Al-Khwarizmi Engineering Journal,Vol. 12, No. 3, P.P. 121- 128 (2016)

Al-Khwarizmi Engineering Journal

Mechanical Properties of MIG Joints for Dissimilar Aluminum Alloys (2024-T351 and 6061-T651)

Nawres Jabar Nasser
Institute of Technology- Baghdad
Email: nawresjabaar@yahoo.com

(Received 14 September 2014; accepted 12 May 2016)

Abstract

The research aims to investigate the effects of GMAW or MIG welding process on the mechanical properties of dissimilar aluminum alloys 2024-T351 and AA 6061- T651. A series of experimental techniques have been conducted to evaluate mechanical properties of the alloys, by carrying out hardness, tensile and bending tests for welded and un-welded specimens.

Metal inert gas (MIG) has been carried out on sheet metal using ER- 4043($AlSi_5$) as a filler metal and argon as shielded gas. The welded joints were tested by X-ray radiography and Faulty pieces were excluded.

Welding joints without defects are subjected to heat treatment including heating the joints in furnace to 170 °C for half an hour then air cooling to relief welding stress.

Tensile test was implemented for all specimens which prepared in the dimensions according to ASTM 17500 by using Testing machine smart series with preload value 100 kN. Vickers hardness test and microstructure examination were made, the last test was bending test which implemented on the welded and un welded specimens which machined into standard test specimen dimensions.

Results of mechanical properties Using MIG welding process appear a general decay compared with un welded and in the dissimilar joint comparing with parent metal that is due to the microstructure change during the welding process. The location of the failure for welded specimens after all mechanical test was found predominantly along the heat affected zone (HAZ).but Unwedded specimens were failed near the center line of the specimen.

Keywords: *Aluminum alloys, welding joining, dissimilar materials welding technologies, mechanical properties.*

1. Introduction

A wide range of applications for aluminum and its alloys are used successfully in industry, from Packaging to aerospace. Because it have a good mechanical properties and low densities, [1, 2] .Heat treatable aluminum alloys (as such 2024 and 6061) are specially produced for critical applications with advanced mechanical properties of high strength and ductility. The term of Gas metal arc welding means a process that melts and joins metals by heating them with an arc arise of the base metal and continuously fed filler wire electrode. During this processes inert gases are used to isolate the weld region from environment effects such as argon and helium which are most widely used in arc welding process for aluminum alloys [3]. Designers and technologists confront many difficulties when dealing with the welding of aluminum and its alloys. mainly related to the presence of a tenacious oxide layer, high thermal conductivity, high coefficient of thermal expansion, solidification shrinkage and, above all, high solubility of hydrogen, and other gases, in molten state [4].These difficulties are also arise when welding a heat-treatable alloys, since heat, provided by welding process, after welding there is a decay in mechanical properties, due to phase transformations and softening induced in alloy. For that aluminum alloys are generally classified as low weld ability because of the poor solidification microstructure and porosity in the fusion zone.

Also, the loss of mechanical properties as compared to the base material is very significant. These factors make the joining of these alloys by conventional welding processes unattractive, there for there must be fetching for other welding processes [5].

Therefore in important applications of aerospace and similar, those special heat treatable alloys are not suitable for conventional welding processes but its need to be friction stir welded [4][6]. The AA6061-T6 alloys can be welded with ER4043 (Al-Si_5) or ER5356 (Al-Mg_5) filler alloys dependent on weld performance requirements. The properties of aluminum alloy affect on welding process, such as high thermal conductivity, high chemical reactivity with oxygen, and high hydrogen solubility at high temperature. The main consideration is to adequately dilute the Mg_2Si percentage in the base material with sufficient filler alloy to reduce weld metal crack sensitivity.

More attention must be taken when welding the 6061-T6 base alloy with the 5356 filler alloys to ensure sufficient additions of filler alloy to prevent the Al – Mg from crack the sensitivity chemistry range [7]. In addition to the base material used in this study is 2024-T3 Aluminum alloy. It is found that copper (Cu) gives substantial increases in strength, allows precipitation hardening, reduces corrosion resistance, ductility and weld ability. Also in this series of aluminum alloys it is difficult to weld by liquid state join because many of these series are thermal cracking sensitive [8].

