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Effect of tool parameter on mechanical properties of friction stirred welded Al joints

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Abstract*: The objective of the work is to investigate the effect of tool parameters on the mechanical properties of friction stirred welded Al joints. To optimize the tool parameters such as tool type, spindle speed, welding rate and tool angle based on microstructure, tensile and hardness properties of friction stir welded joints of Al specimens using optical microscopy, universal testing machine and Brinell hardness machine respectively. The result shows that the tensile strength varies from 125 to 260 MPa for different process conditions. The highest strength found in welding having plane tool, spindle speed of 1000rpm, 40mm/min welding speed and tool tilt angle of 4˚. Hardness in the welding region found to be less than parental metal and harness profile normally in W shape. Microstructure at the welded region gives the variation in grain size at different thermal zones are nugget zone, thermo mechanical heat affected zone and heat affected zone.

***Index Terms*: FSW, Al Joints, FSW Tool.**

I. INTRODUCTION

The Al alloys are the most popular among aerospace materials for structural applications due to their light weight structural alloys along with high specific strength and they can be adjusted by a various ageing process. However, the limitation of Al alloys involves their poor weld ability and frequent formation of weld defects [1]. To overcome the problem many researchers developed friction stir welding (FSW). But Tool material and tool configurations, are major important parameters to get a better good welding [2]. Tool material depends upon the welding material and its melting point because the tool will have to sustain the temperature generated by friction without deformation. Welding speed and spindle speed taken as 0.17cm/s and 275 rpm respectively. Peak temperature during welding due to friction was 1100˚C, at the end of the tool shoulder temperature varied from 750 to 830˚C. Different type of weld configuration can be welded using FSW [3]. Normally Square butt joint, Edge butt joint, Lap joint, T-joint, Fillet joint and multiple lap joint [4-5].

Not only similar metals dissimilar metals also welded using this method. Landry Giraud et al [4]. Joined two dissimilar materials AA7020–T651 and AA6060–T6 using 5mm sheets rotational speed from 1000 to 2000 rpm, advance speed from 300 to 1100 mm/min. Result with good mechanical properties. There are different friction stir welding tool evolved from simple plane tool to complex Tri flute design. Lakshman Rao et al [5] study says different tool geometry effect on welding and designing of the tool. Using different tool welded concluded that plane and tapered design assigned for commonly welded materials.

Kush P. Mehta et al [6] investigated formation of defects in dissimilar metals using different tool pin configuration. AA 6061 – T651 and Electrolytic tough pitch Cu are two metals of 6.3 mm thick and tool material Tool steel M2 grade. Results conclude that cylindrical tool pin gives defect free macro joint and triangular pin profile gives irregular, copper material detached from the base materials. Shude ji et al [7] Researched on Numerical investigation to enhance the material flow during FSW process by varying geometry of the welding tool. Tool with tapered flute and half screw are suggested.SYS FLUENT software helped to solve numerical problem. Numerical results conclude that tool with tapered flute pin shows have maximum material flow and with respect to conventional tools, these half screw and tapered flute are better in performance.

Ashok Kumar et al [8] Experiments were conducted to optimize FSW variable parameters to increase tensile strength of AA6061-T6 / AlNp composite. Process parameters include rotational speed, welding speed, axial force and % of AlNp. Resulted optimized values are axial force of 5.08kN, rotational speed of 1217 rpm and welding speed of 51.81mm/min without any defects with optimized heat generation and good consolidation. Development of friction stir welding is not limited to metals but some of thermoplastic [9], polypropylene [10], polymer –metal composite [11] materials can also be welded. Some of the research conducted to optimize of these non metallic welding process concluding that rotational speed and plunge force are two important parameters to be considered. done on mechanical characteristic of FSW of aluminum alloys are done and less work done on Friction stir welding of aluminum 6061 material and optimization of variable parameters. The objective of the work was to study the microstructure, grain size, ultimate tensile strength and hardness of weld joints.

II. EXPERIMENTAL STUDY

Aluminum alloy Al6061 (chemical compositions are given in Table.1) plate of the dimensions 300 mm length, 100 mm width and 3mm thickness are used for FSW process.

Table 1. Composition of Al6061 for Friction Stir Welding

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
wt%	0.4-0.8	0.7	0.1-0.4	0.15	0.8-1.2	0.04-0.35	0.25	0.15	balance

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H13 chromium hot work steel is used as a friction stir welding process and the chemical composition are given in Table 2.

