https://doi.org/10.33261/jaaru.2023.30.3.003 Association of Arab Universities Journal of Engineering Sciences (2023)30(3):18–25

Association of Arab Universities Journal of Engineering Sciences
مجلة اتحاد الجامعات العربية للدراسات والبحوث الهندسية

The Effect of Bobbin Friction Stir used different tool Design on the Mechanical Properties to Weld 6061-T6 Aluminum Alloy

Mohammed Jaafar Kadhim[1*] and Suhair G. Hussein[2]

[1]*Department of Mechanical Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq, Mohammed.Kadhim2003M@coeng.uobaghdad.edu.iq*

[2] *Department of Mechanical Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq. Suhair.g.hussein@coeng.uobaghdad.edu.iq*

** Corresponding author: Mohammed JaafarKadhim, Mohammed.Kadhim2003M@coeng.uobaghdad.edu.iq*

Published online: 30 September 2023

Abstract—Friction stir welding by use Bobbin tool (BFSW) is one of welding friction stir (FSW) types; this study investigated the effect of different pin profiles on the process of FSW. Four tools with different pin shapes (threaded pin, cylindrical pin, square pin and threaded pin with two flat faces), this tools made from hot work steel (H13) AISI with special heat treatment to produce 48 HRC hardness. The tensile properties of welding parts, the defects, and the surface appearance that produced by different pin shapes were presented and discussed.By friction stir welding bobbin tool using conventional milling machine two pieces of AA6061 Aluminum alloy with thickness of 8 mm were joined; The results showed that the pin profiles effected on the profile and the defects of welding. The threaded pin with two flat faces design influences the material flow pattern and weld quality and surfaces appearance is best compare with other tools pin profileat 300 rpm rotational speed and welding speed 100 mm/min, with no defects and good mechanical properties. Highest tensile strength was 194 MPa equal to 66% of the base material; the hardness was 91.25 HV in the stirred zone.

Keywords—6061Aluminum alloys, Friction stir welding, Mechanical properties, Tool Pin profile.

1. Introduction

Friction stir welding (FSW) has emerged as one of the most successful, and cost-effective welding processes due to its ability to joint a diverse variety of nonferrous materials and ferrous, including aluminum, titanium, steel, magnesium, and certain polymers [7]. It was proven that the friction stir welding (FSW) method is very efficient for joining both similar and dissimilar materials. Aluminum and magnesium lightweight alloys are joined in this process [12]. Because of their low weight, low density, improved strength, high strength, and corrosion resistance, they are widely used in the shipbuilding, automobile, rail, and aerospace industries. However, some of these fusion welding problems alloys include solidification cracks, alloying material losses, pores, a high residual mechanical characteristics drop, pressures, and oxidation due to the requirement for repeated trials for thick section welding. [5]. friction stir welding Bobbin tool (BT-FSW) also called (self-support) friction stir welding (SS-FSW) [1].Bobbin tool name indicate to tool with upper and lower shoulders linked by pin [14]. After Al-Fe and Al-Cu, aluminum (Al) and magnesium (Mg) have emerged as two of the most investigated materials [8]. Because of the typically significant down force applied through welding, the FSW process is usually entirely mechanized. A solid backing plate beneath the work-piece is required. adapt to the considerable down force and avoid deformation of the work-piece, which immediately limits FSW's application in curved and huge constructions (for example, tanks of rocket fuel) closed profiles (for example, hollow extrusions) in which the application of It is difficult or impossible to find a well-supported backing plate [13]. A non-consumable friction tool with a prepared especially shoulders and pin is incorporated into the plates or sheets to be welded and moved along the linked route. Heat created by friction among a spinning tool and the connected sections induces plastic deformation and stir of the portions at the weld junction. [10]. FSW technology is classified into two types: "conventional friction stir welding (CFSW) and BFSW". These processes are distinguished by design of the tool, as shown in Figure 1.

Although the method is similar, the manner in which the weld is generated is influenced by the differing approach [11].

