Friction stir processing joint was developed for modifying the FSW welded zone, FSP depend on Friction stir welding principle [4], welding occurred in double pass (rather than single pass as a FSW) one forward and the other to return along the joint line to achieve maximum performance with low production cost in less time using as illustrated in Figure (1) -(b). In this study the parameters used in FSP and FSW are reviewed and their effect on tensile strength of AA 5083 aluminum Alloys.

2 Related Work

In 2015, Muhsin et al. [4] investigated the friction stir welding (FSW) and friction stir processing (FSP) of AA5086-H32 aluminum alloy. It has been noted that the microstructural grain size of (FSP) welded joints is a little finer and tensile, bending strength, hardness and percentage of elongation are greater than (FSW) joints. In 2011, Ayad et al. [5] Study the welding parameters and their effect on mechanical properties of aluminum alloy 3003 H14 Friction stir-welded (FSW) joints. The experimental results indicated that the process parameters have an important effect on mechanical properties of joints. The optimum results of the weld gained at the parameter 80mm/min weld speed and 1500 rpm rotation speed. In 2012, Sattari et al. [6] study FSW on thin sheet 0.8mm in thickness 5083 aluminum sheets. Mechanical properties show that byincreasing speed ratio (rotational speed w/ travel speed v) up to 28.125 better mechanical properties achieved and the average of micro hardness was decreased. The best results of tensile strength properties and micro hardness areobtained by speed ratio range of 18.58 to 34.84. In 2015, Hiba et al. [7], investigated the mechanical properties of 2024-O aluminum alloy by using two different process parameters have been selected which are: rotational speed of (1300,1500 and 1700rpm) and feed speed of (20,40 and 60 mm/min), the best enhancement of the welding joint at the parameter 40 mm/min feed speed and 1300 rpm rotational speed for FSW, and 40 mm/min feed speed and 1500 rpm rotation speed for FSP.

The present study investigates the effect of the welding parameters on the tensile properties of FSW and FSP joining 3 mm AA5083 - H111 aluminum alloy and comparing the efficiency between FSW, FSP and base metal.



(a) (b)

Figure 1: Schematic Diagram of (a) FSW/ and (b) FSP Joints [3]

3 Experimental Work

3.1 Process Parameters

There are many welding parameters affect quality of weldment in FSW/P. In the present study, two process parameters were studied, which are, rotational speed and welding speed. Three levels for each parameter are used as shown in Table (1).

Table 1 : The parameters of FSW/P

Parameter	Level		
	1	2	3
Rotation speed (rpm)	1000	1500	2000
Travel speed (mm/min)	20	40	60

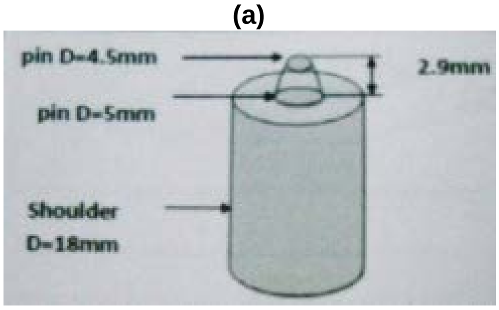
3.2 Materials and Experimental Procedure

In this study AA5083-H111 Aluminum alloy was selected. The material is widely used in pressure vessels, shipbuilding, rail cars, vehicle and tip truck bodies and mine skips and cages.The mechanical properties and chemical composition of AA5083-H111 aluminum alloy were given in Table (2) and Table (3) respectively. In this investigation 200*75*3 mm sheets dimensions are used. The fixture has been used for clamping the samples to be welded on CNC milling machine (MITSUBISHI CNC M70V) and is shown in Figure (2)-(a). Specially prepared tool Figure (2) -(b) was pushed through the bonding line and then traveled through welding line at various rotational and travel speeds under a fixed friction force by single pass, while in friction stir processing was carried out by double pass.

The pin of the tool is tapered in order to reduce the initial high forces during plunging operation, the welding tool was made of rod from tool steel X38, the rod machined to desired dimension by using CNC machine.

Tensile test was carried out on samples taken in a perpendicular direction to the welding line to determine the tensile properties of the welding joints for both welding processes. The shape and dimensions of the tensile specimens were chosen according to ASTM (E 8M) as shown in Figure (3). All tensile tests were performed at 25^{o}C by TESTOMETRIC instruments, which has a maximum capacity of (25kN). Then the average of three samples (Start, middle and end welding line) was transferred to evaluate the tensile properties of each welded joint.

