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Microstructural Characterization and Mechanical Properties of Similar and Dissimilar Al Alloys Joined using Friction Stir Welding

Kharia Salman Hassan
Department of Mechanic Technician/ Institute of Technology -Baghdad
Email: Almaden20002000@yahoo.com

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Abstract

The influence of pre- shot peening and welding parameters on mechanical and metallurgical properties of dissimilar and similar aluminum alloys AA2024-T3 and AA6061-T6 joints using friction stir welding have been studied. In this work, numbers of plates were equipped from sheet alloys in dimensions (150*50*6) mm then some of them were exposed to shot peening process before friction stir welding using steel ball having diameter 1.25 mm for period of 15 minutes. FSW joints were manufactured from plates at three welding speeds (28, 40, 56 mm/min) and welding speed 40mm/min was chosen at a rotating speed of 1400 rpm for welding the dissimilar pre- shot plates. Tow joints were made at rotational speed of 1000 rpm and welding speed of 40m/min from shot and without shot peening plats. Welding temperature was measured in three zones using thermocouple. Micro hardness (HV) and tensile tests were performed to evaluate the mechanical characteristic of the joints. The results show a decay in mechanical qualities when the welding speed was increased and the best result was at (28) mm/min and the opposite result was obtained when rotational speed increased and pre-shot contributed in improving of this decay at 88% of welding speed (40) mm/min and 98% at the rotational speed of 1000 rpm.

***Key word**: Friction stir welding (FSW), Heat input, Maximum Temperature, Mechanical properties, shot peen.*

1. Introduction

The connection of dissimilar materials based on significant engineering uses just "power generation", petrochemical, chemical, Nuclear, aerospace transportation and electronic manufactures, the connection of dissimilar materials gift additional defiance and difficulties than similar by using friction stir welding due to the probability of the realization of "brittle inter-metallic phases" and little period of eutectics dissolution [1].Friction stir welding (FSW) is a method in solid stat include embrace the ascent of a spinning hard steel nail broadens by a cylinder-shaped shoulder between two contacting metal plates [2]. Friction stir welding (FSW generated heat which made the material softer about the pin and transfers from the front of the pin to the back because the revolution and transfer of the tool, here join caused through the mutual action of frictional heating among tool and weld sheet plastic deformation. The method formed heat in percentage 95% which is remain in the work parts and just 5% flows in the tool. During Friction stir welding method quality is determined and controlled by the resultant heat which is rely on parameters like rotational speed, welding speed, and plunge depth while the rotating pin deforms the heated material. [3,4]. Friction stir welding induces dynamic recrystallization and recovery that refines microstructure of the stir region. Therefore friction stir welded joints have amended mechanical qualities like tensile strength, ductility, hardness compering with fusion welded joints [5]., structure of weld, due to hard mechanical stresses shows three clear microstructural zones on the transverse cross section of the FSW joint, .these zones are a nugget, or stirred zone, thermo-mechanical affected zone (TMAZ), and a heat affected zone (HAZ) ,nugget zone NZ is a region through which tool pin passes and thus experiences both high deformation and heat treatment. It generally consists of very fine equiaxed [6]these change in microstructures cause decay in mechanical characteristic this decay can improve by using one of Mechanical surface treatments such as a cold working process (shot peening) in which small spherical shots the surface of plat produce compressive residual stresses and extremely high dislocation densities near the faces films consequent inhomogeneous plastic deformations[7] The figure of effective factors on the shot-peening method is: type, size and shape of the shots, peening time, torrent speed, air pressure on the peened element, distance from nozzle to material surface (peening distance), nozzle angle, peening intensity and face covering percentage[8]many, researchers studied the subject such as:-

Saad Ahmed Khodir[9] studied the impact of apportionment revolution velocity and stable place of material on" microstructure", tensile characteristic and" hardness" apportionment for disparate aluminum alloys joints for 2024-T3 and 7075-T6 create by FSW at invariant welding speed of 100 mm/min and variable rotation speeds of 400, 800, 1200, 1600 and 2000 Rpm and he clear that the weld joint at rotation speed 400 rpm was weak due to no mixed between metals and when increasing it to 1600,2000 the metal was melted remaining many defects due to solidification and he show that the best result at rotation speed 1200 Rpm.

Moreira [10] studied the a metallurgical and mechanical quality of disparate of aluminum alloy 6061-T6 with 6082-T6 of friction stir welded butt joints and contrast the result of its with butt joints of alike material. Microstructure examination, micro hardness, tensile and bending examinations of joints were performing. It was exist that friction stir welded of AA6082-T6 offer lesser yield and ultimate stress while the disparate joints show intermediate characteristics. The disparate joints also displayed the intermediate in tensile tests. And in hardness profile the lesser values were gotten in the AA6082-T6 alloy plate side while rupture happened in the nugget zone in all sort of connections .