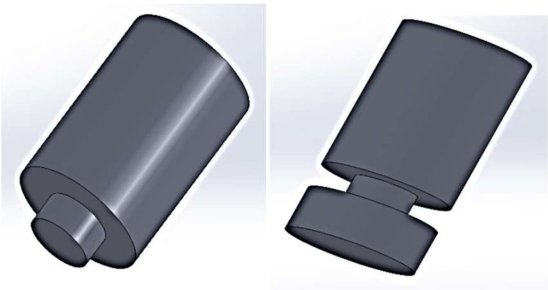

Figure 1: Types of FSW. (a) CFSW (b) BFSW

A solid-state friction stir welding variation is bobbin tool friction stir welding (BT-FSW). The concept of FSW, which creates a strong connection by mixing different plasticized material, is similar to that of BT-FSW. The variation in BT-FSW, frictional heat is delivered from both sides. Two spinning shoulders are linked together by a probe [6].

A rotating tool (equipped with a pin and shoulders) is placed into the work pieces to be connected during the FSW process. At first, a non-consumable tool rotated at a continuous speed. [4]. FSW commonly used Al base metals in recent progress on Al joints are of the 5xxx and 6xxx series. The 5xxx and 6xxx series are on display excellent strength-to-weight ratio, thermal conductivity, and durability recyclability. As a result, these series are frequently used in a variety of contexts, sectors such as marine, construction, architecture, and transportation, in this research Al 6061 used for butt joint by use bobbin tool different pin profiles. Amin, S. A., Hanna, M. Y., & Mohamed, A. F.[3] their research were, the response surface approach technique was utilized in their research to build experimental Mechanical qualities: elongation, tensile strength, and maximum bending force of bobbin friction stir welding AA6061-T6 are quantitatively described, as are the welding parameters (welding speed and tool rotation speed). Determine the ideal is higher mechanical properties from welding parameters for the welded joint using a numerical optimization method.

Mohamed M. Z. Ahmed [2] Joining for the aluminum alloy AA1050 was performed with three various pin geometries (triangular, square, and cylindrical), different jointing rates, and a constant tool speed of rotation of 600 rpm. Welding heat was measured during BT-FSW and comparing to models' predictions under the same circumstances. There was best agreement for all of the measured welding speeds, especially in the instance of the cylindrical pin and square pin. Mohammad HoseinMirzaei [9]. The impact of pin shape on: heat, material flow, grain size, and tensile characteristics. According to the findings, material flowing pattern in the shoulders driven and pin zones differ. In the pin stirred zone, the metal moves from the advancing side to the retreating side; in the shoulders movement zone, the opposite is true. Despite having the longest sweep lever and the ability to move the most material boxes, the trigonal pin, and the hexagonal pin tool achieves the finest material coalescence and consistent material movement. The inner conical pin tool produces the weakest material fluid motion, resulting in the construction of a tunnel cavity in the welding zone. In contrast, the outer conical pin tool generates a secondary substance. Flow and material coalescence are improved, resulting in increased strain, smaller grain size, and superior mechanical characteristics over the inward conical pin tool. The goal of this study was to determine which tool pin designs had the best mechanical qualities.

2. EXPERIMENTAL WORK

2.1. Selection of Material

The powder metallurgy method was used to manufacture In this work, aluminum alloy 6061 used as parent material, the workpiece cut by saw cutting machine to the desire size (10mm*20mm*8mm). As shown in the table (1), the chemical analysis of the used material was conducted using spectrum equipment at the State Company for Engineering Rehabilitation and Inspection (SIER). The mechanical properties were complete for this work piece in Quality Control Department in State Company for Steel Industries (SCSI) given in table (2).

Table 1. The chemical structure of the substrate found via spectrometer device.

Wt% / Material	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Pb	Al
Standard	0.4-0.8	<0.7	0.15-0.4	<0.15	0.8-1.2	0.04-0.35	<0.05	<0.25	<0.7	<0.05	Bal.
Actual	0.498	0.313	0.223	0.0846	0.966	0.0984	0.0031	0.0132	0.0138	0.0160	Bal.

