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RESEARCH ARTICLE

Friction Stir Welding Of 6061 Aluminum Alloy With Different Pin Tools and Rotation Speed

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Abstract

Joined aluminum alloy by fusion welding generated more problems because heat melting point lead to oxide aluminum prevent joined process because oxide metals insulter heating in addition problem in microstructure such as solidification cracks, void,porosity, slag inclusionand pour in mechanical properties. So that friction stir welding consider best method to weld aluminum alloys because of joined low melting point, absence solidification and no filler wire or fluxused results good properties in joint back to recrystallized microstructure in the stir zone. In this work studied mechanical properties (tensile test, microhardness and impact test) of 6061 aluminum alloys with differentpin tool (cylindrical threaded pin SCT, tapered cylindrical threaded pin TCT and triangular threaded pin TT)and different rotation speed (450,560 and 900)RPM at constant welding speed (35mm/min) show thatthe microstructure is very fine and homogenous in all the tools, super tensile strength at TCT tools at rotation speed (560RPM) equals to (370MPa) and hardness also increased but still lower than of base metals and impact increased in all the tools compared to the base metals.

INTRODUCTION

The technique was considered environmentally friendly, less energy efficiency and can be welded dissimilar metals without problem and with different thickness and different profile, was initially for Al-alloys and for welding developed of Mg, Cu, Ti, matrix composites, lead, some steels, stainless steels, and different material combinations known is Friction stir welding [1]. Friction stir welding started by the welding Institute (TWI) of Cambridge in December 1991[2,12]. The principle of FSW is rotating shouldered tool plunges into the joining point of plates and the heat is originally developed from the friction between the welding tool and the welded material as shown in figure (1), which causes the welded material to soften at a temperature less than its melting point[3].

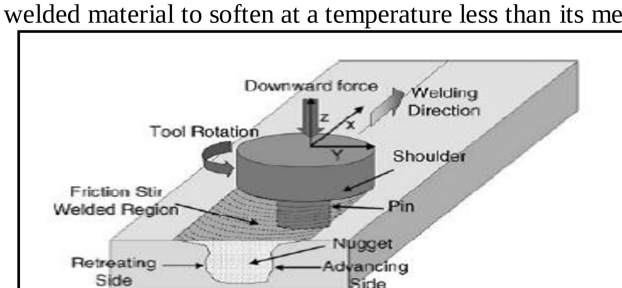


Figure 1: Schematic drawing of FSW process[7].

In FSW, the heat is generated by the friction between the pieces work and tools lead to joint and depended the tool geometry and parame- ters welding[4].The rotating tool moves alone the weld line and develops frictional heating of the material, causing it to plasticize andprodu-ced a high integrity weld. However, there are numerous defects need title in welding proses, such as holes, tunnels, cavity and 'surface lack of fill' defects at the joint area of the aluminum alloy. These defects can lead to the degradation of the tensile properties and ductility strength of the welded material [4]. The tool divided in two main functions: heating pieceof work and movement of material to produce the joint. The degree of heating deals with the tool and pieces that work and plastic deformation of pieces itself. The more heating softens the area around the pin and movement of rotational tool lead to movement from the front to the back thepin[5].Temperature increase and high strain rate deformation lead to the formation of micro structurallydifferent zones [6].Parent metal (BM): where material not deformed, also may be subjected to cycles heating but no changein mechanical properties or structure change, Heat affected zone (HAZ): in this zone mechanical propertiesandmicrostructurechange because of heating cycles, Thermo mechanical affected zone (TMAZ): in this zone material not only is subjected to heating cycles but also deformed plastically, structure is tight deformed and Stir zone (SZ): where re crystallization completely occurred. In this zone because deformation at high temperature soft grain volume can be shown which strength and hardness increase of zone welded metal. Different friction stir welding area shown in figure (2)[7,11].

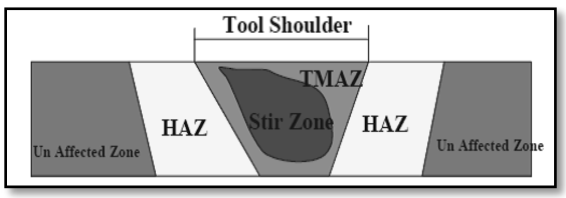


Figure 2. Schematic of different friction stir welding area [7].