Amancio-Filho [11] studied the mechanical ,microstructure characteristic of disparate friction stir welds joints of aluminum alloys 2024-T351 and 6056-T4. This butt joints were made in diverse process parameters, mainly the rotational speed (500-1200rpm) and welding speed (150-400mm/min), while axial force and tool geometry kept constant. On the basis of macro graphic analysis and micro hardness testing, the best found consequence was in the parameters range of rotational speed 800 rpm and welding speed 150 mm/min.

Khaira salman[12] rely on the shot peening method to improve the mechanical characteristic of joints which made using tungsten inert gas (TIG) welding" and friction stir welding (FSW)" methods .Tensile test samples were equipped from the connections metal and original alloy then exposed to shot peening method using steel ball of diameter 0, 9 mm and for 15 min. Vickers hardness , microstructure were examination. Results showed that a general decay in mechanical characteristic in TIG and FSW welded joints comparing with base alloy while the FSW welded joint gives better mechanical characteristic than that of TIG welded joint. This is due to the microstructure changes during the welding process .also it has been found that shot peening improved the mechanical characteristic of both welded joints due to the compressive residual stress generation in the weld zones.

The present study the influence of pre shot peening ,welding speed, rotational speed on mechanical properties for dissimilar aluminum alloys 2024-T3and 6061-T6 friction stir welded joint.

2. Experimental Procedure

2.1. Used Alloys

Sheets of Aluminum alloys AA6061-T_6 and AA2024T_3 are used to produce dissimilar friction stir welded joints. The results of the chemical analyses which is performed by ARL Spectrometer in the specialized institution of engineering industries are listed in Table (1 and 2).

Table 1,
Chemical Analysis of the AA (6061- T6)

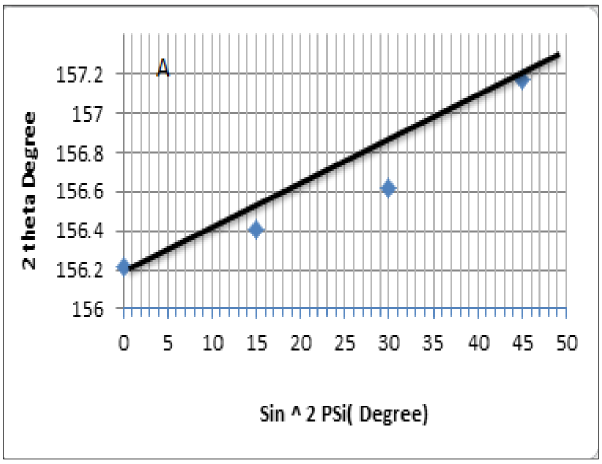
Elements w%	Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
Real value	0.6	0.4	0.3	0.12	1.0	0.2	0.18	Rem.

Table 2,
Chemical Analysis of the alloys AA (2024-T3)

Element	Al %	Ti%	Cr%	Zn%	Si%	Fe%	Mn%	Mg%	Cu%
Real value	92.6	0	0.05	0.1	o.4	0.3	0.6	1.5	4.4

The sheets were prepared into the required dimension (150mm×50 x6mm) by milling machine then some of its were exposed to shot peening process for producing severe plastic distortion on the specimen's surface by steel ball has diameters 1.25 mm for 15 minute from all sides by an air-blast machine tumbles control model (STB – OB) machine No. 03008 05 type., the nozzle askew angle is be removed by 10° with respect to the perpendicular axis. The distance from the nozzle to specimens place is about 120 mm, shot velocity was 40 m/ min.

Computerized (Lab XRD-6000 shiatsu X-RAY diffraction meter) was employed to measure the strain which result from shot peing in the crystal lattice and the quantity of the strain was implemented in brag law to account the compressive residual stress in the shot peening material, the results of residual stress which obtained from device were recorded in table (3). The relation between 2 Theta (deg) which represented the strain and Psi (φ in deg.) represented the specimen location and its incline with the axis was draw as shown in Fig.1 (A and B).