Table 2: The mechanical properties of aluminum alloy 6061-T6.

property	Yield stress (Mpa)	Ultimate tensile stress (Mpa)	Elongation (%)
Standard Value	≥240	≥290	10
Actual Value	246	294	12

2.2 material and Manufacture of a Bobbin Tool

Bobbin tool with different designs was used, the diameter of the flat shoulders was 25 mm, and the pin diameter was threaded 10mm with patch 1.5ø. The shoulders gap was equivalent to work-piece thickness (8.1 mm), this work's tool was made using hot-work tool steel (H13); the chemical composition of which is shown in table 3. For the treatment of the hot work tool steel (H13) AISI , the temperature raised to 1030℃ in furnace for about 40 min but the metal with 25mm must be preheating temperature for 10min when reach 400℃ , 650℃ and 850℃ that made chance for grain arrangement to the metal ,when we have 1030℃ than cooling the metal in oil pool to the room temperature ,after that we made aging process to have desire hardness ,raises the temperature to 550℃ and 500˚C respectively for 60 min and cooling to the room temperature in oil pool which gives 48 HRC hardness. Because the utilized plate was thick, the flat feature on the pin may generate a horizontal flow, which helps to agitate the mushy material, but while the gap is fit between the tool's shoulders and the thickness of the substrate can offer a vertical flow movement of mushy material.

Table 3: Actual and standard chemical structure of (H13) hot- work tool steel found via spectrometer device.

Wt% / Material	C	Si	Mn	P	V	S	Cr	Mo	Fe
Standard	0.32-0.45	0.8-1.25	0.2-0.6	<0.03	0.8-1.2	<0.03	4.75-5.5	1.1-1.75	Bal.
Actual	0.35	1.05	0.3	0.01	1.01	0.006	5.01	1.23	Bal.

2.3 Tool design

This research was focus on tool design, the shapes that chosen depended on the pin shape threaded pin, cylindrical pin, square pin and threaded pin with two flat faces, the effect of pin profile on stirred zone all the profiles have different results on mechanical properties, defects, and surface welded joint the table 4. Explain tool description of all designs. The figure 2a and b show the image of Threaded straight cylindrical with 2 flat surfaces on both sides, this tool given different method of stir. The ration between the shoulders and the probe not less than D/d =2.5 or more in the other material.

Figure 2, a: Threaded cylindrical with 2 flat surfaces

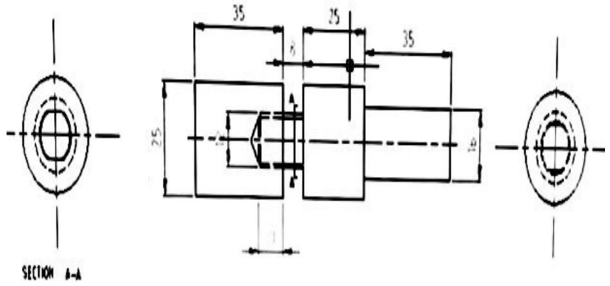

Figure 2, b: Drow threaded cylindrical with 2 flat surfaces

Table 4 :BT-FSW Tool Description

Tool dimensions and feature	**Values**
Upper and lower shoulder	Diameter 25 mm
Pin dimensions and profiles	Square pin with width 10 mm
	Cylindrical=10 mm Diameter
	Threaded – 10x1.5ømm
	Threaded -10x1.5ømm with two flat in both sides of the threaded part
Gap length	8 mm
Length of upper shoulder	25 mm
Length of lower shoulder	35 mm
Holder diameter	16 mm
Holder length	35 mm
Shoulder profile	Smooth

The figure 3 shows the cylindrical pin shape. The figure 4 show the threaded tool, the figure 5 show square pin shape.

