An Investigation on The Effect Of Welding Parameters In Friction Stir Welding Of Aluminium Alloys (AA 6061-T6)

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Abstract- Friction Stir Welding (FSW) is a recent addition to the solid state joining processes that has paved way for joining materials that were considered difficult to be welded by conventional welding techniques. In this process, a cylindrical non-consumable tool, with a profiled probe (pin) rotating about its own axis is slowly plunged into the abrutting edges of work pieces rigidly clamped to a backing plate. When the shoulder of the tool touches work piece surface, the tool is translated (with an axial force) along the length of the joint forming the joint in the solid state. Many specific properties of aluminium alloys including light weight and good structural strength enable them to be applied for structural parts. The demand of aircraft and automotive industries for light weight materials is met by aluminium alloys. The aluminium alloys AA6XXX and AA5XXX are extensively used in the fabrication of aircraft structures and other structural applications. The Conventional fusion welding of aluminium alloys leads to the melting and resolidification of the fusion zone which results in the formation of brittle interdendritic structure and eutectic phases. The formation of brittle structure in the weld zone leads to the drastic decrease in the mechanical properties like lower hardness, strength and ductility. Submerged friction stir welding consumes less energy. It provides improved mechanical properties.In experimental part, the effect of different welding parameters rotational speed, welding speed, axial force, welding medium on thermal histories, tensile properties and micro structural properties are studied.

IndexTerms - Friction Stir Welding, Rotational Speed, Welding Speed, Welding Medium, Hardness, Tensile Strength, Percentage Elongation, Microstructure

I. INTRODUCTION

Friction stir welding was invented and patented by a research team led by Wayne M. Thomas [Thomas et al., 1991] [Thomas et al., 1995] of the Welding Institute in England. FSW is defined by Thread gill of TWI as "a method for joining two or more work pieces where a tool, moving in a cyclic manner relative to the work pieces, enters the joint region, locally plasticizes it and moves along the interface thus causing a solid state joint between the work pieces" [Thread gill, 2007]. A schematic of the friction stir welding process is shown below in figure 1. It can be observed that that, due to the rotation of the tool, friction stirs welding is an asymmetric process with respect to the joint line.

Friction stir welding is performed by a rotating non consumable tool which is plunged into the material to be welded. The tool is traversed along the joint line to create a solid phase weld. The material along the tool becomes softened and highly plasticized from the frictional heat generated during the process and is carried around the tool so that there is complete mixing of material from the two plates. The pin of the rotating tool hence provides the "stir" action in the material of the work piece. This result in a Heat Affected Zone (HAZ) with a better grain refinement required for a good weld joining.

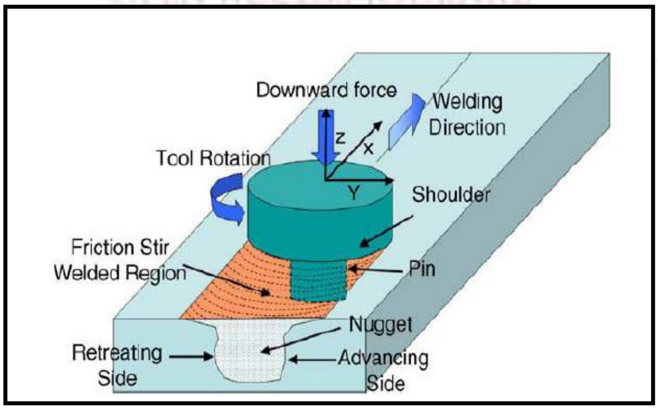


Fig 1: Friction Stir Welding Process

A cylindrical, shouldered tool with different profiled probe (nib or pin) is rotated and slowly plunged into the joint line between two pieces of sheet or plate material, until the shoulder of the tool forcibly contacts the upper surface of the material and the pin is a short distance from the back plate. The pieces are rigidly clamped onto a backing plate in a manner that prevents the abutting joint faces from being forced apart. The fixturing prevents the plates from spreading apart or lifting during welding. Frictional heat is generated between the tool shoulder and the work piece. This heat causes the latter to reach a visco-plastic state that allows traversing of the tool along the weld line. The plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool probe and is forged by the intimate contact of the tool shoulder and the pin profile. It leaves a solid phase bond between the two pieces. Fig. 2 shows the step by step process description of Friction Stir Welding.