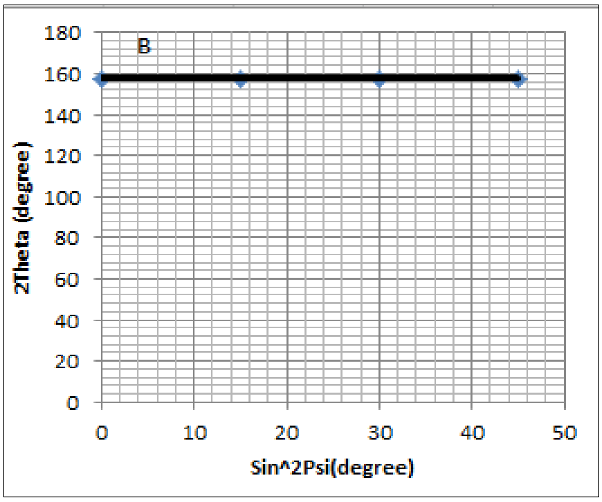


Fig. 1. The relation between 2 Theta (deg) and the specimen location for specimen ((A) 2024-T3and specimen (B) 6061-T6).

Also macro hardness was measured using Vickers method and the results were recorded in Table (3).

Table3,
Residual stress and Vickers hardness for shot peening specimens.

Symbol	Vickers hardness kg/mm^2	Residual stress result (MPa)
2024-T3	152	-162.4
6061-T6	105	-143.543

2.2. Categorization of Specimens

Weld joints which equipped by friction stir method were compiled into party as listed in

Table 4,
Categorization of manufacture sample.

symbol	stat
A	friction stir welding for similar A2024-T3 at 1400 rpm and 40 mm/min
B	friction stir welding for similar AA6061 – T6 at 1400 rpm and 40 mm/min
C	friction stir welding for disparate at1400 Rpm and 28mm/min
D	friction stir welding for disparate at 1400 rpm and 40 mm/min
E	friction stir welding for disparate at 1400 rpm and 56mm/min
F	Pre shot+ friction stir welding for disparate at1400rpm and 40mm/min
G	friction stir welding for disparate at 1000 rpm and 40mm/min
H	Pre shot+ friction stir welding for disparate at1000rpm and 40mm/min

2.3. Welding Process

The plates which equipped for friction stir welding joint from shot and without shot peening material were corroborated in location by mechanical fixeds. Single pass welding process is used to make the butt weld connections. vertical semi-automatic milling machine was used for creation the butt welds joints. A welding tool made of High Carbon steel. The tool dimensions is composed of shoulder of (20mm diameter) and probe of (6mm diameter and 5 mm length).In this study the rotation speed tool (1400 rpm) was used to get many weld joints at mutable welding speed of (28,40,56 mm/min) then fixed the welding speed for (40mm/min) and the same rotation speed (1400 rpm) to join the shot peening plate which is shown in Fig(2) then for comparative the result with second parameter (rotational speed) the rotation speed was taken(1000)rpm at welding speed (40mm/min) to weld butt joint from shot and without shot plate .Fig.(3,4,5)show the Macrograph weld joint of Specimen (A ,B,C) friction stir weld joint.

Fig. 2. Pictures of butt friction stir welding for specimen (F) at (40x).

Fig .3. Macrostructure weld joint of Specimen (A) friction stir weld joint at (40x).

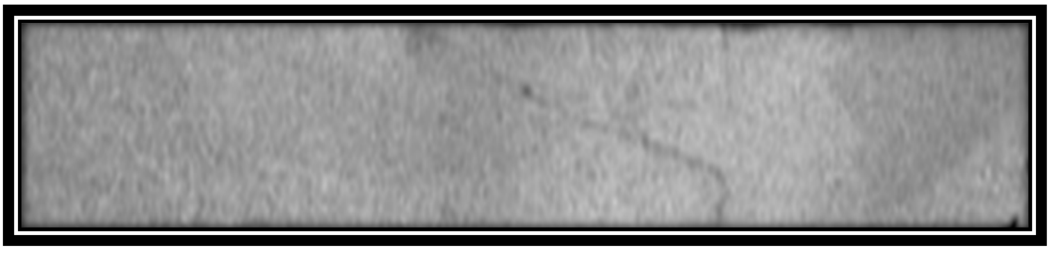


Fig. 4. Macrostructure weld joint of Specimen (B) friction stir weld joint at (40x).

Fig. 5. Macrostructure weld joint of specimen (C) Disparate friction stir weld joint zones at (40x).

