Mechanical Properties Of AA 6061-T6 Aluminum Alloy Friction Stir Welds

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Abstract

The different parameters on mechanical and microstructural properties of aluminium alloy 6061-T6 Friction stir-welded (FSW) joints were investigated in the present study. Different welded specimens were produced by employing variable rotating speeds and welding speeds. Tensile strength of the produced joints was tested at room temperature and the the effecincy was assessed, it was 75% of the base metal at rotational speed 1500 rpm and weld speed 50 mm/min. Hardness of various zones of FSW welds are presented and analyzed by means of brinell hardness number . Besides to thess tests the bending properties investigated and showed good results in some specimen and not in onother the mamximum stress was 240 N/mm^2 at rotational speed 1500 rpm and weld speed 50 mm/min , while the maximum stress at 1250 rpm and 75 mm/min 94 N/mm^2 , hardness results shwed lower values in heat affected and nugget zones than the base metal with improving of hardness at 1500 rpm, 75 mm/min .

Key words: friction Stir Welding , 6061 T6, mechanical properties.

الخواص الميكانيكية لسبيكة المنيوم 6061 T6 ملحومة بطريقة اللحام المزج الإحتكاكي

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الخلاصة

تضمن البحث دراسة الخواص الميكانيكية لعدة سرع خطية ودورانية لسبيكة المنيوم لحمت بطريقة لحام المزج الإحتكاكي.وقد صنعت عدة عينات لهذه السرع المختلفة (السرعة الخطية والدورانية)،تم إجراء إختبار الشد بدرجة حرارة الغرفة وقد كانت قيمة كفاءة اللحام 75% من المعدن الأساس وكذلك تم إجراء إختبار الصلادة بطريقة برينل . إضافة لهذه الإختبارات تم إجراء إختبار الحني أيضاً لدراسة متانة منطقة اللحام والتي أظهرت نتائج جيدة عند بعض السرع و لم تظهر عند بعضها الآخر فعند سرعة دورانية 1500 دورة\دقيقة وخطية 50 ملم\دقيقة كانت قيمة أعلى إجهاد 240 نت\ملم^2 بينما كان اعظم إجهاد عند 1250 دورة\دقيقة سرعة دورانية و75 ملم\دقيقة سرعة خطية كان قد بلغ 94 نت\ملم^2 ، نتائج الصلادة اظهرت نقصان بقيمة الصلادة في مركز اللحام وفي المنطقة المتأثرة بالحرارة عنه في المعدن الأساس بينما كان هنالك تحسن في نتائج الصلادة عند السرعة 1500 دورة\دقيقة و75 ملم\دقيقة.

الكلمات الرئيسية: لحام المزج الاحتكاكي، 6061 T6، الخواص الميكانيكية

1.INTRODUCTION

Friction stir welding (FSW) has proven to be an effective joining technique for a variety of different materials, including metals and polymers. Metals with low melting temperatures such as aluminum and copper were among the first to be joined by this technique using a steel tool **,Heidarzadeh A. ,et al., 2012**. Friction-stir welding (FSW) is a solid-state joining process utilizing a rotating tool consisting of a pin and tool shoulder that applies severe plastic deformation and frictional heating into the joining materials. The benefits and uniqueness of the FSW have been well established for many light-weight metals and alloys that have difficulties in joining by the conventional fusion welding methods. The frictional heat and severe plastic deformation involved in the FSW **,Wanchuck, Woo. , leventa Balogh. ,Tamas Ungar. ,Hahu Choo. and ,Zhili Feng, 2008.** Aluminum alloys are important for the fabrication of components and structures which require high strength, low weight or electric current carrying capabilities to meet their service requirements. Among all aluminum alloys, AA 6061 alloy plays major role in the aerospace industry in which magnesium and silicon are the principal alloying elements. It is widely used in the aerospace applications because it has good formability, weldability, machinability, corrosion resistance and good strength compared to other aluminum alloys. When using the conventional arc welding techniques, long butt or lap joints between AA 6061 and other aluminum alloys are particularly difficult to make without distortion because of high thermal conductivity and special welding procedures and high levels of welder skill are generally required. AA 6061 Aluminum alloy cannot be TIG welded without filler wire because it leads to solidification cracking due to its chemistry The mechanical properties of the alloys are affected not only by their chemical composition but also by their condition, e.g. annealed, cold worked, precipitation hardened. The work pieces are secured against the vertical, longitudinal and lateral forces, which will try to lift them and push them apart during the process **,Indira Rani M., 2011.** This highly plasticized material provides for some hydrostatic effect as the rotating tool moves along the joint, which helps the plasticized material to flow around the tool. The plasticized weld material then coalesces behind the tool as the tool moves away show **Fig.1**.

