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EFFECT OF WE LDING PARAMETERS ON MECHANICAL PROPERTIES OF FRICTION STIR LAP WELDED JOINTS FOR SIMILAR ALUMINUM ALLOYS (AA1100-H112 & AA6061-T6)

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Abstract: Friction stir welding (FSW) is a solid state welding used for joining similar and dissimilar aluminum alloys which are hard to weld by conventional fusion welding processes. In this study friction stir lap welding (FSLW) Joints are made for similar aluminum alloys (AA1100 to AA1100) and(AA6061to AA6061) sheets of 3mm thickness and those alloys have low to medium strength and have difference in melting temperature and other physical properties.FSLW processes were carried out by conventional technique. The friction stir lap welding of similar aluminum alloys was carried out by varying the welding parameters, such as tool rotation speeds (1000, 1250 and 1600pm) and travel speeds (35, 75 and 100mm) and pin length of (5.4 mm) with using cylindrical threaded pin geometry or profile. Many tests and inspections were performed such as X-Ray radiographic and tensile shear test .Microhardness and microstructure observations by using optical and SEM were carried out at the best welding parameters. The above tests were used to evaluate the weld quality and joint efficiency under different welding parameters. The best welding parameters appeared in FSLW were 1250rpm and travel speed 100 mm/min. It was found that higher hardness value was (94.38HV) for 6061-T6 and 49HV for 1100-H112 in stir zone for both FSLW joints of AA6061-T6 and AA1100-H112 and that decrease toward the HAZ and base metals of AA1100 and AA6061.

Keywords: *Friction Stir Lap Weld, Travel speed & Rotational Speed*

تاثير عناصر اللحام على الخواص الميكانيكية لوصلات لحام الخلط الاحتكاكي التراكبية لسبائك الالمنيوم المتشابه(AA1100-H112 & AA6061-T6)

الخلاصة: لحام الخلط الاحتكاكي هو لحام الحالة الصلبة الذي يستخدم لربط سبائك الالمنيوم المتشابهة والمختلفة و التي يصعب لحامها بواسطة عمليات اللحام الانصهاري التقليدية.في هذه الدراسة تم اجراء لحام الخلط الاحتكاكي لوصلات تراكبيه من سبائك الالمنيوم (AA1100+ AA1100) و (AA6061 + AA6061) المتشابهة سمك 3 ملم علما ان هذه السبائك تملك مقاومة شد قليلة الى متوسطة وكذلك تملك درجات انصهار و خواص فيزيائية مختلفة.عمليات اللحام الخلط الاحتكاكي لوصلات تراكبية نفذت بواسطة التقنية التقليدية لوصلات تراكبية لسبائك الالمنيوم المتشابهة مع اختلاف متغيرات اللحام مثل سرع الدوران (1000,1250,1600) دورة/دقيقة و سرع اللحام (35, 75, 100) ملم/دقيقة باستخدام عدة اسطوانية مسننة و طول المسمار4 .5 ملم. تم اجراء عدة فحوصات مثل الفحص بالأشعة السينية (X-Ray) و فحص مقاومة القص وكذلك تم فحص الصلادة و البنية المجهرية باستخدام المجهر الضوئي (OM)والمجهر الماسح (SEM) عند افضل الظروف. وكانت افضل ظروف لحام عند سرعة دوران 1250 دورة/دقيقة ، 100 ملم/دقيقة.وجد بأن اعلى قيمة صلادة ظهرت هي 94.38 فيكرز لسبيكة اللحام AA6061 و 49 فيكرز لسبيكة AA1100 في منطقة الخلط (SZ) وتقل الصلادة باتجاه منطقة التأثير بالحرارة(HAZ) و المعدن الاساس للسبيكة (BM) و لكلا السبيكتين.

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1. Introduction

Friction welding is a type of forge welding, i.e. welding is done by the application of pressure. Friction generates heat, if two surfaces are rubbed together, enough heat can be generated and the temperature can be raised to the level where the parts subjected to the friction may be fused together [1]. The friction stir welding was developed in England by The Welding Institute (TWI) in 1991. High-quality weld can be created by this process with e. g. a milling machine because using same movement conditions but the tool is different [2].

Friction stir we1ding(FSW) is a solid state welding technology that can be used to connect not only aluminum alloys that are weldable by conventional methods but also high-resistance aluminum and some other hard- alloys that are difficult to weld using traditional fusion welding processes [3]. There are several dependent and independent operating variables that could impact the FSW process. According to literature, field of temperature, heating and cooling rate, applied torque, axial force are the key independent variables. In contrast, speed of welding, tool downward pressure, rotational velocity, tool geometry and inclination angle are the chief independent variables [4].