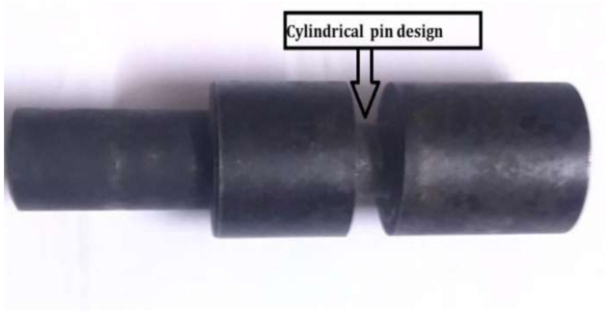

Figure 3: Bobbin tool with cylindrical pin profile

Figure 4: Bobbin tool with threaded tool

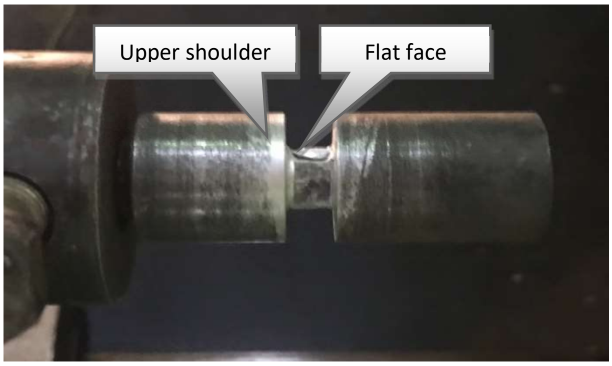

Figure 5: Bobbin tool with square pin

3. RESULTS AND DISCUSSION

The used input parameters were chosen throughout the experimentation based on the author previous research, which was used different parameters the rotational speed (250, 300, 350, 400, and 700) rpm, the liner tool advancement was (50, 100, and 150) mm/min, The rotating speed of the Hartford CNC milling machine is 300 rpm, and the speed of welding is 100 mm/min. These are the ideal specifications for good mechanical characteristics and few defects. When we applied this parameters with different bobbin tool design, work piece 8.1mm thickness the results was:

3.1 Effect of Cylindrical tool pin

When used bobbin tool with Cylindrical pin profile it well be made high temperature in stirred zone, flash defect at the upper surface and rough welding profile in both sides, because cylindrical pin made vibration and torque in the machine when start linear speed, this tool needed for 80 second for preheating the metal and start welding, the welded joint show in the figure 6,a and b.

Figure 6, a: the upper side used cylindrical tool pin

Figure 6, b: the lower side used cylindrical tool pin

3.2 Effect of Threaded tool pin

The action of threaded pin was produce high temperature but the materials in stirred zone was flow to upside that's made decrease in the metal in bottom surface and appear tunnel defect if the other parameter of the process was suitable for joint, the surface of the substrate had extrusion force by threaded pin that caused flash defect. This tool needed for 60 second for preheating the metal and start welding;the welded joint show in the figure 7a, and b.

Figure 7, a: The upper side usedthreaded tool pin

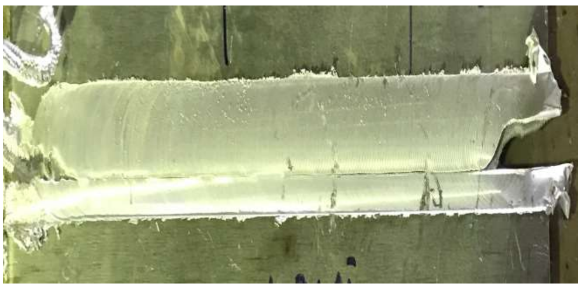

Figure 7, b: The lower side usedthreaded tool pin

3.3 Effect of Square tool pin

The square probe profile was generate high temperature in stirred zone compared with other tools and produce smoother surfaces on the both sides, but produce flash defect this tool needed for 40 second for preheating the metal and start welding. The welded joint shows in the figure 8, a and b.

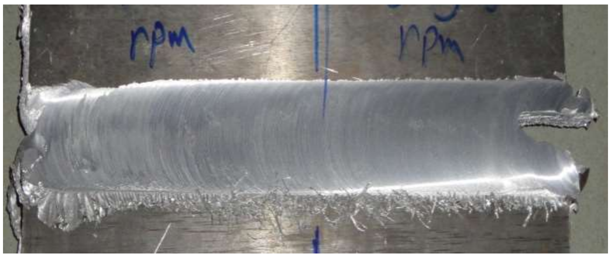

Figure 8, a: The upper side welded bysquare tool pin

Figure 8, b: The lower side welded bysquare tool pin

3.4 Effect of Threaded tool pin design with two flat faces

Threaded tool pin design with two flat faces was generate suitable heat and no flash in the both surfaces, the metal in stirred zone had raise action to the upped direction and go back to the bottom direction, because the two faces in the both sides of the thread open allowed the stirred metal to balance the distribution as show in figure 9. This tool needed for 80 second for preheating the metal and start welding. when used probe diameter less than thickness of the work piece the probe cannot stand the load of the torque of friction in the down shoulder the tool well be fracture , the probe it is must be equal or more than the thickness of the specimen. The welded joint show in the figure 10, a and b.