The basic concept behind FSW is simple: The non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of the two parts to be joined and traversed along the line of joint ,**Mohamadreza, Nourani, and et al, 2011.** The FSW process mechanism and the tool geometry are shown in **Fig. 2, ,J. Adamowski ,and et al, 2007.**

The tool is plunged into the part at a specified spindle speed and plunge rate until the shoulder makes contact with the material to be joined. Following a brief dwell period, the rotating tool advances along the weld path at a specified traverse rate and spindle rotation speed. The combination of heat input and tool geometry cause the material along the boundaries of the weld region to deform and mix together to form a solid joint **,Thomas Oakes, and ,Robert G. Landers , 2009.** ,Aluminum alloys of 2xxx, 6xxx and 7xxx series have been considered for substantial use in these industries. This ensues from their desirable strength to weight ratio, excellent formability, appropriate weldability and acceptable corrosion resistance. Depending on the specific application, corrosion behavior is a significant factor of a welded joint **,V. ,Fahimpour,and et al,, 2012.** As a result, the FSW shows a unique grain structure influenced by the severe thermo-mechanical deformation, recovery, and/or recrystallization at elevated temperatures during welding.

2. EXPERIMENTAL PROCEDURE

2.1 Material

Wrought 6061-T6 aluminum sheets having 4 mm thickness defined by code B0209-04 ASTM standard were welded together by FSW method .The plates were cut and machined into rectangular welding specimens of 200 mm × 100 mm cross-section. A schematic diagram of FSW plate dimensions is shown in **Fig.3**

Chemical composition and the mechanical properties of base metals are presented in **Tables 1. and 2.** respectively. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the joints. Trial experiments were carried out to find the working limits of welding parameters. The welding parameters used to fabricate the joints are presented in Table 3.

2.2 Tool
A CNC perpendicular milling machine used to weld the plates, and cylindrical tool steel X38 with (16mm) shoulder diameter and (5mm) pin diameter with plunging depth equal to 3.9 mm as shown in **Fig. 4**.
Welding system fixed at the machine with clamps and fixtures made of carbon steel as in **Fig.5**

2.3 Welding Parameters
The friction stir welding parameters was listed in **Table 3.** All welds were produced using the same tool,but varying rotational and welding speed. Two welded samples were produced for each weld parameter, in order to have samples for mechanical testing.

3. MECHANICAL TESTS
To the marked welding parameters Tensile , bending and hardness tests done to the welding results as follow:

3.1 Tensile test
It done at room temperature by using testometric apparatus and specimen dimensions ASTM E8 as in **fig. (6- A** and **B**)

3.2 Hardness Test
A brinell hardness number method used to observe and determine the hardness value under 187.5 kgf load for six welding test specimen at seven points (five in welding regio and two at the base metal) , abrinell hardness number test is the using test to investigate the hardness of the welded joints at 60 sec time loading.

3.3 Bending Test
Root and face bend tests were used as an important tool to understand about the ductility and toughness of friction stir welds bending, bending specime are show in F**ig. 7** the dimensions of bending specimen are 10 mm width and 100 mm length.

4. RESULTS AND DISCUSSIONS
Many types of defects can be observed from the overall cross-sectioned samples, like flash, voids and tunnel defects, flash defects could be seen in **Fig. 9**. Most of the as-welded specimens are free of tunnel defects as shown by eye that there is no noted deffected line along the welding line. This indicates that tunnel defects can be fully vanished in a relative broad parameter range. With the increasing of the shoulder diameter, So, it can be considered that, using a welding tool with a relative bigger shoulder is helpful to vanishing tunnel defects in FSW **,Lei Cui, and et al.,2012.** The parametric boundaries investigated in the present study have been defined based on previous experi ence in welding of the non- reinforced alloy 6061 **,G. Raghu Babu, and et al., 2008.**

4.1 Tensile Results
In all cases the samples failed in NZ . The results are presented in **Fig. 10**. This can be attributed to the decreased heat input and relative limited softening of the HAZ **,Vladvoj Očenášeka ,and et al.,2005.** and because of the loss of strength (undermatching). The stirring of the tool has a substantial influence on the reinforcement particle distribution and shape. It break s off the sharp edges of the bigger particles , rounding them up at the same time. This action results in smaller, round particles in the nugget **, Raghu ,and G. et al., 2008.** from fig.8 the

results were defferent according the parameters and the value of the ultimate tensile stress was 75% of the base metal at rotational speed 1500 rpm and weld speed 50 mm/min. yield and ultimate tensile values of welded samples inserted in **Table 4** .