The present work investigated the mechanical behavior of welded joints of Al2024 and Al6061, as well as dissimilar joints between Al 2024T351 and Al6061T651, using ER4043 filler wire and the -GMAW process.

2. Experimental Procedure

2.1. Used Alloys

plates of 200 mm long, 100 mm wide and 10 mm thick of 2024-T351 and 6061-T651 aluminum alloys which its chemical composition analysis by using ARL Spectrometer is given in Table (1,2) and its stander mechanical properties are shown in Table (3) ,were joined together using GMAW process.

ER4043 was used as a filler metal rod, its chemical composition is shown in Table (4).The welded butt joints in dimension of (200*100*8) mm are produced with the preparation angle in shape V of 70^0 and square angle as shown in Fig.(1).

These sheets were cleaned before the welding process with a scraper and acetone then they were butt welded (two pass for each side) by a MIG-350 type semiautomatic welding machine with parameters shown in Table (5).

$$Heat\ \ Input = \frac{I \times V \times 60}{S} \qquad \text{... (1) [9]}$$

Where:
I= welding current (Ampere)
V= welding voltage (volt)
S= welding speed (m/min)
Heat Input= Joule

Table 1,
Chemical Composition of the used metal AA(6061 T651) [10].

Elements w%	Measured value	Standard value
Si	0.6	0.4-0.8
Fe	0.4	Max 0.7
Cu	0.3	0.15-0.4
Mn	0.12	Max 0.15
Mg	1.0	0.8-1.2
Cr	0.2	0.04-0.35
Zn	0.18	Max 0.25
Al	Rem.	Rem.

Table 2,
Chemical Composition of the used metal AA (2024T351)[10].

Elements w%	measured value	Standard Value [9]
Al %	92.6	Rem
Ti%	0	0-0.15
Cr%	0.05	0-0.1
Zn%	0.1	0-0.25
Si%	0.4	0-0.5
Fe%	0.3	0-0.5
Mn%	0.6	0.3-0.9
Mg%	1.5	1.2-1.8
Cu%	4.4	3.8-4.9

Table 3,
Standard Mechanical Properties of 2024T351 and 6061T651 [6].

Material	Yield strength MPa.	Ultimate tensile strength (UTS) MPs.	Percentage of elongation %
2024-T3	380	464	16
6061-T6	295	342	10

Table 4,
Chemical Composition of the Filler Metal (Filer wire ER 4043) Al Si5 [11].

Elements Wt%	Actual value	Nominal value
Si	5.0	4.5-6
Fe	0.4	<0.6
Cu	0.1	<0.3
Mn	0.08	< 0.15
Mg	0.06	< 0.2
Cr	0.25	-
Zn	0.15	< 0.1
Sn	0.15	-
Al	93.44	Rem.

Table (5)
Welding Parameters of MIG Welding

Symbol	Current (Amp.)	Voltage (v.)	Travel speed (mm/s)	Flow rate L/min	No. of passes	Heat input (Joule)	Wire diameter (mm)
C	140	22	220	10	2	456120	1.2
D	150	22	110	10	2	977400	1.2
E	160	24	220	10	3	568669	1.2
F	120	24	120	10	3	130320	1.2