Table 2. Composition of H13 tool steel for Friction Stir Welding

C	Mn	Si	Cr	Mo	V
0.4%	0.4%	1%	5.25%	1.35%	1%

For friction stir welding process was carried out in CNC milling machine. Three different tool configurations were used namely plane, threaded and tapered respectively. IR temperature gun are used to measure the temperature at different points on the aluminum plate at different time interval. Tachometer is used to measure the RPM of the spindle.

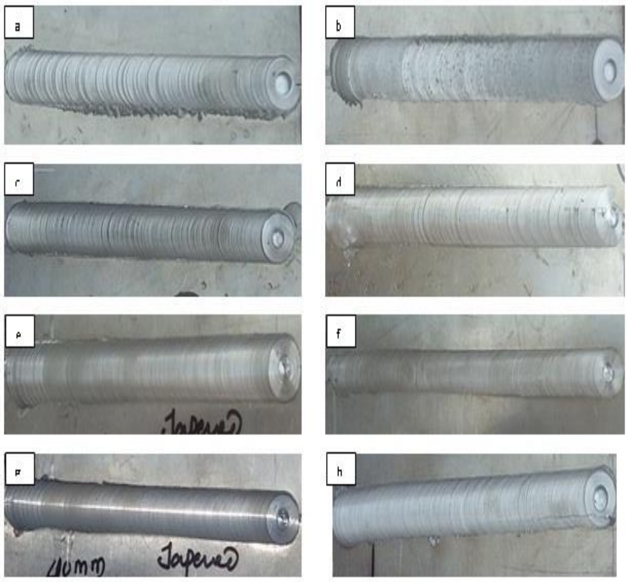

Figure 1. Aluminum Friction stir weld joint for plane tool with a) 1000 rpm b) 1600 rpm c) 2000 rpm, tapered tool with d) 1000rpm, e) 1600 rpm, f) 2000 rpm, Tapered tool g) 1000 rpm h) 1600 rpm and i) 2000 rpm.

FSW tool is fixed to the spindle with the help of collet, tool has 100mm length, shank diameter 18mm, pin length 3mm and pin diameter is 6 mm. Tool is made to rotate in different speed and machine head is tilted to give tilt angle.
The pin is forced into the plate where two plate need to join and shoulder should be in contact with plate surface. After plunging the tool is made to rotate such that it should generate heat due to frictional force between tool and work piece. Heat generation due to friction mainly because of rotational speed & plunge force.
The welded part is shown in Fig.1 each welded part is carried out by considering different variable parameter such as spindle speed, transverse speed, and tool tilt angle and tool type

Microstructure of friction stir welding helps to understand the variation of grain size at different welding speed. Various micro effects can be examined through microstructure analysis. Optical microscope, scanning electron microscope (SEM), and oriental imaging microscope (OEM) are some of the techniques used to investigate microstructure of FSW joints.

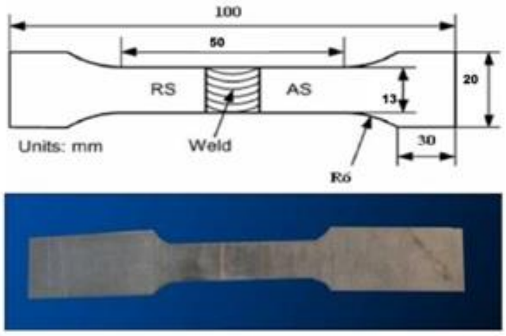

Figure 2. Test Dimensions of ASTM E8

Tensile test is carried to find out the tensile strength at the welded region. Test specimen is cut such a way that welded region is at the center shown Fig.2 and test is carried out according to ASTM E8 [12] standard in 10ton universal testing machine. According to ASTM E8 the gauge length of the tensile specimen is 50mm, width is 13mm and the thickness of the welded specimen is about 3mm. Total cross sectional area of the testing specimen is 39mm².

The test is carried out in 10 Ton universal testing machine. Specimen is held vertically and clamped such a way that specimen should not slip during testing.
The plane tool of diameter 6mm and height 2.75mm, tapered tool having taper angle of 30˚ and threaded tool having pitch of 1mm have taken in tool type configuration. When we come to spindle speed 1000rpm, 1600rpm, 2200rpm and for welding speed or tool travel speed have taken to be 40mm/min, 60mm/min, 80mm/min. Tool tilt angle is the angle made by the tool with the welding plate, it is measured from the vertical line or from the line normal to the welding plate these angle are very small nearly less than 10˚, here we have taken 2˚, 4˚, 6˚ respectively.
Combining these tool pin type, speed, feed and tool tilt angle we form nine combinations including all variable parameters. Nine dumbbell shaped tensile test specimens are prepared according ASTM E8 standard and tested. Tested results are tabulated and graph of load vs strain, stress vs strain are shown, yield and ultimate failure load and stresses are tabulated.
Hardness of friction stir welding samples at the welding point is measured using Vickers hardness testing machine. Testing load was 200gf applied with well time of 5 sec. nine samples were tested, these samples of friction stir welded joint at different tool type, speed and welding rate. Harnesses were taken from transverse section welding.