(a)



(b)

Figure 2:- a- MITSUBISHI CNC M70V milling machine, b- Tool shape and dimension.

Table 2: Mechanical properties of AA5083-H111

	σ_yMPa (proof stress 0.2%)	σ_UMPa	Modulus of elasticity (GPa)	Elongation %
Standard value [8]	145	300	72	23
Actual value	143	300	72.9	27

Table 3: Chemical Composition of AA5083 H111 alloy

Element (wt%)	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Standard value[9]	0.4-0.7	0.4	0.1	0.4-1	4-4.9	0.05-0.25	0.25	0.15	BAL.
Actual value	0.12	0.33	0.05	0.48	4.14	0.06	0.1	0.02	BAL.

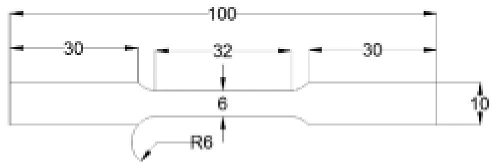


Figure 3: Tensile test specimen dimension according to ASTM E 8M,all dimensions in mm

4 Results and Discussion

The friction stir welding and processing joints were shown in Figure (4) which shows different results of welding shapes where some welds shows presence of flash because of the plunging depth of the tool this can be avoided by controlling it which must be little more than the plate thickness.Tunnel defect was found at the intersection of weld nugget and thermomechanical affected zone due to high rotational speed and travel speed were shown in Figure (5).

The transverse tensile test results are mentioned in Table (4) and Table (5). It can be shown that yield and ultimate tensile strength were reduced in the welded area compared with those of the origin material, due to a combination of dissolution, coarsening and precipitate of strengthening precipitates during FSW or localized deformation, considering that the welded aluminum alloys AA5083-H111 is work hardened alloys meaning that a drop in a the mechanical properties is expected due to the heat generation during FSW/P. The angle of fracture in the parent alloys is 45º and with brittle fracture surface as shown in Figure (6).

The shape of the fracture and its location varies between the base metal sample and welded samples,most of the specimens were failed in HAZ at advancing side and very few specimens were failed at center line of the weld as illustrated in Figure (7) and Figure (8) for FSW and FSP respectively. Some of the FSW specimens were failed in the NZ region as W7 sample due to many causes such as a lack of penetration, existence of defects and oxide layer. W6 is failed due to tunnel along the weld direction. in W5 and W1 the fracture started from the defect position the small defects were ineffective to initiate the crack during the tensile test.

The defect free weld specimens have been broken in the TMAZ and/or HAZ as appeared in tensile tests of all FSP specimens for example P1 and P7 which are illustrated in Figure 8, the fracture angle of the specimens are the same as in the fracture of the parent alloys , the angle of fracture in the test specimens is 45º, based on the tensile test results of the defect free welds.

The tensile test for FSW and FSP were done at room temperature. The results are shown in Table(4) and (5) for FSW and FSP respectively.

$$\text{Efficiency(Eff)}=\frac{UTS of welded sample}{UTS of base metal}\, x\ 100\%$$

Table 4: The result of the tensile test for FSW joints

Sample No.	speed		UTS (MPa)	σ_y MPa	Eff %
	rotation (rpm)	travel (mm/min)			
B.M			300	143	
W1	1000	20	238	129	.79
W2	1000	40	256	135	.85
W3	1000	60	266	142	.88
W4	1500	20	276	143	.92
W5	1500	40	251	141	.83
W6	1500	60	87	85	.29
W7	2000	20	217	139	.73
W8	2000	40	222	141	.72
W9	2000	60	162	121	.53

Table 5 The result of the tensile test for FSP joints

Sample No.	Speed		UUTS (MPa)	σ_y MPa	Eff %
	rotation (rpm)	travel mm/min			
P1	1000	20	282	131	0.941
P2	1000	40	205	140	0.68
P3	1000	60	257	136	0.85
P4	1500	20	267	139	0.88
P5	1500	40	284	144	0.942
P6	1500	60	279	142	0.93
P7	2000	20	276	141	0.92
P8	2000	40	273	141	0.91
P9	2000	60	194	143	0.64