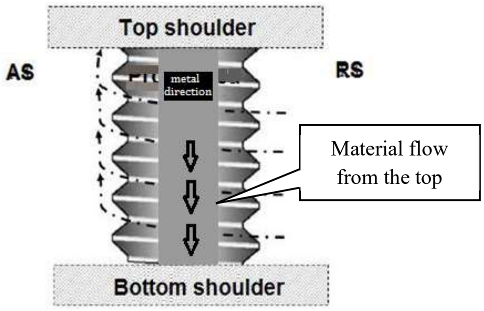

Figure 9: Material flow in welding zone by tool threaded with two flat faces.

Figure 10, a: The upper side welded bythreaded tool with two flat faces.

Figure 10, b: The lower side welded bytool threaded with two flat faces.

3.5 Mechanical Tests

Tensile tests were performed on specimens placed in a direction normal to the welding route to determine the tensile strength for all welding experiments. Figure 6.shows dimensions of longitudinal and the standard-compliant shape tensile samples (ASTM E-8M).

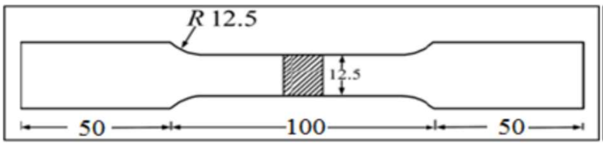

Figure 11: specimenof tensile

3.5.1 Tensile test

All the four tools made welding, but produced different mechanical properties. All tensile tests were performed applied a computerized universal testing machine at room temperature and at load constant rate of 1 mm/min (united tensile test device). Table 5 shows the parameters and results of the test.

Table 5: The Parameters and Results of the test

Exp. No.	Pin shape	Rotational Speed rpm	Welding Speed mm/min	Tensile Strength MPa
1	cylindrical	300	100	180
2	Threaded	300	100	177
3	square	300	100	184
4	Threaded with two flat faces	300	100	194

The histogram of tensile strength is shown in Figure 12. The maximum tensile strength for threaded tool with two flat faces joints is 194 MPa. This bobbin tool achieved the highest tensile strength (194 MPa), which was 66% that of the base material. The tensile strength for BT-square pin profile is 184 MPa because of the heat generated that effect on stirred zone, high heat input from the tool increase the grain size of the weld sample. The threaded pin profile has lowerest tensile strength 177 MPa, because of stirred action of this shape caused the tunnel defect in the welded zone.

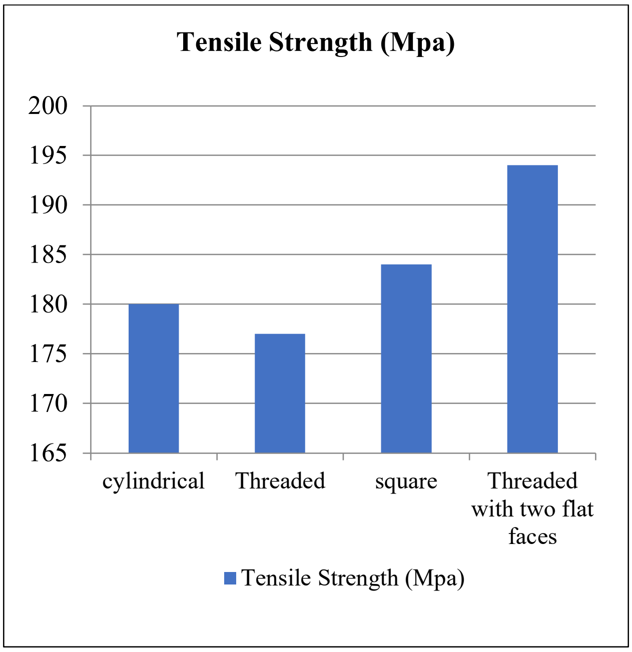

Figure 12: Tensile strength histograms ofboobin tool different pin profiles.