The material of the FSW tool should be carefully chosen; parameters such as tool wear and quality of welding should be taken into account. Tool material properties has direct impact on the weld quality due to their effect on the heat dissipation and generation rates. Furthermore, erosion in the material of the tool has dramatic adverse impacts on both the weld microstructure and in rising the friction stir welding cost [5]. The majority of FSW studies have been based on butt joint geometry. Lap joint configuration which shown in "Fig. 1" is also widely used in conventional welding and friction stir lap welding (FSLW) [6]. Lap joint and its parameters which shown in "Fig. 1" usually used in finishing process of parts in aerospace, air craft and automotive manufacturing. In recent years, FSW has been the most suited for aluminum alloys lap joints [7]**.** H. Bisadi et al. [8] studied the microstructure and mechanical properties in certain FSW process parameters (rotational and welding speed) for lap joint welding. The material used was 5083 aluminum alloy, 2.5 mm thick and the parameters applied were 600, 825, 1115, 1550 rpm rotational speeds and 32, 60 mm/min welding speeds,He found that A superior weld joint is obtained at lower rotational and welding speeds. In this case, it is recommended to use higher welding speeds to increase the thermal gradient at the weld zone. The results showed that reduced heat transfer and not enough stirred area are the cause for the joint defects that occurred at 600 rpm rotational speed.

Muna K.Abbass et al. [9] investigated two welding processes: friction stir welding (FSW) and tungsten inert gas (TIG). For TIG, 4 mm thick Al 6061-T6 and filler metal of Al-Mg alloy were used and FSW was employed through automatic milling machine at various bed speeds (25, 50, 80, 100 and 125 mm/min) and tool rotational speeds (630, 800, 1000, 1250 and1600 rpm). The results of the investigations showed:

For FSW the best results were obtained at 1250 rpm with 50 mm/min and at 800 rpm with125 mm/min. Using these parameters for FSW, the tensile test and joint efficiency results were superior to those of TIG joint (79 % as opposed to 57 %).

FSW joints had superior results of tensile test compared to TIG joints because of the fine equiaxed grains and strengthening precipitates that develop during the FSW process.

Sadiq Aziz et al. [10] applied FSW to obtain butt joints of AA5083 and AA6061 aluminum alloy plates (3 mm thick) to electro-galvanized steel. The conclusions are:- The single-pass FSW attempt of the three dissimilar materials was successful.The highest joint efficiency (73%) was obtained at 900 rpm rotational speed, 20 mm/min welding speed and diffusion technique.

Muna K. Abbass et al. [11] applied FSW for joining AA2024-T3 and AA7075-T73 dissimilar aluminum alloys of 3 mm thickness and They concluded that When the welding speed was increased the tensile strength of the welded joints is increased.Grain refinement and precipitates increase the microhardness in SZ as opposed to the values obtained through TMAZ and HAZ.

Esther T. Akinlabi et al. [12] studied the influence of the rotational speed on the integrity of the weld joint. lap joints obtained through FSW, 1050 aluminum alloy, 3 mm thick plates, 1200 rpm - 2000 rpm rotational speeds, 150 mm/min traverse speed (constant). The results showed that the macrostructure revealed a basin shape in the nugget, due to high deformation and frictional heat occurring at upper surface level. The microstructure showed fine and equiaxed grains with smaller grain size than the original material in the stirred zone. Dynamic recrystallization and plastic deformation produced the transformed stirred zone.

The aim of this work is to study the effect of welding parameters such as tool rotation speed and welding speed on the microstructure and mechanical properties of similar Friction Stir Lap Welding(FSLW)joints for aluminum alloys(AA6061-T6 and AA1100-H112)

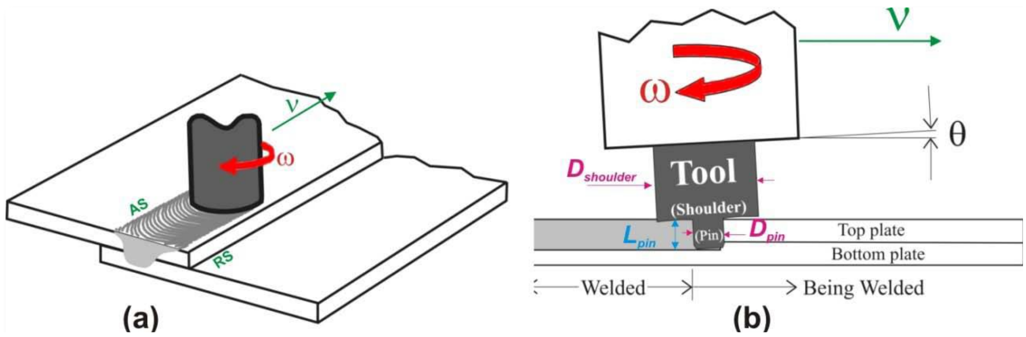


Figure 1. Schematic illustration: (a) FSLW process and (b) various FSLW parameters [2].

2. Experimental Work

2.1. *Materials*

Commercially aluminum alloys (AA1100-H112 and AA6061-T6) plates of thickness 3mm were used and prepared to be joined by FSLW ,The plates dimension were(200×100×3) mm^3. A fixture and back plate were especially made to fixed and supported the plates to be welded on the milling machine table. The chemical composition of the two alloys were shown in “Table 1 and 2”.