The temperature during welding process is measured by Resistance Temperature Detector (RTD which have excellent precision over a wide choice of temperature from200°C to 650°C. Heat is created in friction stir welding method at the communication among revolving tool and plats that plasticizes the material in its. In present work the temperature is measured by placing a sensor at different points on the weld plat perpendicular to weld line and the results was shown Fig.(6a) .The relation between time and temperature was clear in Fig.(6b)

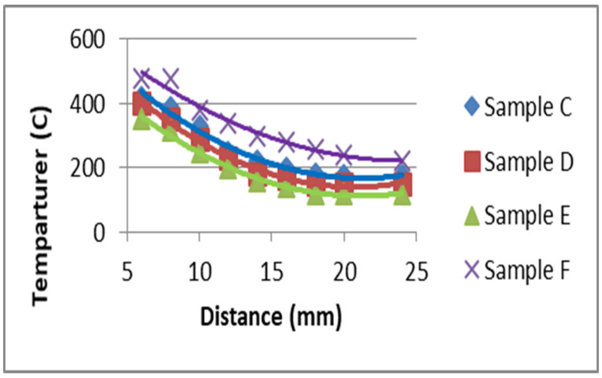


Fig. 6a. Distribution of temperature on surface for specimens (C,D,E,F).

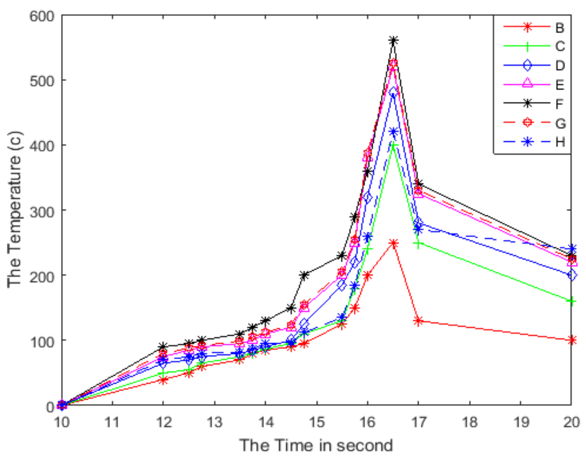


Fig. 6b. Variation in temperature with time on the top surface.

2.4. Microstructure Test

Optical microscope is employed to inspect the Micro structural for specimen (C)in weld zone and specimen(G) in stir zone and for this purpose specimens were equipped including many pace such as grinding process by SiC paper in diverse grits of (240,320,500, 600,800 and 1200). Polishing is done by diamond paste has (0.3µm) with cloth. Then specimens are washed by water and alcohol and desiccated using hot air

Etching for seem the structure by use Keller's reagent having of 95 ml distill water, 2.5 ml HNO_3, 1.5 ml HCl and 1 ml HF then washed after that were examined with ME-600 computerized optical microscope supplier with a NIKON camera, the tested result was shown in Fig.(7) and Fig.(8).

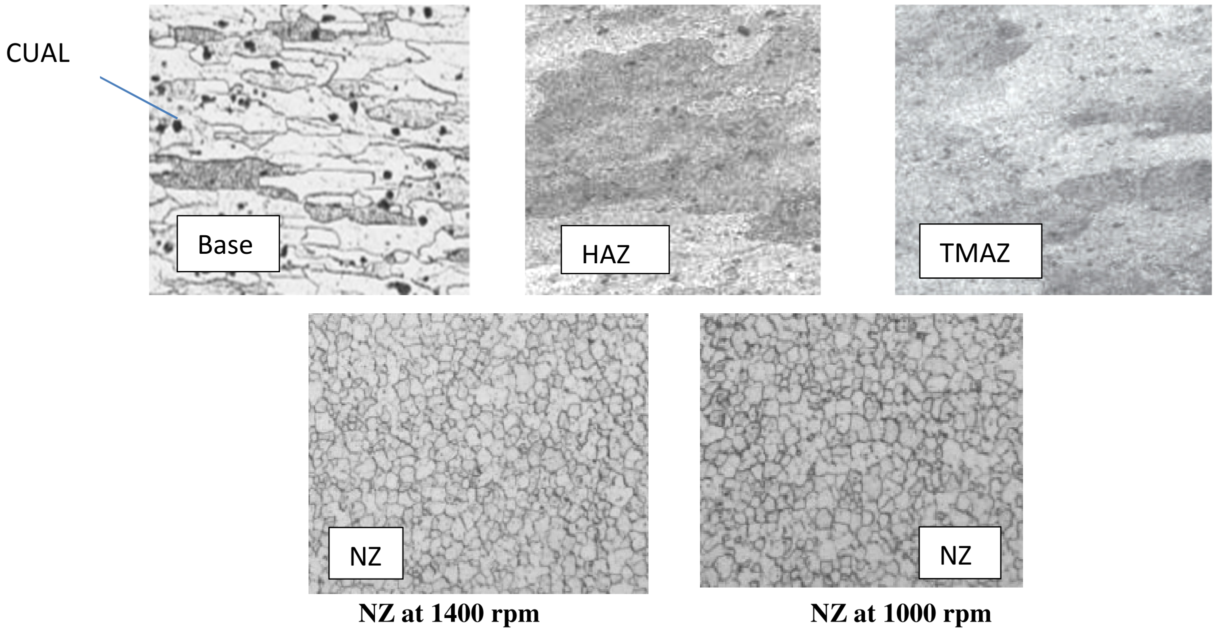


Fig. 7. microstructure of specimens (C) from 2024 –T3 side of the diverse areas for the welded disparate material at(40 x).