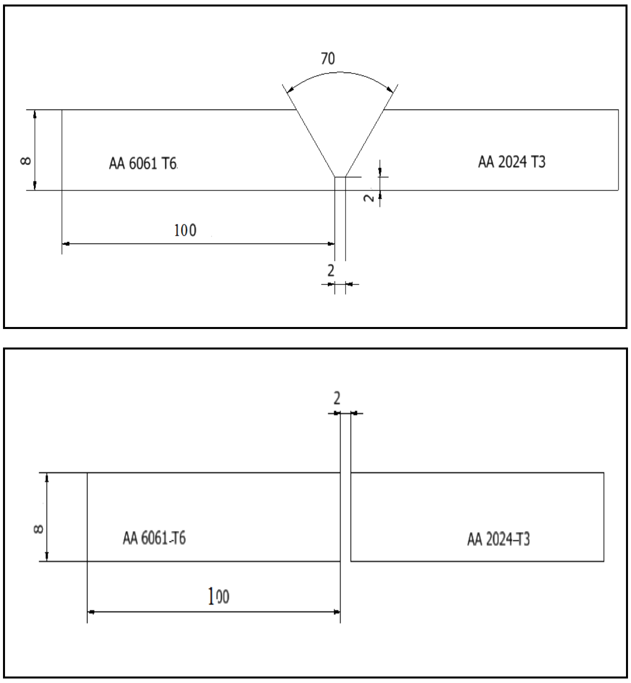

Fig .1. The Welded Joints Dimension in (mm).

2.2. Categorization of Welded Joint

After completing preparation of the specimen, they were categorized to groups as shown in Table (6).

Table (6)
Categorizing of Specimens.

Symbol	Condition
A	AA 6061-T651 as received
B	AA 2024-T351 as received
C	Butt Single V AA 6061-T651 at 70°
D	Butt Single V AA 2024-T351 at 70
E	Butt single V dissimilar AA 6061-T651,2024-T351 at 70°
F	Butt single dissimilar AA 6061-T651,2024-T351 Square Butt joint (angle 90°)

2.3 Microstructure Test

The Changes of micro structural from weld zone to the unaffected base material were tested using optical microscope. Specimens were prepared in many steps for microstructure test including wet grinding operation using emery paper of different grits (120,320,500, 800 and 1000). Polishing process was done by using diamond paste of size (0.3µm) with special polishing cloth. They ere cleaned with alcohol and water and then dried with hot air dryer.
Etching for the structure by use Keller's reagent consisting of 95 ml distill water, 2.5 ml HNO_3, 1.5 ml HCl and 1 ml HF then washed after that with ME-600 computerized optical microscope provided with a NIKON camera, the examined result was shown in Fig.(2).