Table 1. Chemical Composition for the alloy AA1100-H112

Element wt.%	Si + Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Others Each	Others Total	Al
Nominal (value)	0.95 Max	0.2 max	0.05 Max	-	-	-	0.1 max	-	0.05	0.15	Bal.
Measured (value)	0.746	0.154	0.003	Nil	0.0019	Nil	0.006	0.003	0.007		Bal.

Table 2. Chemical composition for the alloy AA6061-T6

Element wt.%	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Others Each	Others Total	Al
Nominal (value)	0.8 max	0.7 max	0.4 max	0.15 Max	1.2 max	0.35 max	0.05 Max	0.25 max	0.15 max	0.05 max	0.15 max	Bal.
Measured (value)	0.539	0.532	0.303	0.092	0.921	0.209	0.0122	0.064	0.016	0.009	0.009	Bal.

2.2. *Preparation of Plates*

Two aluminum alloys plates AA1100-H112 and AA6061-T6 were used to obtain similar welded joints. "Fig. 2" explains the plates dimensions for overlap sheets.

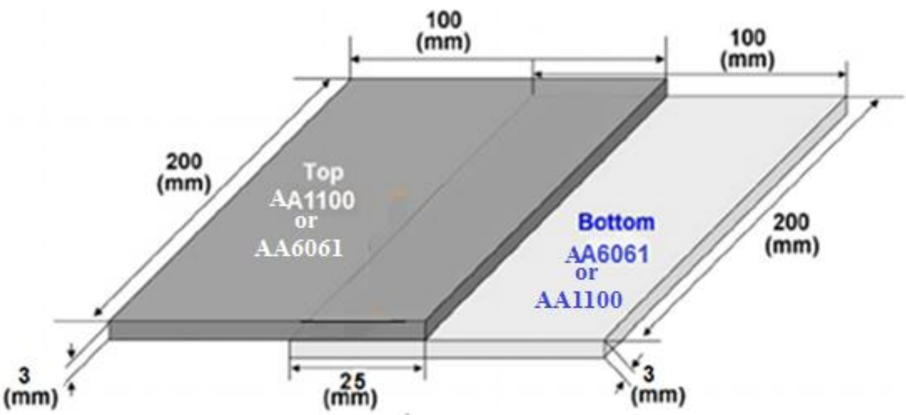
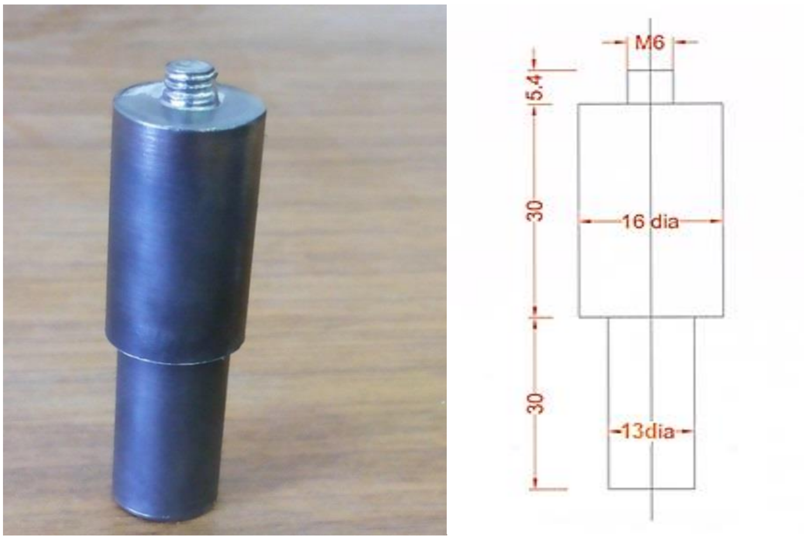


Figure 2. Plates dimensions to be Lap joined, all dimensions in mm

3. *FSLW Process Procedure*

FSLW operation was conducted out to produce lap welding joints for similar aluminum alloys (AA1100-H112 to AA1100-H112) and (AA6061-T6 to AA6061-T6). After experimental setup of milling machine, the specimens were mounted over the back plate then supported firmly by special the clamps and bolts with the aid of fixtures. After that the FSW tool pin was rotated Clockwise at the desired speed. The high speed steel Tool was designed as shown in "Fig. 3", the diameter of the shoulder was 16mm, the pin diameter equal to 6mm threaded by (M6×1) and its length equal 5.4mm.



(a) (b)

Figure 3. Specification of the Tool: (a) Tool picture (CY) (b) Tool dimensions

The Friction stir lap welding (FSLW) method was conducted out at variables welding parameters. The inclined angle is (2º), penetration depth (0.1) mm, and pin length 5.4mm and dwell time (30sec) stay fixed. "Table 3" indicates the welding factors used in this work for similar welded joint of AA1100 with AA1100 and AA6061-T6 with AA6061-T6. Three rotation speed**s (**1000,1250 and 1600) were used and three travel speed(35,75 and 100) used for this research.