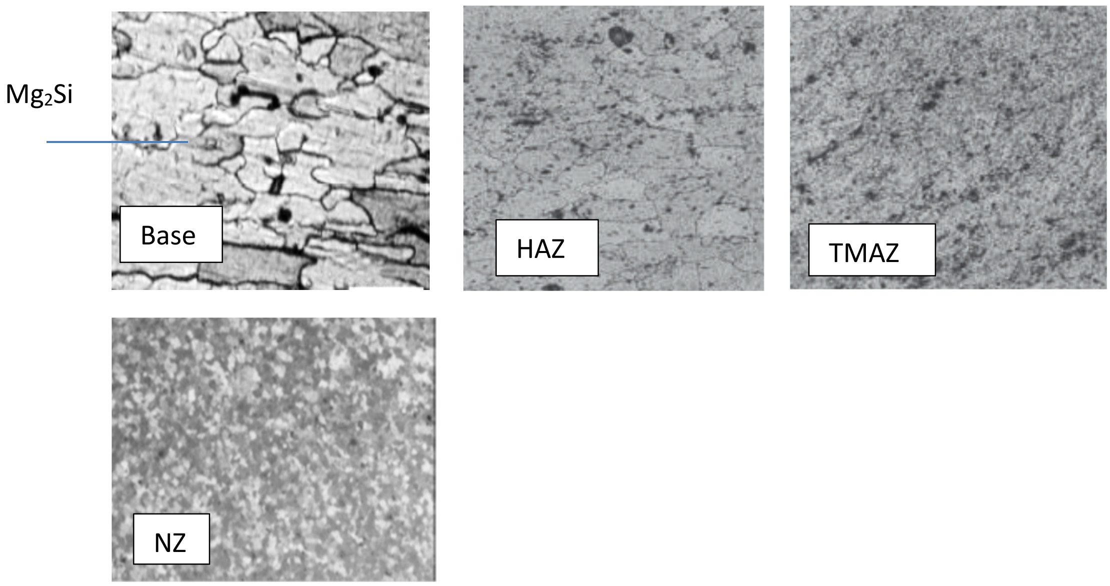


Fig. 8. Microstructure of specimens (C) from 6061 –T6 side of the diverse areas for the welded disparate material at (40x)

2.5. Micro Hardness Test

The Vickers micro hardness equipment with 200 gm load for 15 sec Was used to measure the hardness for all disparate specimens weld joint on a cross section perpendicular to the welding line The result was shown in fig. (9)

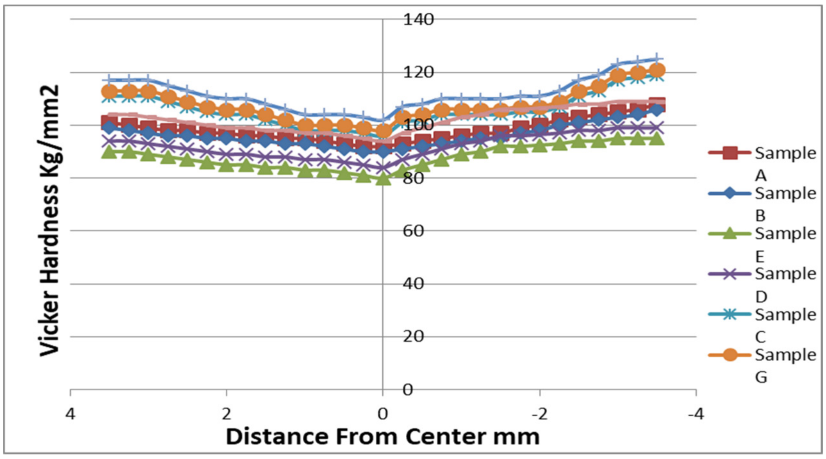


Fig. 9. Micro hardness for specimens (A,B,C,D,E,G)