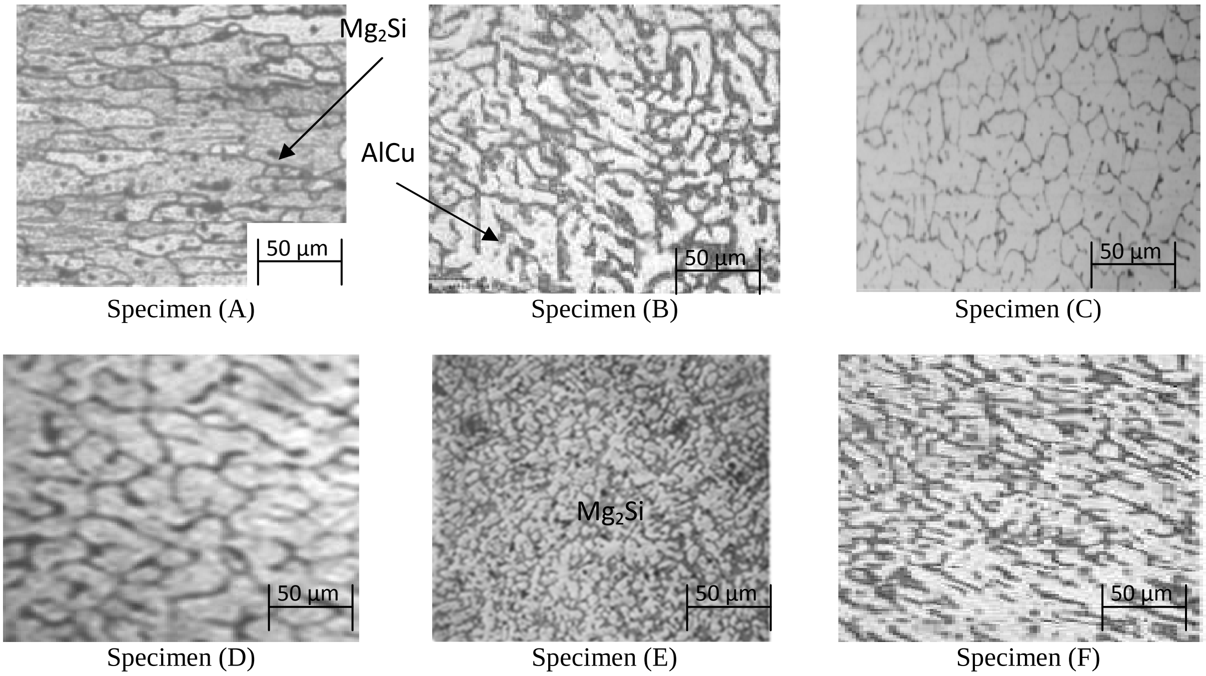

Fig . 2. The Microstructure of (A,B as received and C,D,E,F in weld Zone) (40X).

2.4. Mechanical Tests

Before implementing the mechanical tests, weld joints were characterized by the visual inspection and X-ray radiography. The Radiographic unit was operated for 1 min at 150 kV, 2 mA for the inspection. The joints without defects were used to prepare many specimens for mechanical test.

2.5. Tensile Test

The dimensions of the tensile specimens were prepared according to ASTM (17500) as shown in Fig. (3) Multiples of specimens are cut from welded and un welded plates with the condition that loading axis of the tensile test specimens is transverse (perpendicular) to the welding direction of the plates.

Tensile properties were estimated at room temperature using the computerized Tinus Olsen universal tensile testing machine. All tensile tests were carried out at a constant crosshead speed of 10 mm/min and the average of three specimens was taken to evaluate the tensile behavior of each welded joint. Fig. (4) shows the test specimens after fracture while the test results are shown in Table (7) and the relationship between stress and strain are shown in Fig. (5) for all specimens.

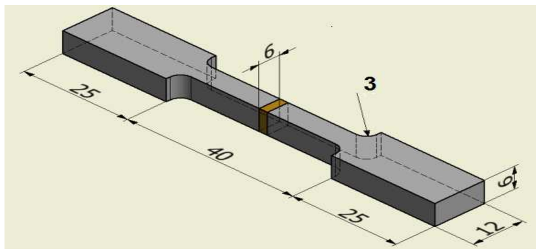

Fig. 3. Dimensions of Tensile Test Specimen in mm.

Fig. 4. Tensile test Fracture specimens.

Table 7,
Mechanical Tests result.

Sample	σu MPa	Yield stress σy MPa	F_B kN	Elongation %	Hardness Hv(kg\\mm^2)
A	270	230	13.42	12	125
B	323	295	11.25	10	130
C	159	123	2.48	9	82
D	165	150	2.18	8	87
E	200	183	2.81	8	84
F	170	152	1.19	10	86

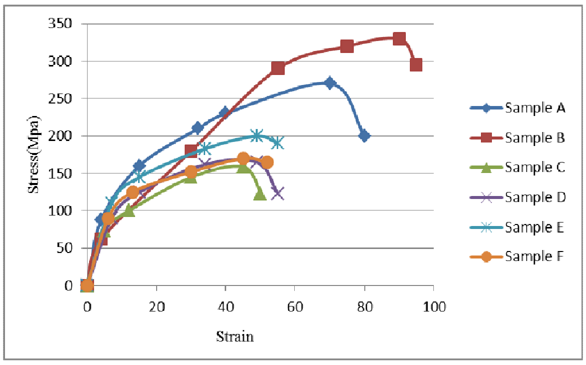

Fig. 5. Relationship between stress and strain for all specimens.

2.6. Bending Test

The dimensions of bending test specimen were prepared according to the ASTM (E 190-192) for the welded joint as shown in Fig. (6).

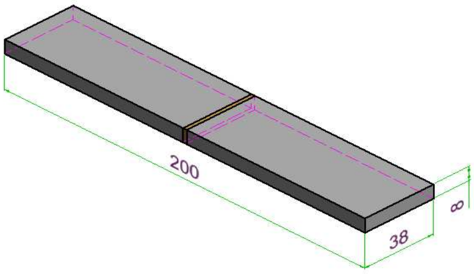

Fig. 6. Bending test specimen dimensions in mm.