4.2 Hardness Results

Fig. 11, represents the hardness diagram of the joint FSW. The hardness of both the heat affected zone (HAZ) and the nugget zone (NZ) is lower than that of base metal (BM),but at speed 1500 rpm and 75 mm/min there is improving in the weld nugget zone and heat affected zone in spit of the still of high properties in the base metal ,also a difference between HAZ and NZ properties , the difference between HAZ (heat affected zone) and NZ (nugget zone) is attributable to the grain refinement in NZ (nugget zone) , caused by intensive stirring. The softest points of the joints correspond to the failure locations in tensile tests, It should be noted that a local material softening occurs in the weld because of the thermal action of the welding process; in particular a localized softening in the NZ (nugget zone) is observed. Note that results will show increasing in hardness from center to the parent metal and the lowest value is observed in the nugget zone **, J. Adamowski a and M. Szkodo, 2007. .**The resultsof hardness due to the welding process and to the tool pin action, a reduction of the density of such particles is observed with the utilized instrument **,A. Barcellona, G. Buffa, L. Fratini and ,D. Palmeri , 2006 .**

4.3 Bending results:

Some FS welded aluminium alloy 6061-T6 samples did not fail in bend test at 1500 rpm and 50 mm/min speed and 2000 rpm and 50 mm/min. The parts have been tested utilizing a customized bending test with the aim of highligh ting their behaviour it showed a very good bending results they stay succesful in high load without failing it ensure the high quilty of welding at some parameters, bending results shown in **Fig.12**, and **Fig. 13**.

5. CONCLUSIONS

1. FSW was successfully at medium rotation and weld speed .
2. Reducing the plunging depth and the weld speed that will decrease the flash defects.
3. By softining the tool surface and the shoulder and pin surfaces voids could be reduced or not appears in weld results.
4. Hardness drop was observed in the weld region. The softening was mostly evident in the heat affected zone on the advancing side of the welds. This zone corresponds to the failure location in tensile tests **,G. Raghu Babu, and et al., 2008.**
5. The material flow around the off-center features is more complicated than the conventional centered pin. It appears that higher temperature allow better material flow and joint strength with the new tool **,Mishra, Freeney, Webband and et al., 2007 .**
6. Some FS welded aluminium alloy 6061-T6 samples did not fail in bend test at 1500 rpm and 50 mm/min speed .
7. The effecincy of welded metal is 75 % of the base metal at 1500 rpm and 50 mm/min.

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Table 1. Chemical Compositin of 6061 alloy **,V. Fahimpour,and et al., 2012.**

Alloy	Cu	Mg	Mn	Fe	Si	Cr	Ti	Pb
6061	0.19	1.07	0.12	0.64	0.65	0.21	0.02	0.05

Table 2. Mechanical properties of base metal 6061 T6 alloy **,J. Adamowski ,and et al., 2007.**

σyield Mpa	σultimate Mpa	E %	VHN
235	283	22	100

Table 3. Welding parameters

Samples	Rotaiting speed rpm	Weld speed mm/min	Plunging depth mm	Reheating time Sec
F1	1250	50	3.9	60
F2	1250	75	3.9	60
F3	1500	50	3.9	60
F4	1500	75	3.9	60
F5	2000	50	3.9	60
F6	2000	75	3.9	60

Table 4. Yield and ultimate tensile results of welding samples.

Samples Of welding	Ultimate tensile stress N/mm^2	Yield stress N/mm^2
F1	198	59
F2	115	34
F3	215	64
F4	125	37
F5	150	45
F6	201	60

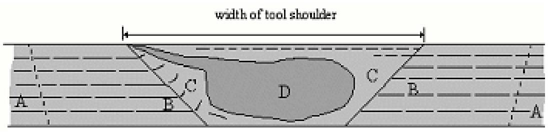


Figure 1. FSW regions **,Indira Rani M., 2011.**
A: unaffected material.
B: heat affected zone HAZ.
C: thermo-mechanical affected zone TMAZ.
D: nugget zone NZ.