2.Experimental Method :

Aluminum alloy 6061 was used in this studymechanical properties and composition of this alloy shown in table (1)and(2).Two aluminum plates, having the dimensions are 8 mm in thickness, 150 mm length and 100 mm in width, were placed on a flat metal plate. Before starting welding process, two pieces of aluminum plates was cleaned using ethanol to removing the oxides on the surface of the plates.

Table 1: Mechanical properties of the 6061.

Yield strength(MPa)	225
Ultimate tensile strength (MPa)	284
Elongation (%)	22.3
Hardness(HV)	235

Table 2: Chemical composition (weight %)

Elements (%)	Measurement (%)
Cu	0.4
Mg	1.2
Fe	0.7
Si	0.8
Zn	0.25
Al	Bal.

In this work three different of tool pin geometries profiles (1)Cylindrical threaded pin SCT,(2) Taper cylindrical threaded pin TCT and (3) triangular threaded pin TT. The X13 tool process parameters used are given in table 3. The shoulder of the tool was the same with the diameter of 20 mm. The length of the pin was 7.6 mm as the required welding depth of the plates. The rotation speed (450,560 and 900) RPM and at welding speed35 mm/min, with a 2 tilt angle. The process parameters of FSW and tool dimensions shown in table 4.

Table 3 : Chemical composition (weight %) of FSW tool .

C	Cr	Mn	Si	Fe
2-2.3	11.5-13	0.3-0.35	0.34-0.4	Rem

Table-4: FSW process parameters and tool dimensions.

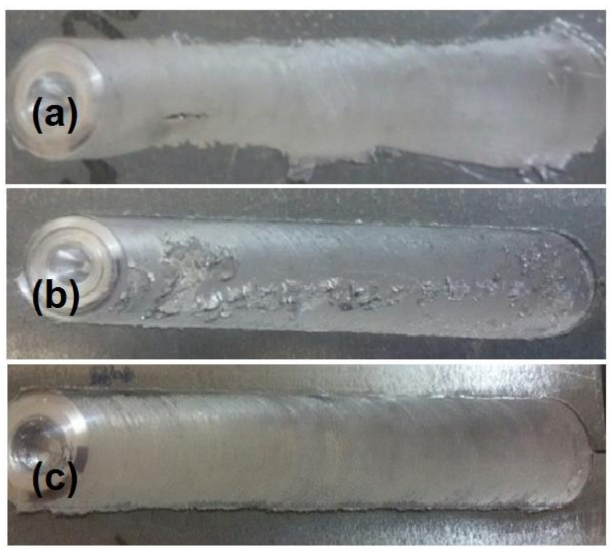
Process Parameters	Values
Rotation speed (RPM)	450,560,900
Welding speed(mm/min)	35
Pin length (mm)	7.6
Shoulder diameter(mm)	20
Pin diameter(mm)	8
Tool pin geometry	SCT, TCT, TT
Tool materials	X13 tool steel

After welding, the specimens were cut in the direction perpendicular to the line of the work of welding features for preparing tests (tensile, impact, micro hardness). Tensile test was measured according to the ASTM B 557M , charpy impact test according to ASTM E23 and Vickers hardness .

3. Results and Discussion.

3.1 Effect of pin profile and rotationspeed on the appearance of the weld :

Shows the photos of weld surface appearance madewithdifferentfrictionstir tools(SCT,TCT and TT) and different rotation speed (450,560 and 900) RPM at constant welding speed (35mm/min). It can be seen from the pictures that good surface appearance will be obtained using all this tools at high rotation speed because increase heat input lead to flow and stir materials. The appearance of the weld was clean and no clear defects can be found. Figure(3): shows the photos of weld surfaceappearance made with the cylindrical threaded pin (SCT) profile at different rotational speed(450,560 and 900)RPM at constant welding speed (35mm/min). It can be seen from the pictures that surface appearance of the weld is tunnel defect at 450RPM because low tempera- true and low material flow .