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III. RESULTS AND DISCUSSION

3.1 Microstructure

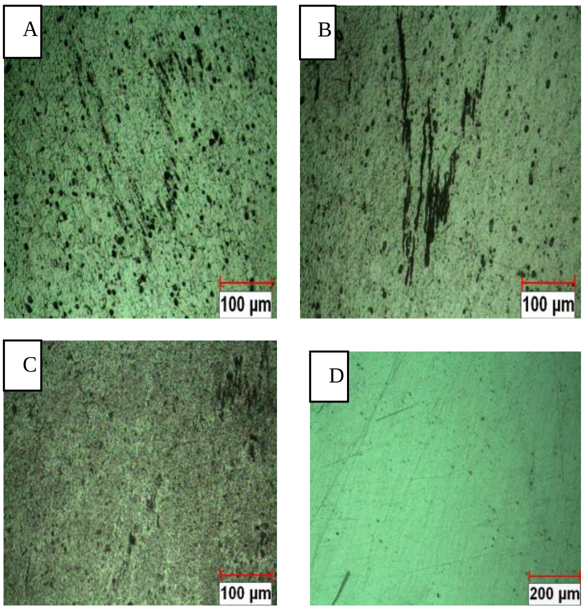

Figure 3. Microstruture of FSW Al6061 at different zone after etching with Keller's reagent (A)HAZ (B)TMHAZ (C)NZ (D)BM

Friction stir welded samples were cut and examine it through optical microscope, we can easily differentiate different zone like heat affected zone (HAZ), thermo-mechanical affected zone (TMHAZ) and nugget zone (NZ). Fig.3 clearly A, B, C, D indicates heat affected zone (HAZ), thermo-mechanical affected zone (TMHAZ), nugget zone (NZ) and base metal respectively. Maximum temperature generate at the nugget zone where more grain refinement take place so that grain size at nugget zone are smaller than the remaining zones. Grain size at HAZ > TMHAZ > NZ and variation in grain size at different samples as shown in Table 3 such that size of the grains are small at lower speed and increases as speed increases.

Table 3. Grain size at variable combination samples

Sample no.	Tool pin type	Speed RPM	Traverse speed mm/min	Tilt angle θ˚	grain size in µm
1	plane	1000	40	2	7.5
2	plane	1600	60	4	9.8
3	plane	2200	80	6	11.4
4	Tapered	1000	60	2	6.4
5	Tapered	1600	80	4	10.1
6	Tapered	2200	40	6	12.2
7	Threaded	1000	80	2	6.9
8	Threaded	1600	40	4	10.3
9	Threaded	2200	60	6	9.6

3.2 Tensile strength

From the tensile test results it was found each one has different yield and failure stress. These variations can be differentiated by the variable parameters: tool pin type, speed, and welding speed. Here we discussed effect of tool pin and speed on welding strength.

For friction stir welding, tool pin to generate contact and friction and spindle speed to stir the tool are essential parameters. These will give great influence on mechanical properties as well as on microstructure.

Fig.4 shows variation in ultimate failure stress with respect to spindle speed for different tool pin type. Here we can observe that failure stress decreases when speed of the tool increases for taper and threaded tool, but for taper failure point increases from 1000 rpm to 1600 rpm and then decreases. In this we can say that if speed increases tensile fracture strength decreases so that speed of spindle should be minimum, to get a good welding strength. Considering the individual tool type for plane tool at 1000 rpm found to be highest strength value 260.39N/mm², for tapered tool value 226.50N/mm², at 1600 rpm and for threaded tool value 193.99N/mm², at1600 rpm

Welding speed is one of the important parameter to consider in friction stir welding. Here welding speed of 40 mm/min, 60 mm/min and 80 mm/min are considered to examine with respect to plane, tapered and threaded tools.