4. CONCLUSIONS

From the experiment by and bobbin tool with different pin profile the conclusion was:

1. All experiments were successful by using different pin shapes and fixed process parameters, Rotation speed 300 rpm, welding speed 100mm/min, and fixed gap distance 8 mm
2. The tools need different times for generate frictional heat welding process , because effects of pin shapes, and this prove that pin assist to raise the temperature and stir the welded zone .
3. Tool pin profile effect in the mechanical properties for welded joint, which was 66% that of the base material, the best tensile strength was 194 MPa for tool threaded with two flat faces, while tool threaded pin profile was 177 Mpa 60%of the base material.
4. The heat generated depended on the shoulders and the pin shape specially the pin that have more angles, as the square pin which made excessive heat compare with other shapes.
5. The bobbin tool with two flat faces made best results, because the welding have good appearance, no flash in

both surfaces, best stirred zone, and best mechanical properties.

REFERENCES

[1] Ahmed, Mohamed MZ, Mohamed IA Habba, Mohamed M. El-Sayed Seleman, Khalil Hajlaoui, SabbahAtaya, Fahamsyah H. Latief, and Ahmed E. El-Nikhaily. "Bobbin Tool Friction Stir Welding of Aluminum Thick Lap Joints: Effect of Process Parameters on Temperature Distribution and Joints' Properties." Materials 14, no. 16 (2021): 4585.

[2] Ahmed, Mohamed MZ, Mohamed IA Habba, Nabil Jouini, Bandar Alzahrani, Mohamed M. El-SayedSeleman, and Ahmed El-Nikhaily. "Bobbin tool frictionstir welding of aluminum using different tool pin geometries: Mathematical models for the heat generation." Metals 11, no. 3 (2021): 438. DOI: 10.3390/met11030438

[3] Amin, Samir Ali, MohannadYousif Hanna, and AlhamzaFarooq Mohamed. "Modeling and Optimization of Bobbin Friction Stir Welding for AA6061-T6 alloy Utilizing Response Surface Methodology." Journal of University of Babylon for Engineering Sciences 26", no. 4 (2018): 1-17.

[4] Fabregas Villegas J., Arnold MartínezGuarín, and JimyUnfried-Silgado. "A coupled rigid-viscoplastic numerical modeling for evaluating effects of shoulder geometry on friction stir-welded aluminum alloys." International Journal of Engineering 32, no. 2 (2019): 313-321. Doi: 10.5829/ije.2019.32.02b.17

[5] Fuse, K. and Badheka, V., "Bobbin tool friction stir welding: A review", Science and Technology of Welding and Joining, Vol. 24, No. 4, (2019), 277-304 DOI: 10.1080/13621718.2018.1553655.

[6] Goebel, Jannik, Martin Reimann, Andrew Norman, and Jorge F. dos Santos. "Semi-stationary shoulder bobbin tool friction stir welding of AA2198-T851." Journal of Materials Processing Technology 245 (2017): 37-45. doi:10.1016/j.jmatprotec.2017.02.011

[7] Hasan, Mohammed M., M. Ishak, and M. R. M. Rejab. "Influence of machine variables and tool profile on the tensile strength of dissimilar AA7075-AA6061 friction stir welds." The International Journal of Advanced Manufacturing Technology 90, no. 9 (2017): 2605-2615.

[8] Kumar, Uday, Anurag Prajapati, Uttam Acharya, Tanmoy Medhi, BarnikSaha Roy, and S. C. Saha. "Welding condition & microstructure of friction stir welded AA 6061-T6 and AZ31B." Materials Today: Proceedings 46 (2021): 9484-9489.DOI.org/10.1016/j.matpr.2020.03.242

[9] Mirzaei, MohammadHosein, ParvizAsadi, and Ali Fazli. "Effect of tool pin profile on material flow in double shoulder friction stir welding of AZ91 magnesium alloy." International Journal of Mechanical Sciences 183 (2020): 105775. DOI.org/10.1016/j.ijmecsci.2020.105775

[10] Nakhaei, Mohammadreza, NasrollahBaniMostafa Arab, and GholamRezaei. "Investigation on tensile strength of friction stir welded joints in pp/epdm/clay nanocomposites." International Journal of Engineering 28, no. 9 (2015): 1382-1391. DOI: 10.5829/idosi.ije.2015.28.09c.17

[11] Sued, M.K. and Pons, D.J., "Dynamic interaction between machine, tool, and substrate in bobbin friction stir welding", International Journal of Manufacturing Engineering, Vol. 2016, No., (2016), DOI: 10.1155/2016/8697453.