Figure(3): Appearance of welding usingcylindrical threaded pin(SCT) at different rotation speed (a) at 450 RPM,(b) at 560 RPM and (c) at 900RPM.

Figure(4): shows the photos of weld surface appearance made with the taper cylindrical threaded pin(TCT) at different rotational speed (450, 560 and 900)RPM. It can be seen from the pictures that good surface appearance has been obtained at high rotational speed.

Figure (5): shows the photos of weld surfaceappearance made with the triangular threaded tool pin profile(TT) at different rotationalspeed (450,560 and 900)RPM. It can be seenfrom the pictures that in all the three cases weldappearance is good at high rotation speed 560RPM and 900 RPM but less in 450RPM.

Note ,the resingood welding at high rotation speedbecause alltools concavity play vital role to restrict material inside shoulder and the screw thread will be beneficial to the heat generation, underthe same weld parameter, the pin with screw thread willgenerate more heat than the pin without screw thread. Moreheat input can improve the flow of the plastic material. On the other hand, the screw thread on the pin exerts an extradownward force that will be beneficial to accelerate the flow of the plastic material[8].

Figure(4) : Appearance of welding using tapered cylindrical threaded pin (TCT) at different rotation speed (a)450RPM,(b)560RPM and (c) 900RPM.

Figure (5) : Appearance of welding using triangular threaded pin (TT) at different rotation speed (a) at450RPM(b)560RPM and (c) 900RPM .

3.2 Microstructure

The specimens were test at variable rotation speed (450,560 and 900)RPM and different tools “pins” The microstructure of nugget zone where microstructure consisted of equaled grains with the volume of less than large grains of BM. welded by SCT tools show the microstructure is smaller as shown in figure 6 (b, c and d) different tool sbecause More heat input can improve the flow of the plastic material. In (TCT) tools has experienced high temperatures and extensive plastic deformation, and ischaracterized by dynamically recrystallized grains. Pin form influence the nugget structure greatly. The structure of Fine grain concomitantly in the nugget area welded by (SCT) tools and the size of the grain is smaller . The distribution of precipitate was in flounced by pin. The volume of the precipitate is finer and the density distributions is higher. The nuggetmicrostructures welded by (TT) tools the volume of the grain is bigger compared by (TCT) and (SCT).

Grain size in creases with rotation speed increasing in all the tools. The one of important stages of the FSW is the different of plastic zone on advanced and retreated side, which structure different in nature[6].The microstructures in weld nugget decreased size in grain with increased rotation speed in all the tools. That microstructure change smoothly from nugget to TMAZ. Welded by SCT tools ,the material flow possible easily, the grade of speed is smaller and the structure is even. The volume grains changes from one area to another from nugget to TMAZ, this will not influence the property very much. welded by (TT) tools. That it is the process of welding, the area of nugget zone represent temperature and plastic deformation very high ,however after recrystallized, soft grain came into existence, so speed at nugget is very high alsoTMAZ, but the temperature and deformation in TMAZ is not like in nugget zone area[8,13].