Ultimate failure stress varies from 130 N/mm² to 260 N/mm². Fig.5 shows variation of ultimate stress in Y axis to welding speed in X axis for three welding tools. Result shows that for tapered and threaded tools ultimate stress increases as welding speed increases and for plane tool decreases as welding speed increases. For a welding speed of 40 mm/min, plane, tapered and threaded tool yield ultimate stress of 260.397 N/mm², 199.879 N/mm² and 186.23 N/mm² respectively, for 60 mm/min 230.427 N/mm², 191.413 N/mm², 125.732 N/mm², and for 80mm/min 64.62 N/mm², 226.503 N/mm², 193.904 N/mm² respectively. We found 260.397 N/mm² was the higher for the combination of plane tool with welding speed of 40 mm/min like in tapered 80mm/min and in threaded 80 mm/min, found to be good combination.

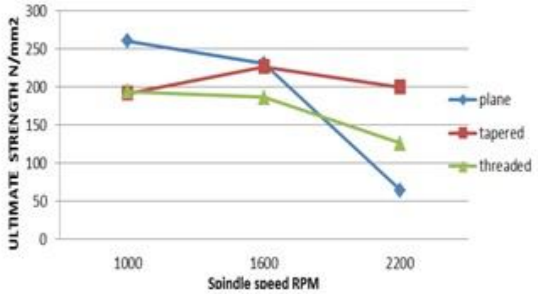

Figure 4. Ultimate tensile strength of FSW joints at different tools and speed

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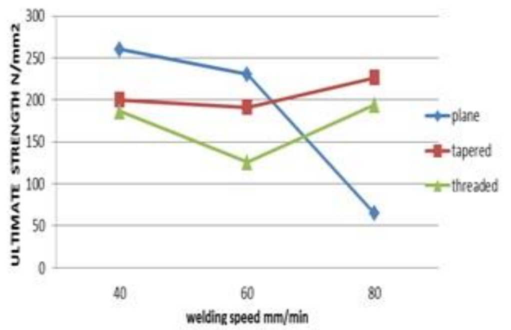


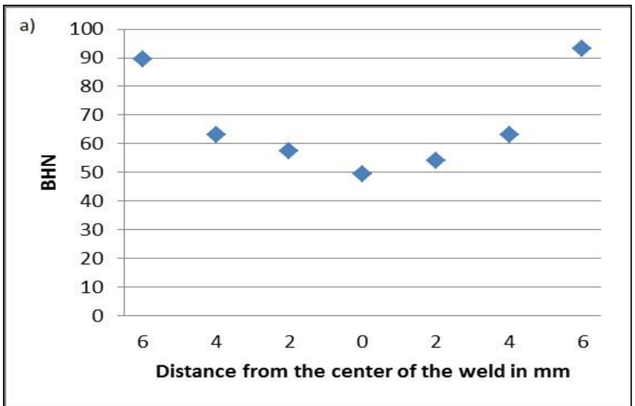
Figure 5. Ultimate tensile strength of FSW joints at different tools and welding speed

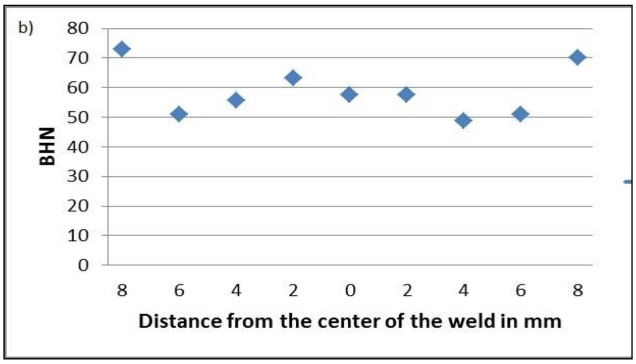
3.3 Hardness test result

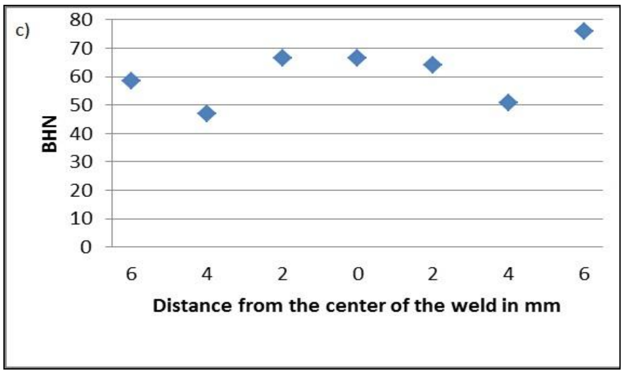
In friction stir welding generation of heat and force at the weld region, grain size will reduce and it increases the hardness at weld region. Hardness values are investigated shown in Fig.6.