Face bending tests were carried out at room temperature using three point's method Fig. (7). A cylinder-shaped line load is applied against the weld line, also the center line, of the specimen. As the specimen is supported on the sides by a steel fixture, it begins to yield because of bending. This test was conducted out on a 100-kN universal testing machine at a speed of 3.5 mm/min. The maximum load registered by the machine during bending was used to indicate the strength of the weld joint.

Fig .7. Bending Setup (Push travel technique).

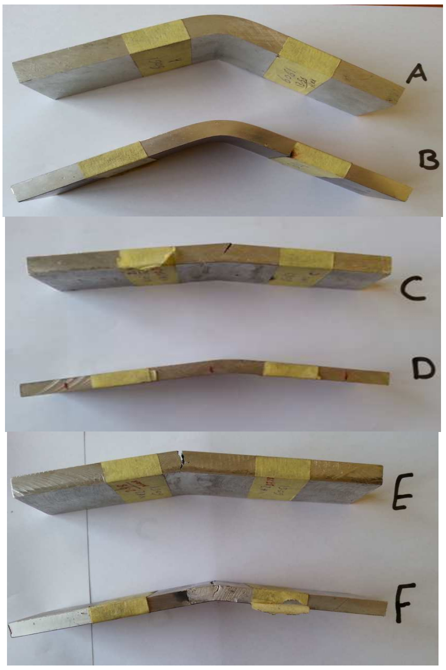

Fig. 8. Photos of bending test specimens after fracture

2.7. Micro Hardness Test

Micro hardness test of the welded joints was accomplished using the Vickers hardness tester. According to the ASTM, Vickers hardness measurements were taken 2 mm below the top surface of the specimen perpendicular to the welding direction across the weld zone, heat affected zone (HAZ) and the base materials using a diamond pyramid indenter with a load of 30 kg and loading within 15 sec.

Tests' results for all specimens are shown in Fig. (9).

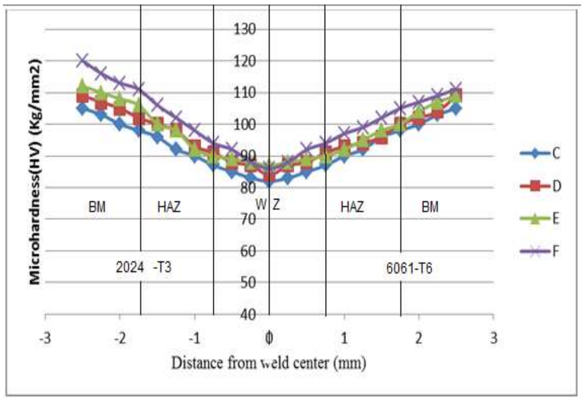

Fig. .9. Micro Hardness Result for All Specimens.

3. Discussion

In this work chemical composition and mechanical properties have been conducted for the material used to check the composition, mechanical properties of the Al-alloy type and compare it with the standard, as shown in Table (1, 2, 3).

The microstructure of base metal aluminum alloy 6061-T651 was shown in Fig. (2) Specimen (A) observed coarse and elongated grains with uniformly distributed very fine precipitates. The presence of alloying elements such as silicon and magnesium contribute to the higher strength of the base metal. These two elements combined together and subjected to precipitation reaction and form a strengthening precipitate of Mg_2Si. Resulting the fine and uniform distribution of these precipitates throughout the aluminum matrix which give higher strength to these alloys [12] and microstructure of base metal aluminum alloy 2024-T351 in Fig. (2) specimen (B) reveal coarse dendritic structure and elongated grains with uniformly distributed very fine precipitate and from the chemical Composition of alloys which referred in table (2)The copper (Cu) is the main element in alloy 2024 T351 gives substantial increases in strength, permits precipitation hardening [13]. The fusion zone of MIG welded joints for 6061-T651 and 2024-T351 shown in Fig. (2) specimens (C,D) contain dendritic structure. The heat input fuses the base metal and filler metal to generate a zone with a composition that is in different from that of the base metal Excess silicon in Composition of wire filler is found to be beneficial for increasing the ductility of the welded structure.