[12] Thakur, Ankit, Varun Sharma, and Shailendra Singh Bhadauria. "Investigation of metallurgical characterization and mechanical properties of double-sided friction stir welding of aluminum 6061 T6 alloy." Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 237, no. 1-2 (2023): 16-30.

[13] Wang, Guo-Qing, Yan-Hua Zhao, and Ying-Ying Tang. "Research progress of bobbin tool friction stir welding of aluminum alloys: A review." ActaMetallurgicaSinica (English Letters) 33, no. 1 (2020): 13-29. DOI.10.1007/s40195-019-00946-8

[14] Yang, C., D. R. Ni, P. Xue, B. L. Xiao, W. Wang, K. S. Wang, and Z. Y. Ma. "A comparative research on bobbin tool and conventional friction stir welding of Al-Mg-Si alloy plates." Materials Characterization 145 (2018): 20-28.DOI.org/10.1016/j.matchar.2018.08.027

أسم الموضوع. تأثير أداة بكرة اللحام الاحتكاكي باستخدام بكرات مختلفة التصاميم على الخواص الميكانيكية للحام سبيكة المنيوم T6 – 6061

محمد جعفر كاظم* [1]، سهير غازي حسين [2]

[1] *قسم الهندسة الميكانيكية، كلية الهندسة،جامعة بغداد، بغداد، العراقMohammed.Kadhim2003M@coeng.uobaghdad.edu.iq*

[2] *قسم الهندسة الميكانيكية، كلية الهندسة، جامعة بغداد، بغداد، العراق، Suhair.g.hussein@coeng.uobaghdad.edu.iq*

الباحث الممثل: محمد جعفر كاظم,Mohammed.Kadhim2003M@coeng.uobaghdad.edu.iq

نشر في: 30 ايلول 2023

الخلاصة – يعد لحام الخلط الحتكاكي باستخدام أداة البكرة (البوبين) أحد انواع لحام الخلط الاحتكاكي (FSW). ؛ حققت هذه الدراسة في تأثير اشكال نتوء الغرز المختلفة على عملية FSW. تم استخدام أربع أدوات ذات أشكال مختلفة لنتوء غرز (سن ملولب ، نتوء غرز أسطواني ، نتوء غرز مربع ، نتوء غرز ملولب ذو وجهين مسطحين) ، هذه الأدوات مصنوعة من الفولاذ المعمول على الساخن (H13) (AISI) مع المعاملة الحرارية الخاصة لإنتاج صلابة HRC 48 ، تم عرض ومناقشة خصائص الشد لأجزاء اللحام ، والعيوب ، والمظهر السطحي الناتج عن الأشكال المختلفة لنتوء الغرز . تم ربط قطعتين من سبائك الألومنيوم AA6061 بسمك 8 مم بواسطة أداة بكرة لحام الاحتكاكي باستخدام آلة تفريز تقليدية . أوضحت النتائج أن جوانب نتوء الغرز أثرت على شكل اللحام والعيوب. يؤثر تصميم نتوء الغرز الملولب ذو الوجهين المسطحين على نمط تدفق المواد وجودة اللحام ومظهر الأسطح بشكل أفضل مقارنة مع بقية اشكال نتوء الغرز بسرعة دوران 300 دورة في الدقيقة وسرعة لحام 100 مم / دقيقة ، مع عدم وجود عيوب وخواص ميكانيكية جيدة . اعلى اجهاد شد للقطعد الملحومة كان 194 ميكا باسكال والذي يساوي 66 % من المعدن المستخدم وكانت الصلادة في المنطقة الملحومة تساوي 91.25 حسب مقياس فيكرز.

الكلمات الرئيسية – سبيكة المنيوم 6061 , لحام الخلط الاحتكاكي , الخواص الميكانيكية , اشكال نتوء الغرز