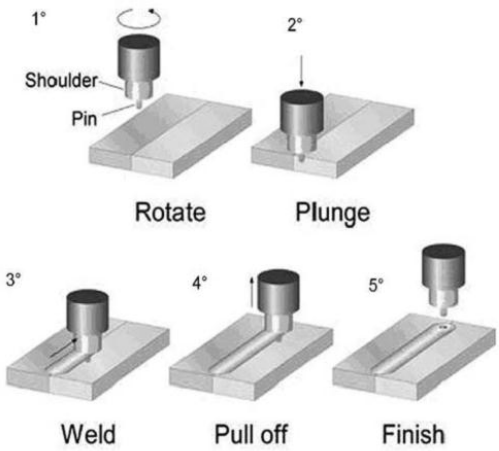


Figure 2. Schematic representation of FSW process **,J. Adamowski ,and et al., 2007.**

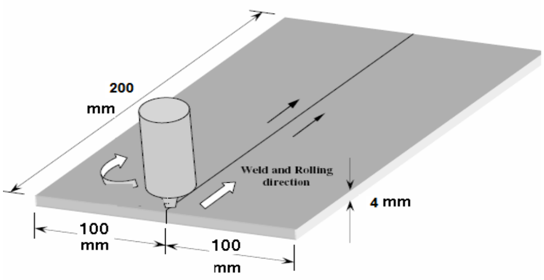


Figure 3. FSW plates dimensions.

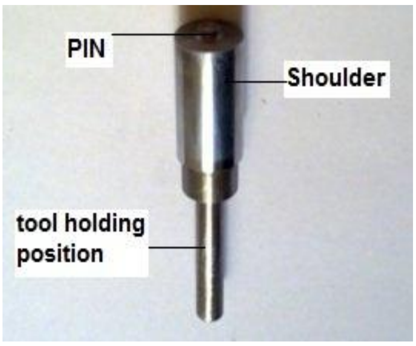


Figure 4 . Welding tool dimensions.

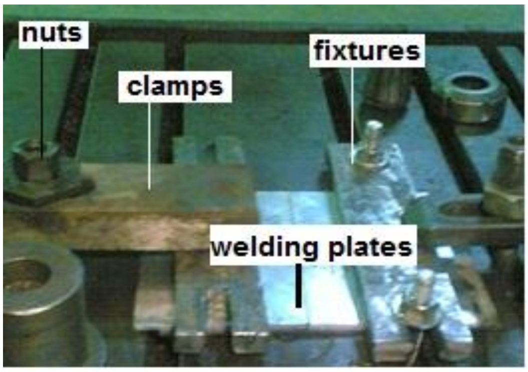
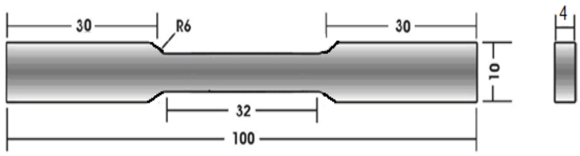
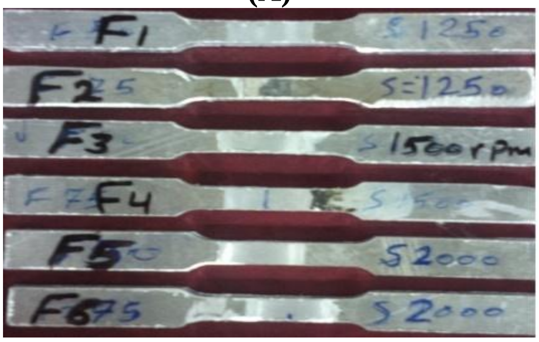


Figure 5. Welding clamping and fixtures system.



(A)



(B)

Figure 6. Tensile test specimen dimensions before test**.**

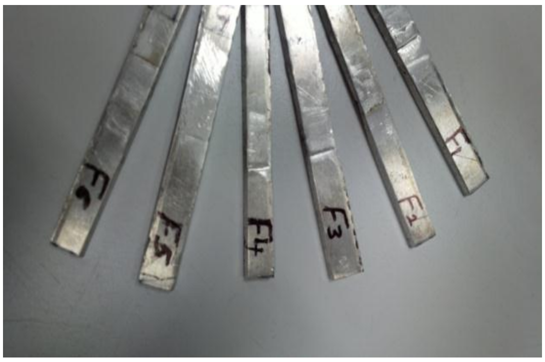


Figure 7. Bending test specimen.

Figure 8. Tensile specimen after test.