2.6. Tensile Stress

Mechanical characteristic like strength and ductility by tensile examination of the specimens such as the ultimate tensile stress (UTS) yield strength (YS) and % elongation are determined. Numerous samples for tensile examination are equipped from weld and un weld plate by measurements shows in Fig.(10) agreeing to ASTM 176000 to test using Testing machine smart series with preload value (N) 100 and cross head speed (mm/min) or rate. 20. Extension the tested results are shown in Table (5) and Fig (11 a, b, c)

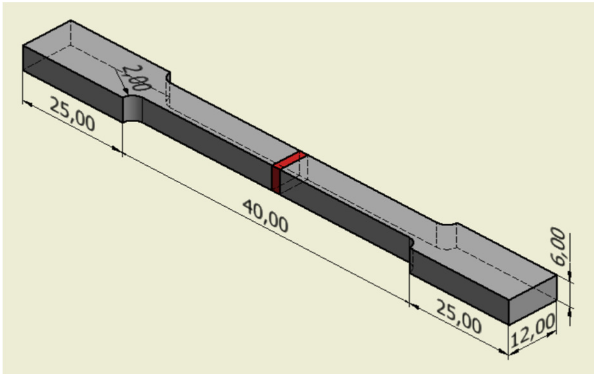


Fig. 10. Dimension of tensile test specimenز

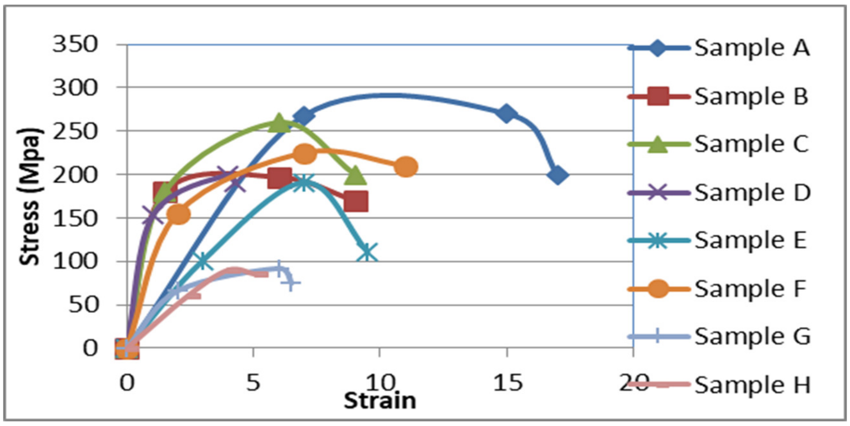


Fig. 11a. Relationship between stress and strain for all specimens.

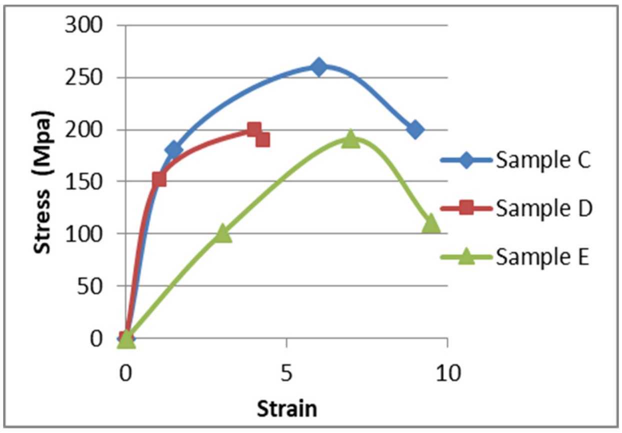


Fig. 11. b.Relationship between stress and strain for specimens(C,D,E).

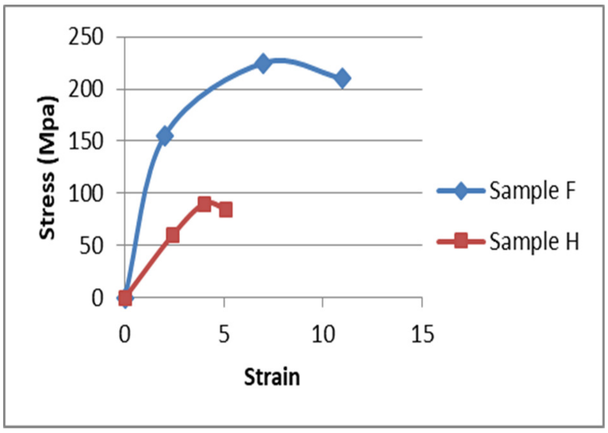


Fig. 11. C.Relationship between stress and strain for specimens (F, H).