P1
P2
P3
P4
P5
P6
P7
P8
P9
W1
W2
W3
W4
W5
W6
W7
W8
W9

Figure 4: The appearance of the welding beads of AA5083-H111 plates produced with Friction Stir Processing and friction stir welding joints

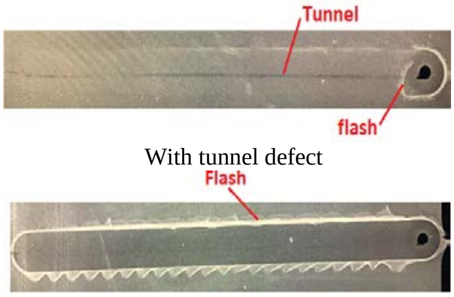


Figure 5: result of x-ray of some welded plate

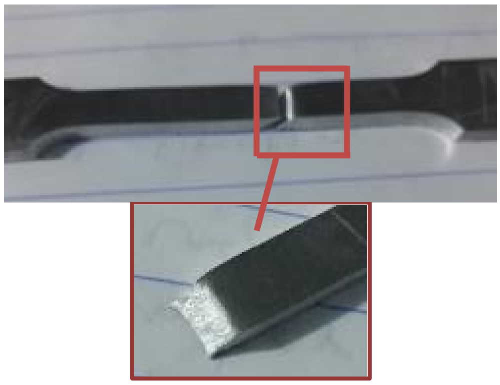


Figure 6: Fracture of parent alloys AA5083-H111 in the tensile test

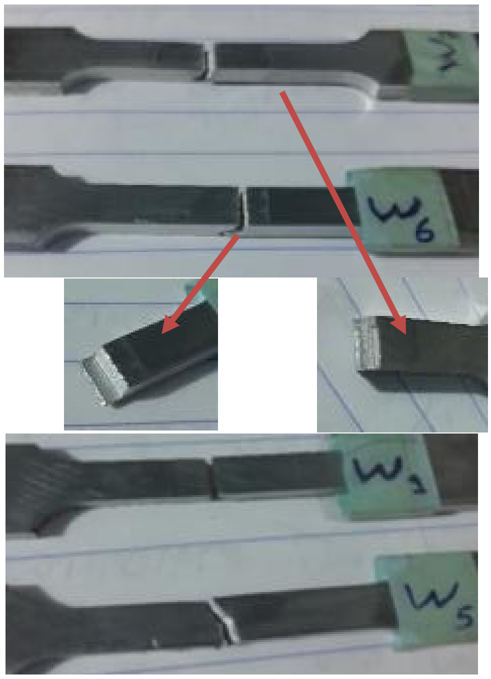


Figure 7: Fracture during tensile test of FSW sample

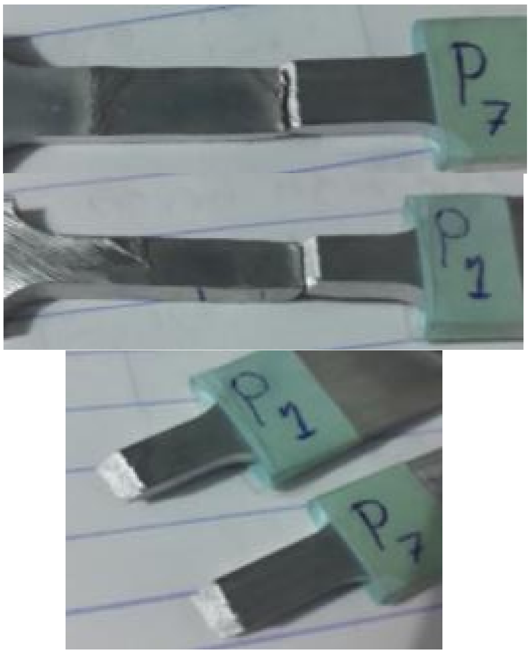
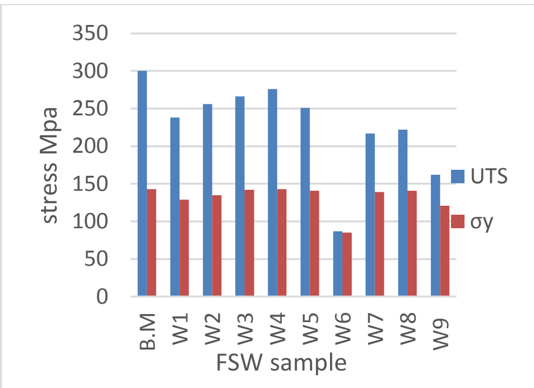