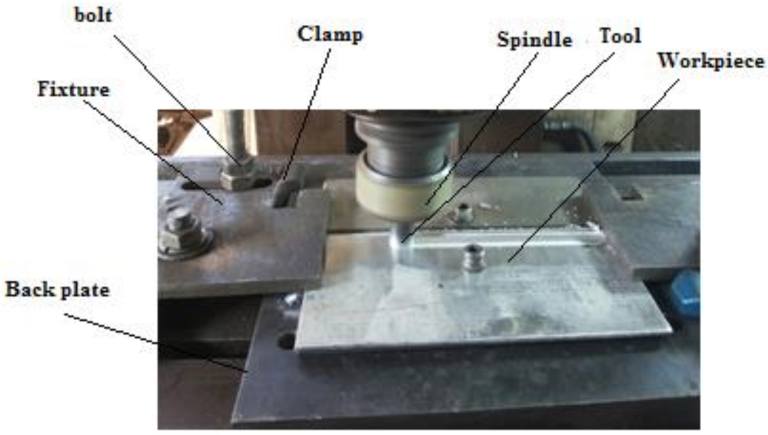


Figure 4. Shows the Welding tool , work piece clamp & fixture on the milling machine bed

FSLW Operation was conducted out to produce lap welding joint for similar aluminum alloys (AA1100-H112 and AA6061-T6).

Table 3. FSLW joints for the similar aluminum alloys (AA1100 and AA6061)

Specimen No.	Rotation Speed (rpm)	Travel Speed mm/min	Max.shear force KN	σ lap N/mm	Joint efficiency %
A1	1000	35	4.68	234	88%
A2	1250	35	4.83	241.5	91%
A3	1600	35	4.44	222	83%
A4	1000	75	4.3	215	81%
A5	1250	75	4.45	222.5	84%
A6	1600	75	4.08	204	77%
A7	1000	100	4.28	214	80.7%
A8	1250	100	5.1	255	96.2%
A9	1600	100	4.85	242.5	91.5%
B1	1250	100	5.1	260	96.2%
B2	1250	100	3.49	127	66%

4. Results and Discussions

4.1. *Tensile Shear Force Test*

Tensile-shear test of lap weld has been used to evaluate the shear strength of FSLW joint. T

est samples with 20 mm wide that are perpendicular to the welding direction were machined from the welded plates, "Fig. 5" shows the tensile shear Force sample. The load deformation tests were conducted for all lap welding joints under different conditions to make sure getting the maximum shear force between the tested specimens and "Fig. 6", shows load-deformation for AA1100 similar joint at the best welding conditions.

It was obtained that shear force of similar FSLW joints (AA1100 + AA1100) as shown in “Table 3” were higher than the similar FSLW joints(AA6061 + AA6061). This is due to following probable reasons:

1- The high weldability of AA1100 sheet helps to produce plastic deformation and dynamic recrystallization to get fine grain size that leads to increase the welding tensile shear force.
2- While for the AA606I joint the shear force was lower and this is due to the presence of a micro defects in the welding joint.

3- Because of the low weldability of AA606I which is a heat treatable alloy so that it has a precipitating hardening phases as well as the presence of second phase particles in addition to some metallic components and inclusions which affect the force.