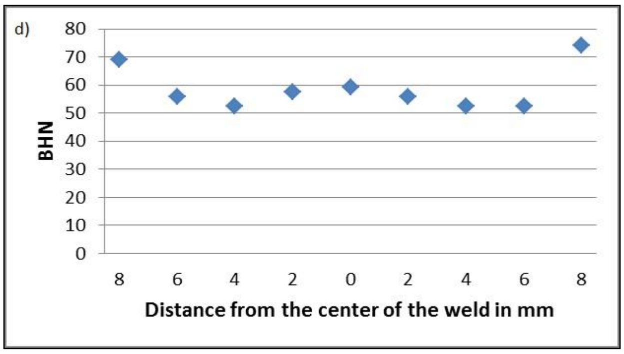
Aluminum alloys thermal conductivity is high due to this hardness varies at different region where metal deformation takes place. From the result we conclude that within deformation region nugget zone having hardness value 55 to 60 BHN. Microstructure at nugget has fine grains compare to TMHAZ and HAZ, this recrystallized grain structure makes nugget to have good hardness. Immediate to the nugget microstructure found to be more deformed and elongated due to this hardness at this point decreases slightly compare to nugget so hardness reaches minimum at TMHAZ or at the boundary between TMHAZ and HAZ. Outside HAZ hardness increases as metal region reaches parent metal. Parent metal has unaffected by deformation and heat from friction stir welding.

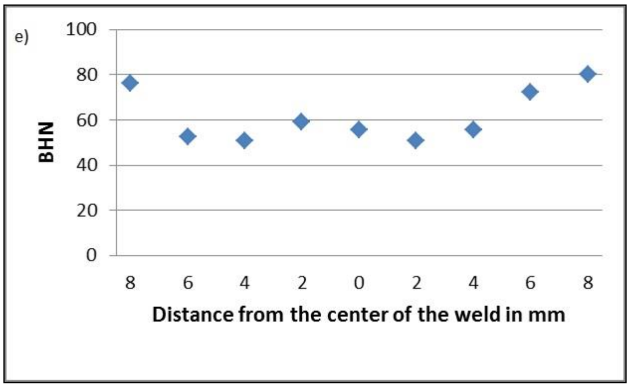
Two types of hardness profile we normally found i.e., W type and U type in which out of six specimens 5 W type and one exhibit U type profile. Hardness at nugget ranges 50 to 60BHN, thermo mechanical affected and heat affected zone have found 45 to 50BHN and parent material hardness is 85 to 95 BHN. From this we conclude that hardness at nugget always0greater than the other two zones and it is mainly depend on material recrystalization.











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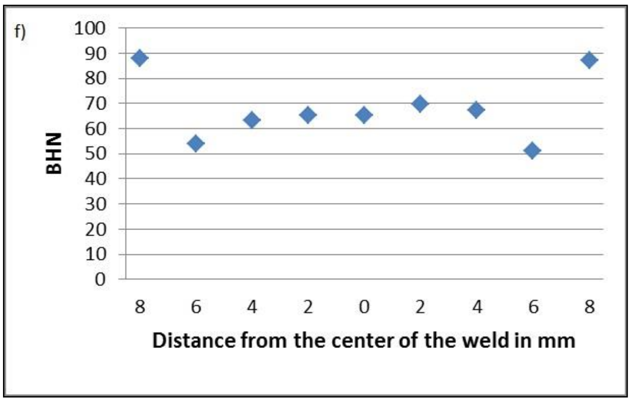

Figure 6. Hardness profile for a) plane tool, 1000 rpm, b) Tapper tool, 1000 rpm, c) threaded tool, 100 rpm, d) plane tool, 1600 rpm, e) Tapper tool, 1600 rpm, and f) threaded tool, 160 rpm.

IV. CONCLUSION

From the experimental investigation of Friction stir welding on mechanical properties, microstructure variation, and effect of variable parameters on welding strength concludes the following

- From the mechanical strength of the friction stir welding conclude that the strength of the weld varies with different tools, with speed and welding rate and also tool tilt angle.
- The highest welding strength of 260 MPa get by using plane tool, with 1600 rpm of speed and 60mm/min of welding rate.
- Hardness at the welded part is slightly below the parent material and Two types of hardness profile we normally found i.e., W type and U type in which out of six specimens 5 W type and one exhibit U type profile.
- Hardness at nugget ranges 50 to 60BHN, thermo mechanical affected and heat affected zone have found 45 to 50BHN and parent material hardness is 85 to 95 BHN. From this we conclude that hardness at nugget always greater than the other two zones and it is mainly depend on material recrystalization.
- Maximum temperature generate at the nugget zone where more grain refinement take place so that grain size at nugget zone are smaller than the remaining zones. Grain size at HAZ > TMAZ > NZ.

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