Figure 8: Fracture during tensile test of FSP samples

The diagram in Figure (9) illustrates the results comparison between FSW, FSP and base metal shows the values of the tensile strength and yield strength for the FSW and FSP for different values of the studied parameters (rotational and travelling speeds). The best result of the welding joint is obtained with the 20 mm/min feed speed and 1500 rpm rotational speed for FSW, and with the 40 mm/min feed speed and 1500 rpm rotation speed for FSP. The efficiency of the ultimate tensile strength reaches to 92% for FSW and 94% for FSP.

The efficiency samples welded by FSP are mostly above 80%, while FSW vary from 30% to 90%, because of the FSP welded sample was exposed to force and heat longer than the FSW welded sample where the time used in the first operation is twice the last that provide sufficient heat to softening the material and the re-stirring provide good refining and recrystallisationthat give higher strength in welded area.



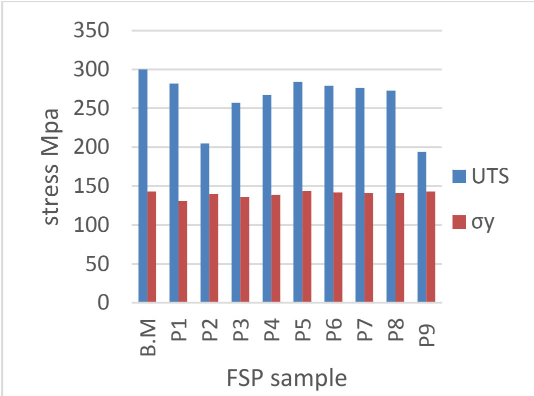


Figure 9: Results of tensile test

FSW results are illustrated in Figure (10) showing the relation between the yield stress and rotational speeds at different travelling speeds and Figure (11) shows the relationship between the UTS and the travel speeds at different rotational speeds. From both figures it can be shown that the yield stress slightly increases with increasing rotation speed while ultimate tensile stress decreases with increasing travel speed during using high rotation speed (1500-2000) rpm. while during the lowest rotation speed (1000) rpm ultimate tensile stress will increase with increasing travel speed.

FSP results illustrated in Figure (12) shows the relationship between the yield stress and rotational speeds at different travel speeds and Figure (13) shows the relationship between the UTS and the travel speeds at different rotational speeds. From the two Figures it can be found that the yield stress slightly increases with increasing rotation speed while ultimate tensile stressdecreases with increasing travel speed where by using 20 mm/min (lowest travel speed) in different rotational speed give the best results.

The ultimate tensile stress increases with increasing rotational speed and travel speed which exert a significant effect on the higher heat input and mechanical properties.Where the weldability is significantly affected by the rotational speed, whenever the rotation speed is increased the input heat increases to softening the material below melting point but should not exceed the reasonable limitthat leads to generate heat over of melting temperature.

It is believed that the increase in weld strength with increasing welding speed is attributed to the reduced heat input per unit length which results in less over aging of the weld zone.

The elongation of all FSW and FSP samples is less than that of parent metal as shown in the engineering stress-strain diagram in Figure (14),the measured elongations were very low in most of FSW samples, while a little decrease in the elongation has been resulted in FSP samples as compared with the elongation of the parent alloys represented by aluminum alloy AA5083-H111.

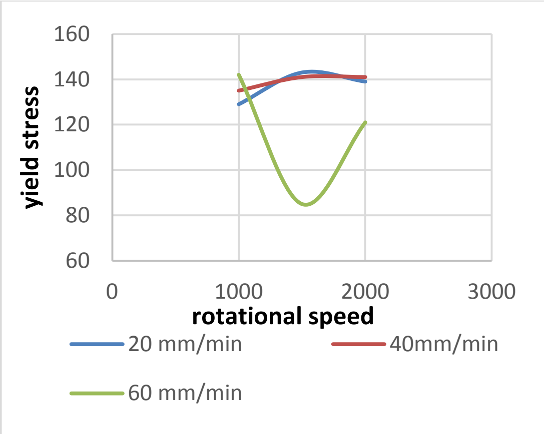


Figure 10: Relationship between Yield stress and rotational speeds at different travel speeds for FSW metals