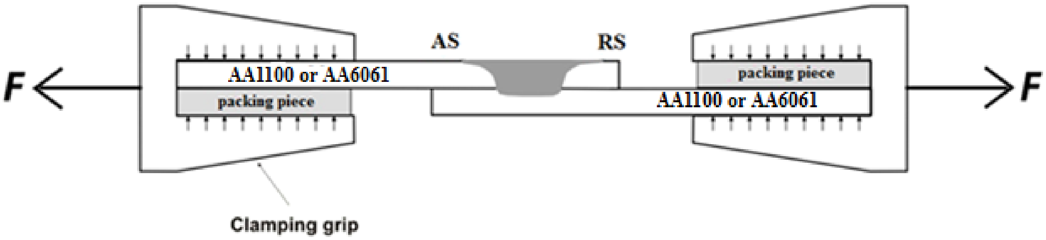


Figure 5. Sample for shear force test, all dimensions in mm

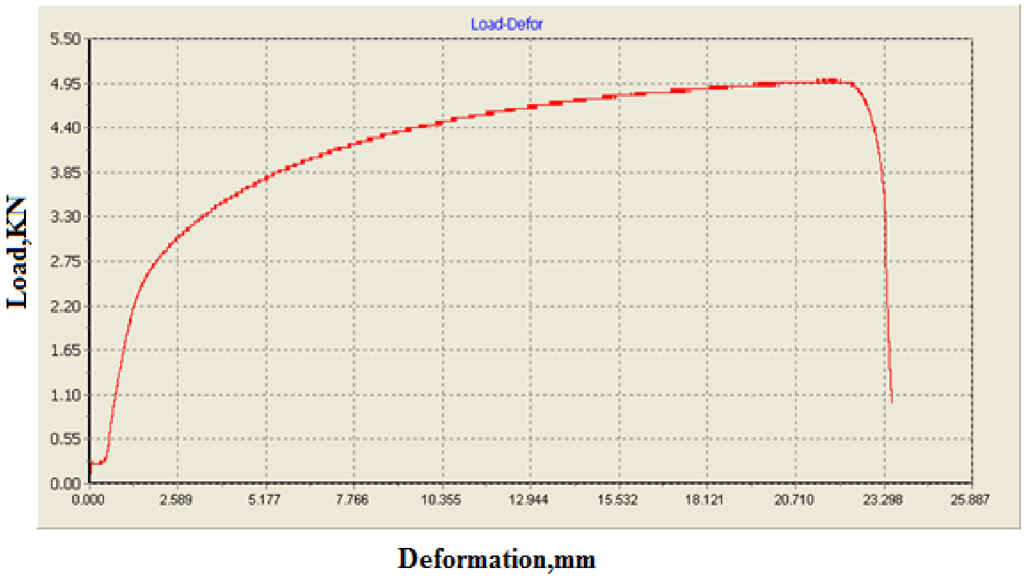


Figure 6. Load-Deformation relationship for FSLW similar joint of(AA1100)under the best condition,1250rpm &100mm/min.and pin length 5.4mm

4.1.1. *Effect of tool travel speed on tensile shear force*

The tensile shear test results. There is benefit from increasing the feed rate, and the best travel speed was 35 mm/min as illustrated in "Fig. 7".

This decrease in force joint may be due to reduction in heat input of weld line. In addition, the best weld efficiency reached was 88% with a tool rotational speed of 1000 rpm and Travel speed of 35mm/min and giving a defect free welded joint.

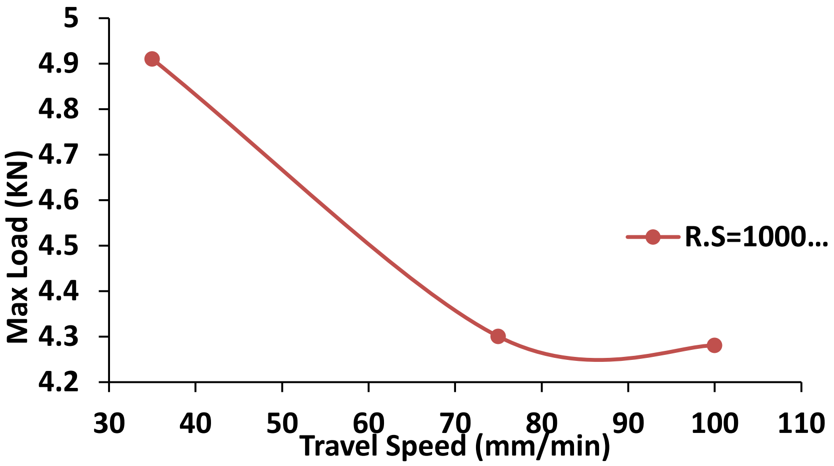


Figure 7. Effect of tool Travel speed on tensile shear Force for similar welds, using cylinder thread with rotation speed 1000rpm

4.1.2. *Effect of tool rotational speed on tensile shear strength*

Travel speed at 100 mm/min and a high tool rotational speed of 1000,1250,1600 rpm were used. Maximum weld efficiency reached was 96.2% at a rotational speed of 1250 rpm. The tensile shear force were 5.1KN at these conditions as illustrated in "Fig. 8".These results mean that using flat shoulder & cylindrical threaded pin lead to more uniform flow of metals and heat input will be enough to get good weld properties. In addition to the capability of use this tool in high rotation speeds welding.

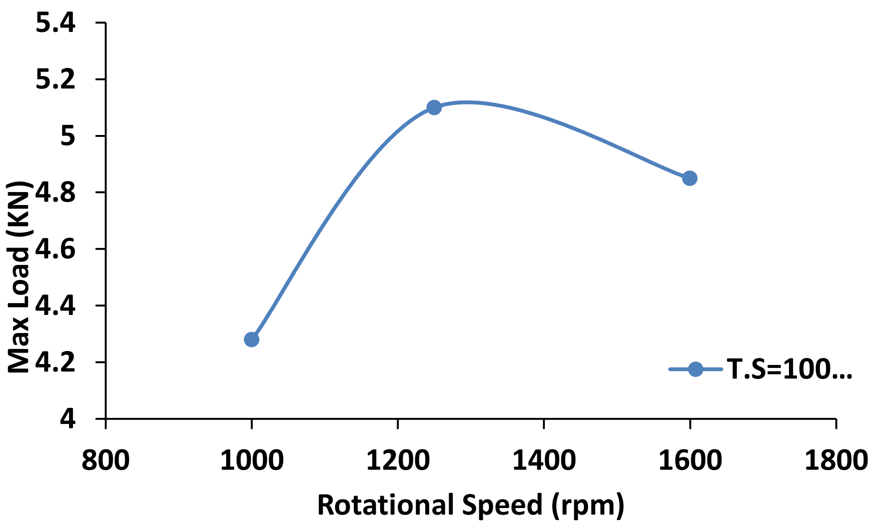


Figure 8. Effect of rotational speed on tensile shear force for similar welds, using cylinder thread with rotation speed 100mm/min

4.2. *Microstructure examination of similar welded joints*

The microstructural observations of cross section of similar FSW joints for 6061-T6/ 6061-T6 welded at best welding parameters are presented in "Fig. 9".