Table 5,
Results of tensile properties and hardens for all specimens.

symbol	σu Mpa	σyMpa	σF Mpa	E%	Hardness kg/mm^2
A	270	268	200	7.0	105
B	197	180	170	7.5	84
C	262	157	175	9.5	90
D	200	153	165	4	87
E	191	101	110	9.5	85
F	225	155	210	9.5	97
G	92	66	75	6	85
H	90	60	90	2.8	90

3. Discussion

Fig,(7) represented microstructure of weld zone to specimen (C) from the side of AA 2024-T3 which contain elongated grains besides coarse dendritic structure with uniformly precipitates in very fine of (Cu Al) due to have the main element alloys is copper (Cu)which is signed in Table (2) that gives substantial increases in strength to allow precipitation hardening [13,14] also Fig.(8) shows the microstructure in base metal from the side of AA 6061-T6 which contains coarse and elongated grains with regular repartition strengthening sediment of (Mg_2Si.) due to existence of alloying elements such as silicon and magnesium. These two elements chain and undergo to sediment reaction and form strengthening sedimentation (Mg_2Si) as shown by darkens particles.[13,14].but in stir zone (ZN) for the same specimens seeing equated fine grain structure due to the material undergoes to deep plastic deformation at elevated temperature which it's become more fine when rotational speed is increased Fig (7) at (1400)r. p.m. Hardness profile rely strongly on sedimentation conduct and a little on the grain size in the weld zones thus breakup and growth of the sediment would result in softening of Joints in all specimens in table (4) and the hardness which measured in nugget was lower than the two base material AA2024-T3 and 6061-T6 in the same zone due to heat input and cold cooling . Fig.(9)and table(5) which show the received result of tensile examinations for all specimens in table (4) that seeing increases in the welding speed resulting in decrease of the tensile strength of all the FS welded joints Fig(11b). This is due to deficient in a little contact period in the weld zone with deficient heat input Fig. (6b) and reduced plastic inflow of the metal and reasons several void-similar faults in connections. The lowered of plasticity and rates of diffusion in the material causes a weak in interface. When welding speeds are higher connected with little heat inputs Fig (9b), which effects in quicker cooling rates of the welded joint. This can meaningfully decrease the degree of the metallurgical changes happen through welding and the local strength of the individual regions across the weld zone[15,16].

From the other hand increasing in rotational speed contributed in increasing tensile strength Fig.(11b) due to increasing in fractional heat input (9a,b).heat in put is effected on hard ness distributions which encounter more reduction when welding speed decrease And rotational speed increase Fig.(11C) terminally we see pre shot peening process contributed in improvement of mechanical properties due to comparison residual stress which be mentioned in Fig (11C).

4. Conclusion

1. Welding process for similar weld joint material have little effect on mechanical properties compared with dissimilar weld joint material.
2. Welding speed at 28 mm/min and1400r.p.m offer the best results for mechanical properties of the dissimilar weld joint
3. Pre shoot contributed to improve 88% mechanical properties at increase welding speed to 40 mm/min and1400r.p.m for dissimilar weld joint compered without pre shot joint at the same weld conditions.
4. decreases in rotational welding speed cause decay in mechanical which proved at 98% when subjected to pre shot peening at rotational welding speed 1000r.p.m and 40 m/min welding speed.

5. Reference

[1] Ahmed O.Al-Roubaiy" Experimental and theoretical analysis of friction stir welding of AL-Cu joint " Int .j .Adv. Manuf. Technol.(2014) 71: pp1631-1642

[2] S. Jannet P.K. Mathews R. Raja "Comparative investigation of friction stir welding and fusion welding of 6061-T6 and 5083-O aluminum alloy based on mechanical properties "Journal Achievements in Materials and Manufacturing Engineering and microstructure volume 61 issue 2 ,2013

[3] M. Song, R. Kovacevic" Thermal modeling of friction stir welding in a moving coordinate system and its validation "International Journal of Machine Tools & Manufacture Vo.43 (2003)pp 605–615

[4] Renju Mohan " Finite element modeling for maximum temperature in friction stir welding of AA 1100 and optimization of process parameter by taguchi method "IJRET: International Journal of Research in Engineering and Technology Volume: 03 Issue: 05 | May-2014, pp2319-1163 |

[5] Radisavljevic1"Influence of FSW parameters on formation quality and mechanical properties of Al 2024-T351 butt welded joints" Trans. Nonferrous Met. Soc. China 23(2013)pp 3525−3539