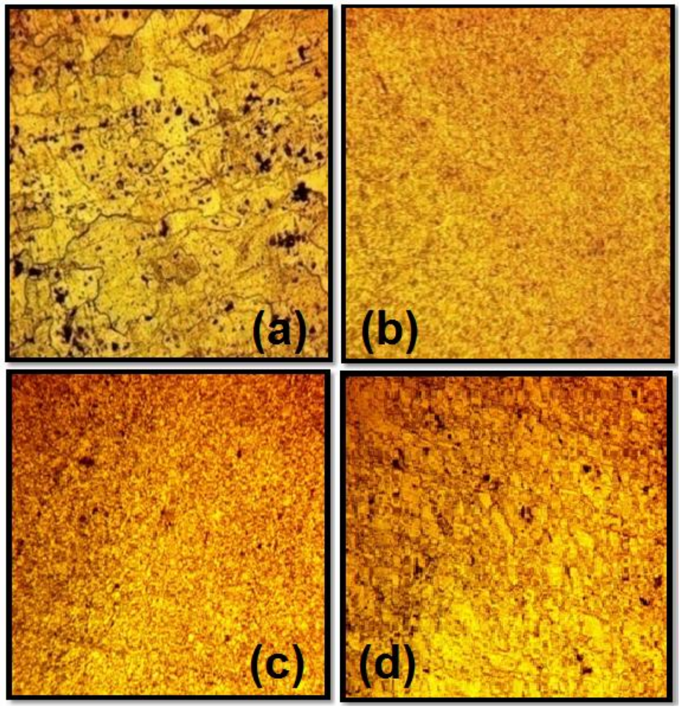


Figure (6): The microstructure of (a) base metal ,(b) 560RPM at TCT tools, (c)560RPM at SCT tools and (d) 560RPM at TT tools.

3.3 Microhardness

The table (5) shown microhardness profile transverse cross NZ,TMEZ,HAZ and BM on the transverse crosssection of joints welded at different rotation speeds. Increasing rotation speed influenced on hardness of NZ and TMEZ but slightly effective for HAZ Micro- hardness in NZ and TMAZ increases with increasing rotation speed but stay lower of BM at a 450 RPM rotation speed and welding speed 35 mm/min in TCT tools higher than value in SCT and TT tools. This tendency suggests that significant increase of hardness with increasing rotation speed is not a function of grain size but a function of size and distribution of second phase particles and precipitates. Grain size is less effective on hardness in NZ comparing with other factors.
At rotation speed 560 RPM hardness value starts again to increase and a higher value than that of base metal was obtained at NZ region.

Table(5): The microhardness (HV) measurement at SCT

SCT				
Rotation speed (RPM)	BM	HAZ	TMEZ	NZ
450	234	185	123	143
560	198	190	120	166
900	200.5	170	111	135

Hardness in these regions towards TMAZ is still lower than that of BM. Unlike coarsening, dissolution leads to a subsequent recovery of hardness in all the tools in table (6) hardness starts to decrease and a minimum value is achieved at about 900 RPM in all the tool same effect where some precipitates might have coarsened and lost their coherency due to thermal history. This significant increase of hardness could be attributed mainly to the second phase particles size and distributions and dislocation density, where increasing rotation speed mean increasing strain[14].

Table(6): The microhardness(HV) measurements at TCT.

TCT				
Rotation speed (RPM)	BM	HAZ	TMEZ	NZ
450	222	170	152	173
560	206	163	140	193
900	197	170	142	159

All the tool same effect with rotation speed but the reasons the (TCT) give higher other tools because (TCT) more homogenous and produce high temperature during flow metals in the friction stir welding lead to high plastic deformation and also some defect produced results which have low heat input and poor material mixing results. In general the effect of tool geometry less than effect of the rotation speed and welding speed on hardness. Table (7) .

Table(7): The microhardness (HV) measure-mentsat TT .

TT				
Rotation speed (RPM)	BM	HAZ	TMEZ	NZ
450	204	165	120	129
560	248	160	125	149
900	227	155	120	155

3.4 Tensile strength

The stress-strain curves shown in figure (7),(8) and (9) the engineering stress-strain relationship of welded products for cylindrical threaded pin (SCT), tapered cylindrical threaded pin(TCT) and triangular threaded pin (TT) at(450,560,900)RPM rotation speed. Show that ultimate tensile strength (UTS)equals (280Mpa) at tapered threaded pin (TCT) as compared (SCT) and (TT) tools equals (250MPa) and (210Mpa) at rotation speed (450 RPM) and welding speed(35 mm/min).