This figure indicate the distinct microstructural regions such the stir zone (SZ), thermo-mechanically affected zone (TMAZ),HAZ-hook crack and base alloy AA6061-

T6.. It was observed that the nugget zone for (AA 6061) was composed of fine equiaxed grains as shown in Fig.9a. "Fig. 9b&9c" shows the TMAZ and hook crack respectively while in case of the base alloy, there is no obvious change in the grain structure and there is no plastic deformation in this zone as shown in Fig.9d.

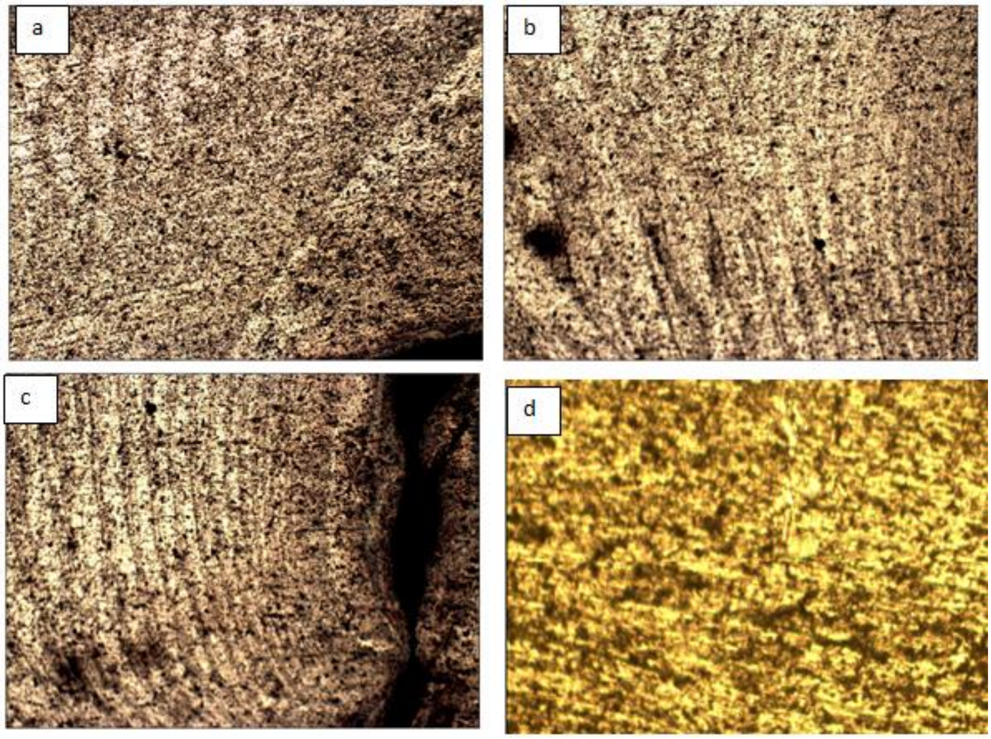
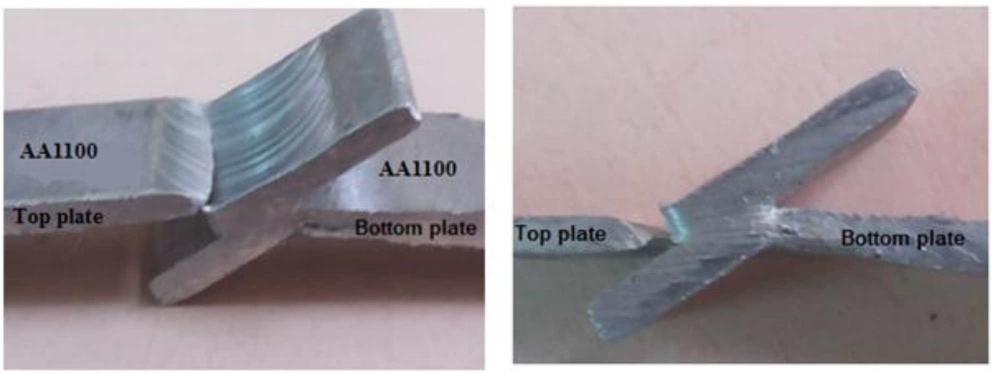


Figure 9. Microstructure of the welding zones of similar FSLW joint AA 6061 at 100x
a- Stir zone b- TMAZ c- TMAZ -hook crack d- base alloy AA6061-T6

4.3. *Fracture Analysis*

Samples fractured in three different manners. Fracturing of a joint could proceed without necking and the failure was simply by fracturing across the bottom part of the nugget and along or near the original lapping surfaces of the whole joint. "Fig. 10a and b" represents fracturing that is similar to a normal tensile fracture (after local bending) but the crack originated from the hook.