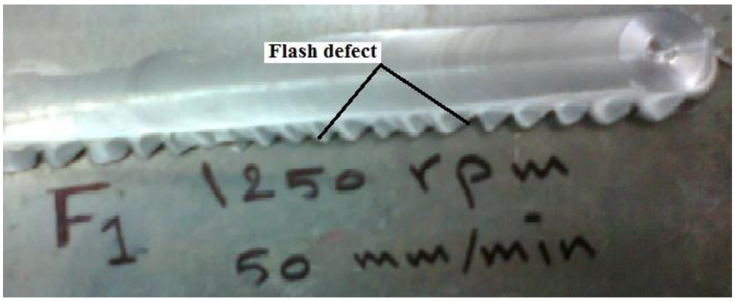


Figure 9. Flash defects at 1250 rpm, 50 mm/min.

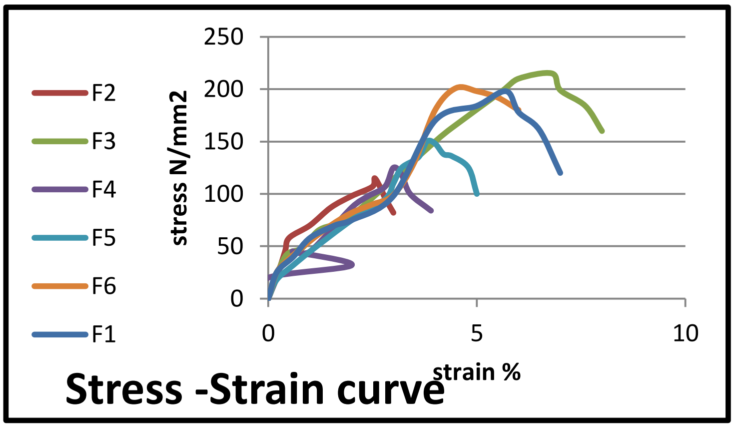


Figure 10. Tensile test results.

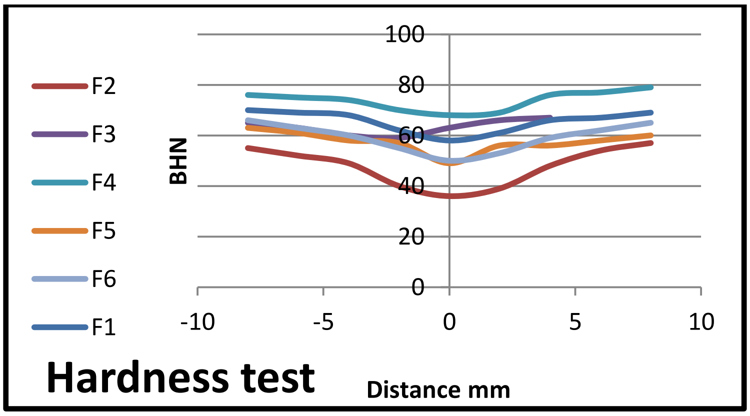


Figure 11. Hardness test.

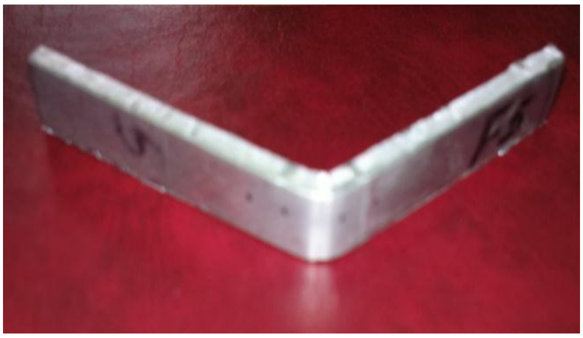


Figure 12. Bending sample result at 1500 rpm , 50 mm/min.

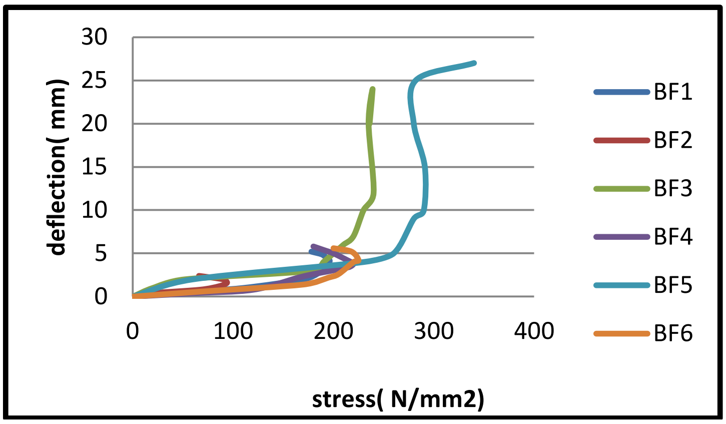


Figure 13. Bending results curve