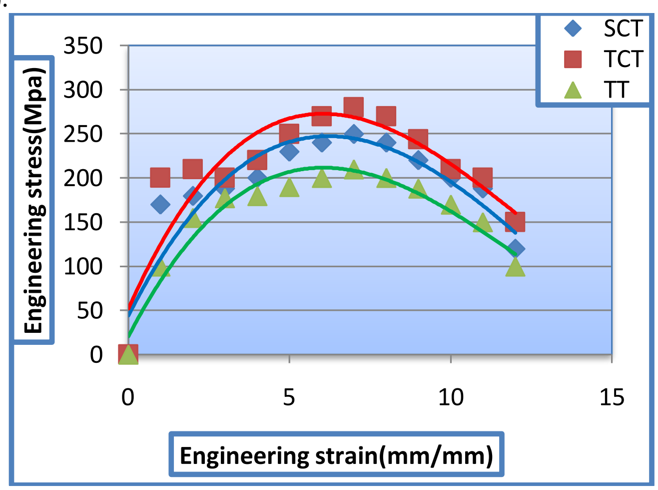


Figure7: The relationship between engineering stress-strain curveat rotation speed (450RPM) and welding speed (35 mm/min) .

Show that maximum tensile strength and elongation in (TCT) equals (370Mpa) and (310Mpa) at (SCT) and (230Mpa) at (TT) at rotation speed equals (560RPM).The tensile strength, yield strength and elongation all the tools increased at increase rotation speed and decrease welding speed and give super tensile strength at (560RPM).The anthers factors effects the properties may be due to the fact that the shoulder surface provides most of the thermal flux through friction and the probe geometry affects the local material flux during the FSW process.

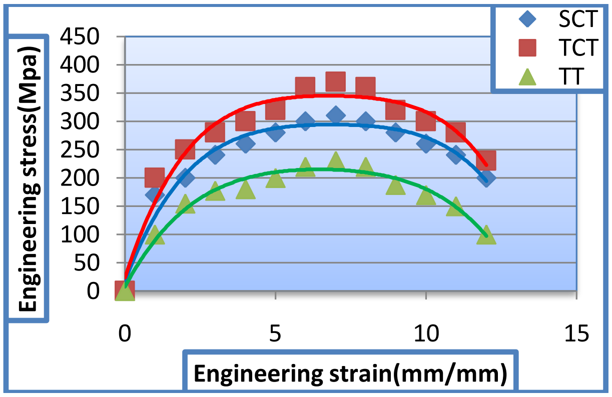


Figure8: The relationship between engineering stress-strain at rotation speed 560 RPM and welding speed 35mm/min.

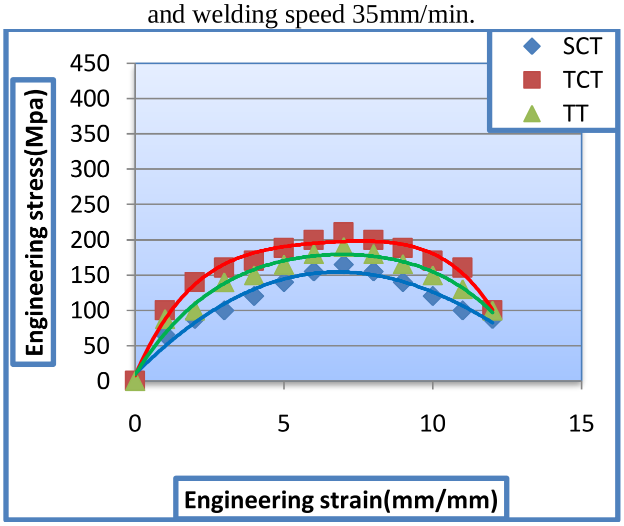


Figure9 : The relationship between engineering stress-strain at rotation speed (900RPM) and welding speed 35 mm/min .

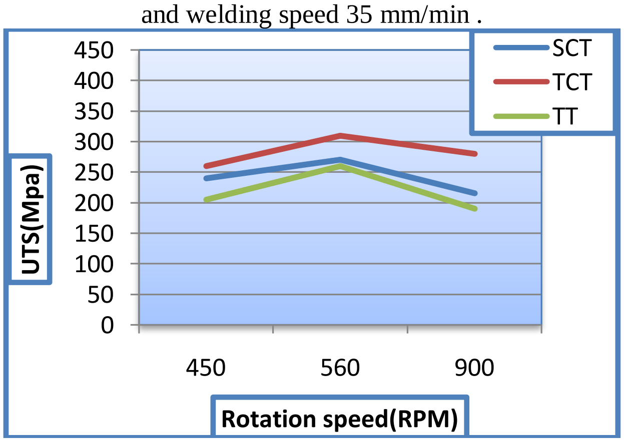


Figure 10 : Effect of tool pin profile and rotation speed and ultimate tensile strength at welding speed 35mm/min .