(a) (b)

Figure 10. Tensile fracture with crack propagated due to hook mode at similar 1100 FSL joint under the condition, ω =1000rpm,υ =35mm/min and pin length 5.4mm

SEM photographs of the fracture surfaces of the joints that were produced by 100rpm, 100 mm/min. are shown in Fig. 11. Figures 11(a) and (b) are the fracture surfaces of similar aluminumAA110 to AA1100 sheet joint that was produced by 1000rpm and 100mm/min. condition with pin length 5.4mm. The aluminum fracture surfaces shows the Onion rings due to tool stir movement & dimples patterns which indicates the ductile features of the joint respectively.

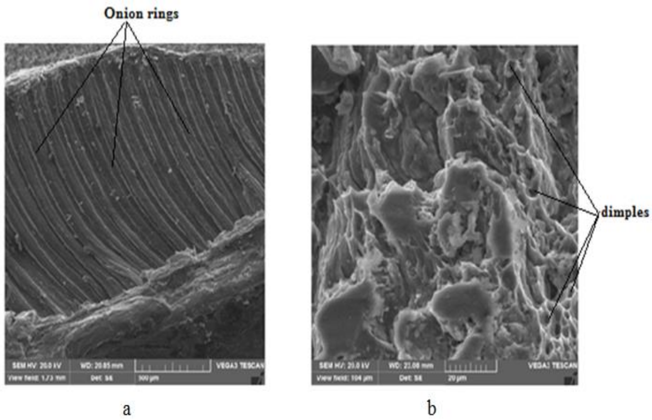


Figure 11.SEM fractography images for simmilar 1100/1100 FSL joint fracture at 1000rpm & 100mm/min.

4.4. *Hardness Tests*

"Fig. 11" shows the results of the micro hardness distribution test at the weld area. The minimum hardness was found that in the base metal for each (AA1100) and (AA6061)similar joints and begin to increase slightly through the heat affected zone HAZ and TMAZ for both the advancing and retreating side toward the stir zone. The hardness of the stir zone was the higher than other weld areas 94.38HV at AA6061joint and 49HV at AA1100 joint . This may be cause of the formation of very fine re-crystallized grains in the stir zone. Many researchers[9,13] confirmed these results in their studies when they welded the similar and dissimilar aluminum alloys.

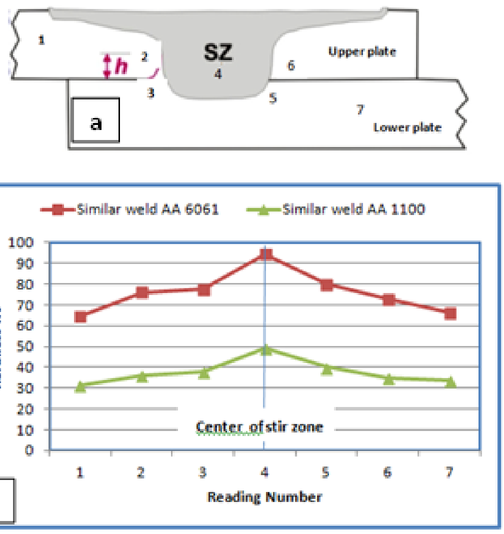


Figure 12. Hardness distribution in the cross section of the similar FSLW joints of AA 1100 and AA 6061 at the best welding conditions of 1250 rpm /100 mm/min and pin length 5.4mm

4.5. *XRD Analysis*

"Fig. 12" shows XRD results for similar AA6061/AA6061 welding joint for sample as welded at 1000rpm & 75mm/min using cylindrical threaded pin..It was seen that the main phase in a welded sample is Al3Mg2 where present in stir zone of similar weld.