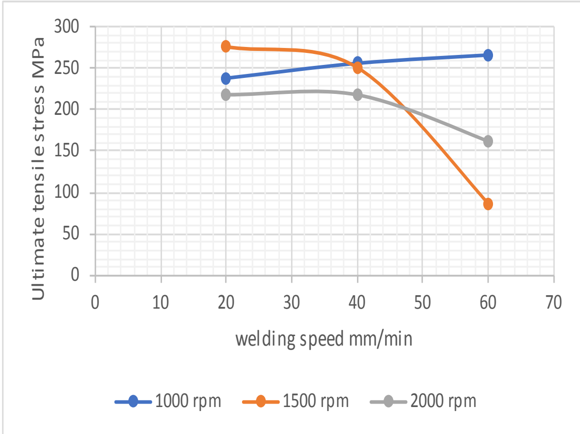


Figure 11: Relationship between ultimate tensileStressand travelspeeds at different rotational speeds for FSW metals

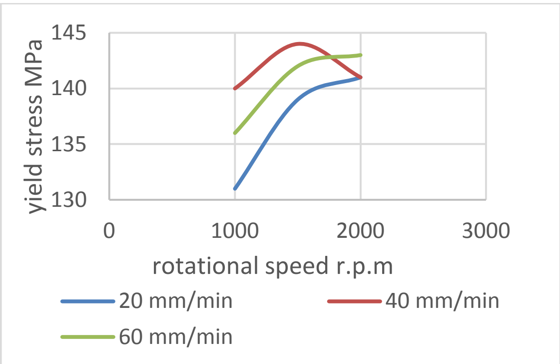


Figure 12 : Relationship between yield stress and rotational speedsat different travel speeds

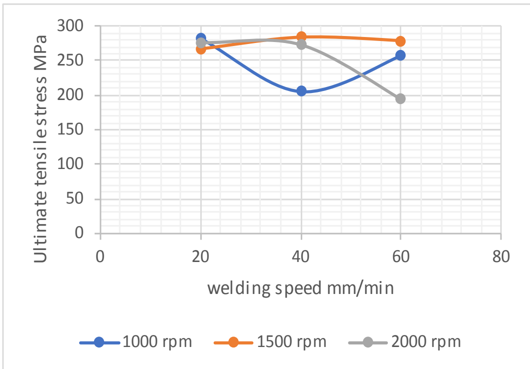
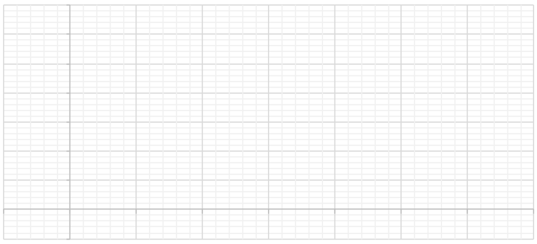
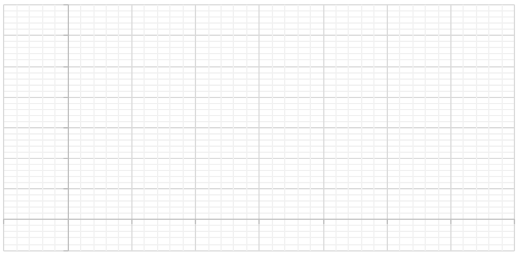


Figure 13: Relationship between UTSand rotation speeds at different travel speeds



(a) (b)

(c) (d)



(e) (f)

Figure 14: Engineering stress-strain curve of base metal , FSW and FSP specimens, (a) FSW samples at $\omega = 1000\ rpm$,(b) FSW samples at $\omega = 1500\ rpm$,(c) FSW samples at $\omega = 2000\ rpm$,(d) FSP samples at $\omega = 1000\ rpm$,(e) FSP samples at $\omega = 1500\ rpm$,(f) FSP samples at $\omega = 2000\ rpm$

5 Conclusions

The main findings of this investigation are:

1. some of the FSW specimens failed in the NZ region due to various reasons such as the lack of penetration, existence of defects, oxide layer or failed due to tunnel along the weld direction all this reason occurs because insufficient heat to softening the welded metal.
2. FSP samples have been broken in the TMAZ and/or HAZ as appeared in tensile tests and the fracture angle are the same as in the angle of the parent alloys based on the tensile test results of the defect free welds.
3. The best result of the welding joint is obtained with the 20 mm/min feed speed and 1500 rpm rotational speed for FSW, and with the 40 mm/min feed speed and 1500 rpm rotation speed for FSP. The efficiency of the ultimate tensile strength reaches to 92% for FSW and 94% for FSP.
4. Efficiency samples welded by FSP mostly above 80%, while FSW vary from 30% to 90%.
5. In FSW the yield stress slightly increases with increasing rotation speed while ultimate tensile stress decreases with increasing travel speed.
6. In FSP the yield stress slightly increases with increasing rotation speed while ultimate tensile stress decreases with increasing travel speed.
7. The weldability is significantly affected by the rotational speed, and the increase in weld strength with increasing welding speed is attributed to the reduced heat input per unit length which results in less over aging of the weld zone.
8. The elongation of all FSW and FSP samples is less than that of parent metal**.**

References

[1]. FSW -Technical - Handbook, ESAB AB, Welding Automation, SE -695 81 LAXÅ, Sweden

[2]. Darras, Basil Mohammad. Integrated thermo-mechanical investigations of friction stir processing of light weight alloys. ProQuest, 2008.

[3]. JeganathanArulmoni, V. R,S, Mishra. Friction Stir Processing of Aluminum alloys for Defense Applications' International Journal of Advance Research and Innovation, 2(2): 337-341, 2014.

[4]. Muhsin J. Jweeg, Ayad M.Takhakh, Nawzad K. Kareem. Comparison Between Friction Stir Welding (FSW) And Friction Stir Processing (FSP) of AA5086 Aluminum Alloy. International Journal of Technical Research and Applications, 3(6): 205-210, 2015.

[5]. Ayad, M. Takhakh, Asmaa M. Abdullah. An Experimental Investigation on Fatigue Properties of AA3003-H14 Aluminum alloy Friction Stir Welds. Journal of Engineering, University of Baghdad, 17(6): 1391-1400, 2011.

[6]. Sattari, S., H. Bisadi, and M. Sajed. Mechanical properties and temperature distributions of thin friction stir welded sheets of AA5083. International Journal of Mechanics and Applications 2(1): 1-6,2012.

[7]. Hiba K. Hussein. Optimization of Process Parameter For Friction Stir Welding and Processing of 2024-O Aluminum alloys. M.Sc. thesis University of Baghdad, College of Engineering, Mechanical Engineering, Department,2015.

[8]. Material Data Sheet 5083-O H111 ,ThyssenKrupp Materials (UK) Ltd, Cox's Lane, Cradley Heath ,West Midlands B64 5QU,2013.

[9]. ASTM International 'Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate'Designation: B 209-02a,2004.

تأثيرمتغيرات اللحام والمعالجة بالمزج الاحتكاكي على كفاءة الربط

أ.م.د محسن عبدالله الشمري
قسم الهندسة الميكانيكية
جامعة بغداد

ورود حسين ابراهيم
قسم الهندسة الميكانيكية
جامعة بغداد

الخلاصة

تعد طريقة اللحام بالمزج الاحتكاكي واحدة من اكثر طرق اللحام في الحالة الصلبة فعالية، بينما المعالجة بالمزج الاحتكاكي تستخدم لتحسين البنية المجهرية للمنطقة الملحومة بالمزج الاحتكاكي.ان الدراسة الحالية تحقق في تأثير متغيرات اللحام على خصائص الشد لسبيكة الالمنيوم AA 5083-H111 بسمك 3 ملم بواسطة دراسة مخطط الاجهاد - الانفعال .تم تصنيع العينات بسرع دورانية و خطية مختلفة (1000 - 1500 - 2000 دورة/ دقيقة) و (20 -40 -60 ملم/دقيقة) على التوالي .افضل نتيجة للحام بالمزج الاحتكاكي تحققت بسرعة دورانية 1500 دورة /دقيقة و خطية 20 ملم /دقيقة بكفاءة تصل الى 92% من المعدن الاصلي ،اما المعالجة بالمزج الاحتكاكي فتحققت بسرعة دورانية 1500 دورة/دقيقة و خطية 40 ملم /دقيقة بكفاءة 94% وقد تم حساب الكفاءة بالاعتماد على اقصى مقاومة شد للقطع الملحومة مقارنة مع اقصى مقاومة شد للمعدن الاساسي.