The properties of fracture and tensile of materials that friction stir welded depend on hardness and welding defects in area joints, of which in return are function of the welding parameters. If no defects in joints, the properties of tensile are only affected by the micro hardness distributions .increasing tensile strength of joints welded at rotation speeds from (450 to 900) RPM could be attributed to a clear increase hardness in the HAZ. The freed efects in the joints, the fracture get on retreating side more than advancing side. Higher temperature due in break in retreating side and therefore fracture happens in this side. This result sufficiently indicates that the tensile strength on the advancing side is higher than that in the other side. The advancing side shows slightly hardness veryhigh than the other side[14].For the purpose examine defects variables and welding operation on tensile properties of the joints, tool (TCT) produced better welds was used. Figure(10) show the effect of tool rotational speed and figure (11) effect of welding speed on tensile strength of the joints a maximum tensile strength of (370MPa) was obtained at rotation speed (560 RPM) by used tool (TCT). Increase the tensile strength by increase rotation speed and decrease the welding speed but continuous increase the rotation speed lead to decrease the UTS and elongation as shown in figure (12) because increase the temperature leads to dislocation and growth of the precipitates[9].

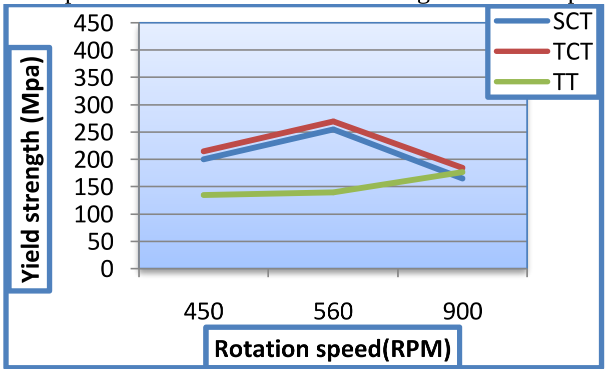


Figure 11: Effect of tool pin profile and rotation speed onthe yield strengthat constant welding speed 35mm/min.

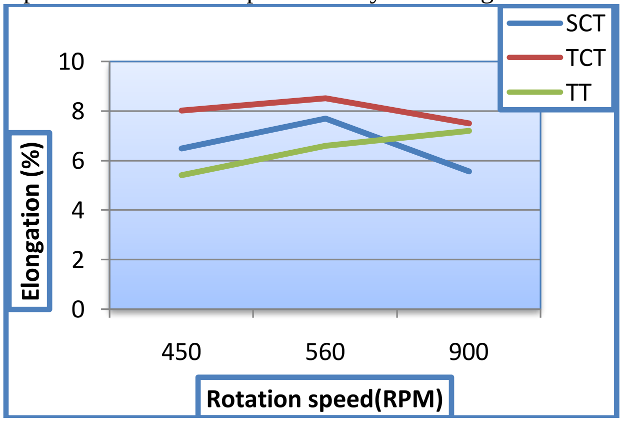


Figure 12: Effect of tool pin profile and rotation speed on the elongation at constant welding speed (35 mm/min).

3.5 Impact test

The two pieces of6061 Welding by FSW with different tools (Cylindrical threaded pin SCT, Tapered cylindrical threaded pin TCT, Triangular threaded pin TT) with change rotational speed.results the impact of weldinghigher than the impact energy of base metal because that the grains in the center welding area (nugget zone) to be fine and equiaxed and smaller than base metals, the reason for the occurrence of recrystallization process and temperature generated during friction between tools (pin) and metals[9] .