The spacing of weld region is wider in MIG joint and as result of the increase in welding heat of the base metal and fast cooling of molten metal Segregation appear.

The mechanical tested results of all specimens in this study was listed in Table (7) .Include the yield strength, UTS and elongation, bending force and macro hardness as compared with that of the base metal .Table (3) the alloy 2024-T351 in un welding and welding conditions has better mechanical properties than the 6061T651 because of copper effected which increases in strength.

These alloys using MIG welding process evidence the difference in the microstructure and contributes to reduced mechanical properties and poor elongation observed during testing. MIG welding process required high temperature for fusion, the HAZ region was large as well as and the subsequent melting and solidification that occur, voids are common defects found in fusion welds which contributed in that decay . The fracture surface section of tensile test specimens is shown in figure (4). The location of the failure for welded specimens after all mechanical test was found mainly along the HAZ region, they had failed at the weld metal with sudden fracture without reduction in area or necking. But Un welded specimens were failed near the center line of the specimen. Bending test results show that the bending load was reduced as compared with that of the base alloy but did not show any crack in the weld joints. The bend test showed Fig.(8) that joints welded in all welding conditions were very brittle and subjected of very low bend angle without cracks ,specimens (C,D) gives a lower bending force comparing with un welded alloys that goes with [14, 15, and 16], while bending in dissimilar specimens (E,F) has a slightly better bending result than similar joints.

When comparing bending and tensile results of sample (E, F) it shows that sample (E) gives better results because of the welding angle preparation, where V shape angle contributed of heat input distribution causing a homogeny in microstructure compared to sample (F).

Table (7) shows the hardness values of the specimens, in general it was reduced as compared with the base alloy. The minimum hardness value was recorded in sample (C),where hardness in weld metal area was about (82 HV) and in the HAZ was about (100 HV), this value was larger than in the weld metal but lower than of the base alloy which is about (130HV)Fig. (9), this reduction in hardness occurs due to high heat input and grain growth in this region, it can be observed that all specimens hardness profile have the same hardness distribution in different values.

4. Conclusions

1- Higher heat input in the MIG process has reverse effects on the mechanical properties of the welded alloys .

2-The maximum tensile strength of the welded joint is (200MPa) compared to (323 MPa) of the base alloy, i.e., the decay of strength about (40%).

3-Hardness value is affected by the amount of the heat input during the welding process.

4- The base metal has high tensile strength compared with the dissimilar materials welding.

5-It has found that the fracture occurred on the side of the aluminum alloy 6061 -T6 compared with that of aluminum alloy 2024-T3.

5. References

[1] A. S. Vagh1, S. N. Pandya," influence of process parameters on the mechanical properties of friction stir welded AA 2014-t6 alloy using taguchi orthogonal array", International Journal of Engineering Sciences & Emerging Technologies, Volume 2,Issue 1, pp: 51-58 April 2012.

[2] Benachour M., Hadjoui A., Benguediab M.,"Heat Treatment Effect On Fatigue Crack Growth" ,3rd International Conference on Integrity, Reliability and Failure, Porto/Portugal, 20-24 July 2009 .

[3] Klas Weman ,"Welding Process Handbook", Cambridge, England, 2003.

[4] 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 and microstructure", Journal of achievements in materials and manufacturing engineering, Vol. 6, issue 2, December 2013.

[5] Marek St. Weglowski, Adam Pietras, Aleksandra Weglowska," Effect of welding parameters on mechanical and microstructural properties of al 2024 joints produced by friction stir welding", Journal of Kones Powertrain and Transport, Vol. 16, No. 1, 2009.

[6] 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.

[7] Aendraa Azhar Abdul Aziz ,"Effects of Different Fillers on Microstructure and Tensile Properties of Welded AA6061-T6 ",Key Engineering Materials Vols. 462-463 (2011) pp 1189-1193.

[8] Mustafa Kemal Kulekci," Experimental Comparison of MIG and Friction Stir Welding Processes for EN AW-6061-T6 (Al Mg1 Si Cu) Aluminum Alloy", The Arabian Journal for Science and Engineering. 35: 2006, pp.321-330.