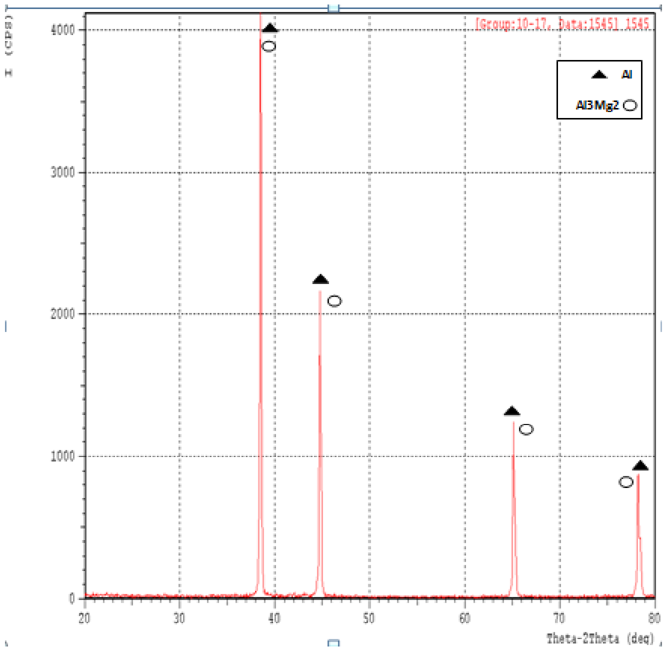


Figure 13. XRD result for similar 6061/6061 welding joints XRD at 1000rpm & 75mm/min using cylindrical threaded pin

5. Conclusions

1. Friction stir lap welding (FSLW) process for similar aluminum alloys (AA1100 and AA6061) was successfully performed and gave good lap joints efficiency (96.2% and 66% respectively).
2. The best welding conditions or parameters in FSLW process were tool rotation speed (1250rpm),Travel speed (100mm/min.) with using pin length of 5.4mm and cylindrical threaded pin profile.
3. The tensile shear force increased with increasing tool rotation speed and decreasing the travel speed until reach maximum value.
4. The joint efficiency of similar (AA1100) FSLW joint was higher than similar (AA6061) joint at same welding conditions.
5. The higher hardness value were (94.38HV and 49HV), for both AA1100 and AA6061 respectively in stir zone in FSLW and it drops toward the HAZ and to base metals for each AA1100 and AA6061.

6. References

1. Ranjan Sahoo and Pinaki Samantaray.(2007). "*Study of friction Welding*", National institute of technology,Rourkela,India.
2. Florian A. Besler, Paul Schindele, Richard J. Grant, Michael J.R. Stegmüller. (2016). "*Friction crush welding of aluminum, copper and steel sheet metals with flanged edges*", Journal of Materials Processing Technology 234, 72–83.
3. Ákos Meilinger, Imre Török. (2013). "*The Importance Of Friction Stir Welding Tool*", Production Processes and Systems, vol. 6, No. 1, pp. 25-34.
4. Shamzin Yazdanian.(2012)."*Metallurgical Studies of Friction Stir Lap Welding*", PhD thesis, Auckland University.
5. T. Pavan KumarȦ, A. Venkata VishnuȦ and Rakshit. SȦ. (Feb 2014). "*Influence of Tool Geometry in Friction Stir Welding on Material Flow Pattern*", International Journal of Current Engineering and Technology, Special Issue-2.
6. Aleem Pasha M.D.,Ravinder Reddy P. Laxminarayana P.and Ishtiaq Ahmad Khan.(2014). "*Influence Of Process And Tool Parameters On Friction Stir Welding–Over View*", International Journal of Applied Engineering and Technology, Vol. 4 (3) July-September, pp.54-69
7. Z.W. Chen, S. Yazdanian.(December 2012). "*Friction Stir Lap Welding: material flow, joint structure and strength*", Journal of achievements in materials and manufacturing,volume.55 ISSUE 2.
8. H.Bisadi, M. Tour, A. Tavakoli.(2011). "*The Influence of Process Parameters on Microstructure and Mechanical Properties of Friction Stir Welded Al 5083 Alloy Lap Joint*", American Journal of Materials Science; 1(2): 93-97.
9. Muna Khethier Abbass, Hassan Hady Abd.(2013). "*A Comparison Study of Mechanical Properties between Friction Stir Welding and TIG Welded Joints of Aluminum Alloy (Al 6061-T6)*", Eng. &Tech. Journal, Vol. Part (A), No.14.
10. Sadiq Aziz Husseina,S. Thirua, R. Izamshaha, Abd Salam Md Tahir.(2014). "*The Joining Of Three Dissimilar Metallic Alloys By A Single-Pass Friction Stir Welding*", Sci.Int.(Lahore),26(4),1569-1574.
11. Muna K. Abbass, Munthir M., Ruqaya Abdulkadhim. (2016). "*Optimization of Friction Stir Welding Process Parameters Dissimilar AA2024-T3 and AA7075-T73 Aluminum Alloys by Using Taguchi Method*", Al-Khwarizmi Engineering Journal,Vol. 12, No. 1, P.P. 100- 109.
12. Esther T. Akinlabi, Member, IAENG and Stephen A. Akinlabi.(2016). "*Member, IAENG,Effect of rotational Speed on Joint Integrity of Friction Stir Lap Welded Aluminium*", WCE, June 29 - July 1, London, U.K.
13. Muna Khethier Abbass, Sabah Khamass Hussein & Ahmed Adnan Khudhair, (2016)"*Optimization of Mechanical Properties of Friction Stir Spot Welded Joints for Dissimilar Aluminum Alloys (AA2024-T3 and AA 5754-H114), AJSE.Arabian*" Journal of Science and Engineering.Vol. 41,No.11.