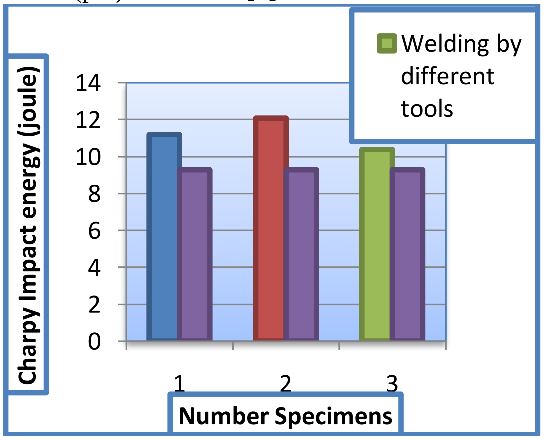


Figure 13: Effect between impact energy and shape of tools at rotation speed (450RPM) and welding speed (35mm/min)

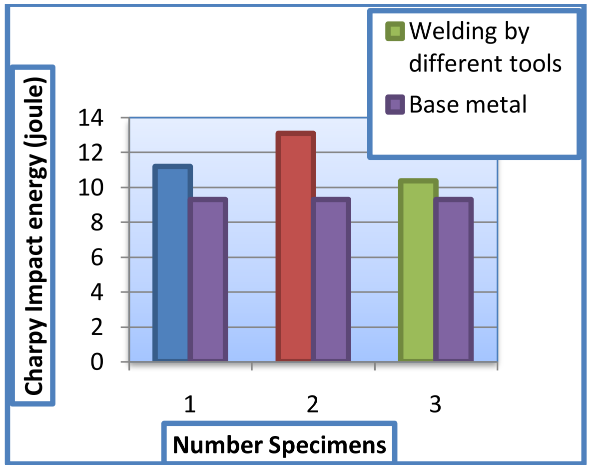


Figure14: Effect between impact energy and shape of tools at rotation speed (560RPM) and welding speed (35mm/min) .

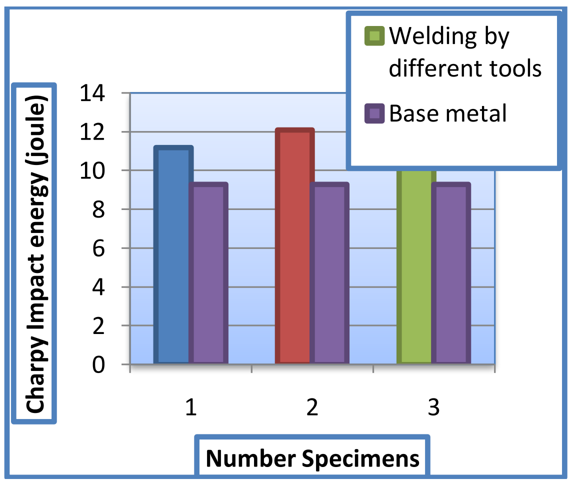


Figure15: Effect between impact energy and shape of tools at rotation speed (900RPM) and welding speed (35mm/min) .

That maximum impact energy in (TCT) tools at (450 RPM) rotation speed and (35 mm/min) welding speed equals to (12.1J) as compared to (SCT) equals to (11.2) and (TT)equals to (10.4J) indicates to improve the impact that heat input in this time help to increase strength and therefore improved the impact toughness and also effect of tool shape . and the effect tool geometry small to the impact energy the results approximate in the most speed and also shows increase the rotation speed into (900 RPM) the impact energy of the welding decrease general atsimilar welding speed and not improved tangible in the impact energy by increase the welding speed because effect of rotation speed is oppressor where the biggest part in the temperature friction results in rotation speed in the tool welding as seen in figure (13, 14 and 15)[10] .

4. Conclusions :

In this investigation an attempt has been made to study the effect tool form profile (Cylindrical threaded pin SCT, tapered threaded pin TCT and triangular threaded pin TT) on formation of friction stir welding zone welded 6061. From this investigation, the following important conclusions are derived:

1. The relationships between the form of the tool andvariables operation for FSW of 6061 aluminum alloy. Tool formis very specialist for deciding the weld quality.
2. Hardness is high value in NZ and TMEZ at TCT tools compared with SCT and TT and Hardness increased with increased rotation speed and decreased welding speed in all the tools because the SZ and TMEZ is fine and equaled grain size .