[9] Jatinder Gill, JagdevSingh, "Effect of Welding Speed and Heat Input rate On Stress Concentration Factor of Butt Welded Joint of is 2062 e 250 a Steel" International Journal of Advanced Engineering Research and Studies E-ISSN2249–8974 IJAERS/Vol. I/ Issue III/April-June, 2012/98-100

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

[11] Annual Book of ASTM Standards, Standard Practice for Calculation of Corrosion Rates and Related Information, G102-89, Vol. 03.02,2004.

[12] T Senthil Kumar, V Balasubramanian, M Y Sanavullah,"Influences of pulsed current tungsten inert gas welding parameters on the tensile properties of AA 6061 aluminum alloy",. Materials and Design 28 (2007) 2080-2092.

[13] M R Ahmad, M A Bakar, "Effect of post-weld heat treatment on the mechanical and microstructure properties of AA6061 joints welded by the gas metal arc welding cold metal transfer method", Materials and Design 3.

[14] P. Cavaliere, R. Nobile, F. W. Panella andA. Squillace, "Mechanical and microstructural behavior of 2024-7075aluminum alloy sheets joined by friction stir welding", International Journal of Machine Tools and Manufacture 46, September 2005, pp. 588-594.

[15] Muafaq Mehdi Salih, "Studying the effect of joint design, angle and heat treatment on mechanical properties of the aluminum alloy weldments (7020-T6) by MIG process", Master Thesis, Technical College/Baghdad, November 2005.

[16] S. Missori and A. Sili, "Mechanical behavior of 6082-T6 aluminum alloy welds" Metallurgical Science and Technology, Vol. 18, 2000, pp.12-18.

الخواص الميكانيكية لوصلات لحام القوس الكهربائي (MIG) من سبائك الالمنيوم غير المتشابهة (2024 T351, 6061-T651)

نورس جبار ناصر
معهد التكنولوجيا- بغداد
البريد الاليكتروني: nawresjabaar@yahoo.com

الخلاصة

يهدف البحث الى بيان تاثير طريقة لحام القوس الكهربائي المحمي بالغاز على الخواص الميكانيكية لسبائك غير متماثلة من سبائك الالمنيوم عالية المتانة هما T3-٢٠٢٤، 6061-T6 حيث تضمن البحث اجراء سلسلة من التجارب التقنية لتقييم الخواص الميكانيكية للسبائك الملحومة وغير الملحومة وهي خصائص الشد و الصلادة، والحني والبنية المجهرية .انجز اللحام على صفيحتين من السبائك اعلاه للحصول على وصلات تناكبية بالابعاد (200*100*8) ملم بعد عمل زاوية تحضيرية من جهة واحدة مقدارها ٧٠ درجة حرف (V) ووصلة اخرى بنفس الابعاد بدون زاوية باستخدام سلك لحام ٤٠٤٣ ER والاركون كغار حماية بعد عملية اللحام والتاكد من خلو الوصلة من العيوب من خلال فحصها بواسطة جهاز X-ray radiography اجريت معاملة حرارية تضمنت تسخين الوصلة في فرن كهربائي عند درجة حرارة 170 درجة مئوية لمدة نصف ساعة ثم التبريد بالهواء بهدف ازالة اجهادات اللحام .تم تحضير عينات اختبار الشد من وصلات اللحام والمعدن الاساس وفق المواصفة القياسية ASTM17500 وكذلك عينات اختبارالحني وفق المواصفة ASTM (E 190-92) ثم اجراء عمليات تحضير من تنعيم وصقل لغرض فحص البنية المجهرية لمناطق اللحام والمعدن الاساس واجري اختبار صلادة عيانية, وصلادة دقيقة لبيان تأثير اللحام على الخواص الميكانيكية .اظهرت النتائج انخفاض في الخواص الميكانيكية للعينات الملحومة مقارنة بالمعدن الاساس وللسبائك غير متماثلة مع السبيكه الاساس وان موقع الفشل في منطقة الوسط للعينات اما العينات الملحومة فقد ظهر الفشل في المنطقة المتاثرة بالحرارة.