[6] H. S. Pati "Effect of weld parameter on mechanical and metallurgical properties of dissimilar joints AA6082–AA6061 in T6 condition produced by FSW" Fractural ed Integrity Structural, 24 (2013)pp151-160;

[7] Nazar abdulwadood1, Burak Sahin1, Nihat yildirim" effect of welding parameters on the mechanical properties of dissimilar aluminum alloys 2024-t3 to 6061-t6 joints produced by friction stir welding" Niğde Üniversitesi Mühendislik Bilimleri Dergisi, Cilt 3, Sayı 1, (2014), pp. 25-36

[8] P. Prasanna[1],"experimental and numerical evaluation of friction stir welds of A A6061-T6 aluminum alloy "ARPN Journal of Engineering and Applied Sciences vol. 5, no. 6, june 2010 PP 1-18

[9] Saad Ahmed Khodir "Microstructure and Mechanical Properties of Friction Stir Welded Dissimilar Aluminum Joints of AA2024-T3 and AA7075-T6 Materials Transactions, Vol. 48, No. 7 (2007) The Japan Institute of Metals pp. 1928 to 1937

[10] Moreira P M G P, Santos T, Castro P M S T "Mechanical and metallurgical characterization of friction stir welding joints of AA6061-T6 with AA6082-T6", *Materials and Design,* Vol .30, (2009), pp. 180-187.

[11] Amancio-Filhoa S T, Sheikhi S, "Preliminary study on the microstructure and mechanical properties of dissimilar friction stir welds in aircraft aluminum alloys 2024-T351 and 6056-T4", Journal of materials processing technology, Vol.206,2008 pp. 132–142.

[12] Khairia Salman1 "Effect of Shot Peening on the Mechanical Properties For Welded Joints Of Aluminum Alloy 6061-T6" NDMRP 2015

[13] Metals Handbook, Vol.2 - Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, ASM International 10th Ed. 1990.

[14] Ashwani Kumar1 "friction stir welding of dissimilar materials/alloys": Int. J. Mech. Eng. & Rob. Res Vol. 1 , No. 1, January 2014pp 106-112

[15] Terry Dickerson " heat flow into friction stir welding tools" 4th International Symposium on Friction Stir Welding. Park City, Utah, USA, 14-16 May 2003 Page 2 of 11

[16] Aleksandar Sedmak1" heat input effect of friction stir welding on aluminum alloy AA6061-t6 welded joint "THERMAL SCIENCE, Year 2016, Vol.20, No.2, pp.637-641.

خواص البنية المجهرية والميكانيكية لوصلات لحام الخلط الاحتكاكي لسبائك المنيوم متماثلة وغير متماثلة

خيرية سلمان حسن
قسم التقنيات الميكانيكية / معهد التكنولجيا- بغداد
البريد الالكتروني:Almaden20002000@yahoo.com

الخلاصة

ان تاثير القذف بالكرات الفولاذية السابق لعملية اللحام وكذلك سرعته الخطية والدورانية على الخواص الميكانيكية والمتالورجية لوصلات لحام انتجت بطريقة الخلط الاحتكاكي لسبائك الالمنيوم المتشابهة وغير المتشابهة وذات المتانة العالية - AA2024 T3–AA6061 .تم تحضير عددا من الصفائح من السبائك المختارة بابعاد ملم وان عدد من هذه السبائك تعرضت الى القذف بكرات فولاذية قطرها (1.25) ملم ولمدة (15) دقيقة بعدها عدة وصلات لحام انجزت من الصفائح غير المتماثلة والمتماثلة المقذوفة وغير المقذوفة وبسرعة لحام (28,40,56)mm/min مع تثبيت السرعة الدورانية عند (1400)Rpm وقد انتخبت سرعة لحام (40)mm/min وبالسرعة الدورانية نفسها (1400)Rpm في عملية لحام صفائح اللحام التي تم قذفها لبيان تاثير عملية القذف على اما الخواص الميكانيكية فقد تمت عملية اللحام بواسطة ماكنة تفريز عمودية وتم قياس التغير في درجة الحرارة في مناطق اللحام باستخدام مزدوج حراري وكذلك اجري اختبار الصلادة المايكروية والشد ومن النتائج التي تم الحصول عليها وجد انخفاض في الخواص الميكانيكة عند زيادة في السرعة وان افضل نتيجة ظهرت عند سرعة خطية مقدارها (28m/min) وان عملية القذف بالكرات الفولاذية قبل عملية اللحام ساهمت في تحسين الخواص الميكانيكية لدرجة مقاربة لنتائج المعدن الاساس وقد وجد تحسن في الخواص الميكانيكة عند زيادة السرعة الدورانية.