3. Maximum tensile strength by using tapered cylindrical threaded pin (TCT) equal to(370 MPa) at rotation speed (560RPM) .
4. Tensile,yield strength and elongation increased with increased rotation speedbut still lower frombase metal.
5. Most of the result, the impact strength increasesat all the too welding as compared to the base metals and equal to (9.3J).The impact strength in (TCT) tools equals (12.1J) at (450RPM) .

References

[1]P.Prakash, S. Kumar Jha and S.PrakashLal"A Study Of Process Parameters Of Friction Stir Welded AA 6061 Aluminum Alloy " International Journal of Innovative Research in Science, Engineering and Technology , Vol. 2, Issue 6, June (2013).

[2]M.KazemBesharati"Advances in Friction Stir Welding and Processing"Mechanical Engineering, University of Tehran (2014) .

[3]G.Shrikant Dalu1 and M. T. Shete2 "Effect Of Various Process Parameters On Friction Stir Welded Joint: A Review" IJRET:in Engineering and Technology ISSN: 2319-1163 | ISSN: 2321-7308.(2014) .

[4]H. K. Mohanty, D.Venkateswarlu, M. M. Mahapatra, Pradeep Kumar and N. R. Mandal "Modeling the Effects of Tool Probegeometri -es and Process Parameters on Friction Stirred Aluminium Welds" Journal of Mechanical Engineering and Automation , Vol.2, No. 4, P: 74-79 ,(2010) .

[5]P. Surendrababu, A. GopalaKrishna and Ch. SrinivasaRao "Material Flow Behaviour in Friction Stir Welding Process-A Critical Review on Process Parameters and Modeling Methodo- logies" International Journal of Emerging Technology and Advanced Engineering Website, Vol. 3, Issue 6, June (2013) .

[6]P.Carloneand Gaetano S. Palazzo "Influen-ce of Process Parameters on Microstru- cture and Mechanical Properties in AA2024-T3 Friction Stir Welding " MetallogryMicrostruct. , Vol.2,P: 213–222, (2013) .

[7]S.Sattari, H. Bisadi and M. Sajed "Mechani-cal Properties and Temperature Distributions of Thin Friction Stir Welded Sheets of AA5083" International Journal of Mechanics andApplica- tions, Vol. 2, No. 1,P: 1-6 , (2012) .

[8]Yan-hua Zhao, San-bao Lin, Lin Wu and Fu-xingQu "The influence of pin geometry on bonding and mechanical properties in friction stir weld 2014 Al alloy" Materials Letters, Vol. 59 , p: 2948 – 2952, (2005) .

[9]Radisavljevic, A.Zivkovic, N. Radovic and V. Grabulov4 "Influence of FSW parameters on formation quality and mechanical properties of Al 2024-T351 butt welded joints" Trans. Non. Met. Soc. ,Vol. 23, p: 3525−3539, (2013) .

[10]W. Jalal Ali and Q.Hazim Ismael "Effect of Friction Stir Welding Parameters on the Impact Energy of the Weldments of Poorly Weldable Aluminum Alloys by Fusion Welding" Mosul University Vol.21, No. 6, (2013) .

[11]D.trimble, H.Mitrogiannopoubs and S.mcfadden, " Frictuion stir welding of AA2024-T3 plate, the influence of different pin types", Mechanical Sci.,Vol.6, P:51-55 ,(2015) .

[12]D.Vinayak and S.Bhatwadekar " Friction stir welding of Dissimilar Aluminum Alloys AA1100 to AA6061-T6",INJRAME ,Vol. 3, ISSUE 1 , P: 2321-3051 ,(2015) .

[13]M.ILangovan, S.Ragendra and V.Balasu-bramannian,"Microstructure and Tensile properties of Friction stir welding dissimilar AA6061-AA5086 Aluminum Alloy joints" Trans.Non.Met.Soc.Vol.25,P:1080-1090, (2015)

[14]V. Rajesh and Subramanian " Analysis of Microstructure size and Temperature Distribution in Aluminum Alloy 6061 using Friction stir welding" , IJIRSET ,Vol. 4 ,Issue 2 ,P: 2319-8753, (2015) .