Step 1: Tool rotates at constant rpm about its axis as shown in step (a) of figure 1.

Step 2: Tool pin plunges into the abutting edges of the material to be joined due to the frictional heat between the tool pin and material. Tool shoulder contacts the material and plasticizes due to frictional heat between shoulder and material as shown in step (b) of figure 2.

Step 3: Welding is made on the material and tool withdrawn from the plate as shown in step (c) of figure 2.

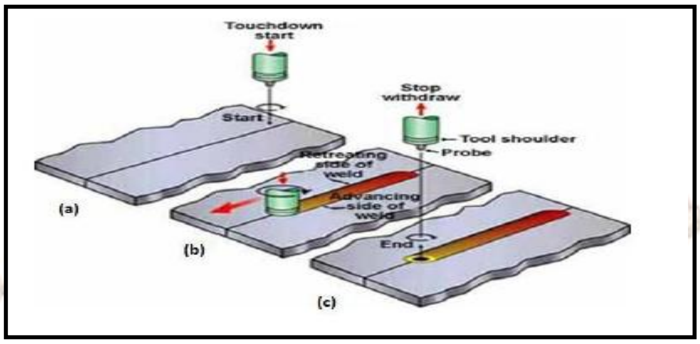


Fig.2: Process Overview of FSW (TWI)

Micro-Structural Features Of Friction Stir Welds

The first attempt at classifying microstructures was made by P L Thread gill (Bulletin, March 1997). This work was based solely on information available from aluminium alloys. A more comprehensive scheme has been developed by TWI, and has been discussed with a number of appropriate people in industry and academia. This has also been accepted by the Friction Stir Welding Licensees Association. The system divides the weld zone into distinct regions as follows. They are: (A) Unaffected parent material (B) Heat affected zone (HAZ) (C) Thermo mechanically affected zone (TMAZ) (D) Weld nugget (Part of thermo mechanically affected zone). The formation of above regions is affected by the material flow behavior under the action of rotating non-consumable tool.

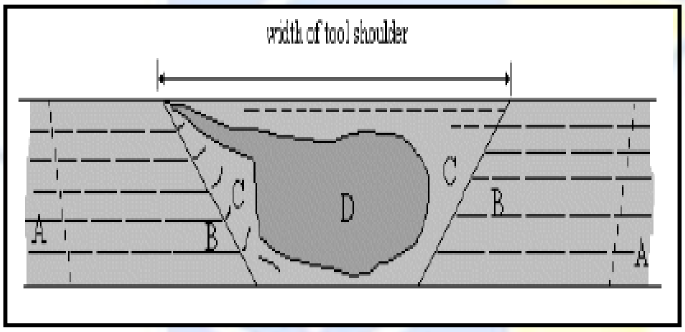


Fig.3: Micro Structural Study of Plate (TWI)

Submerged Friction Stir Welding

Submerged Friction Stir Welding is a solid state welding process. It takes place at temperatures below the melting point of the material. In this method, a non-consumable rotating tool runs over the substrates under the submerged medium which results into the generation of heat due to friction. This leads to plastic deformation and softening of substrates near the tool area. Then, the substrates can be easily joined.

It also minimizes various welding defects like porosity, shrinkage, splatter, embrittlement, solidification, cracking etc. This process doesn't require shielding gas and filler material for welding which make this process cheaper. It consumes less energy and gives improved mechanical properties. It also provides well defined variation in grain size between different zones along the high quality weld joint produced.

II. LITERATURE SURVEY

Thomas *et al* (1991), [1] carried out the action of rubbing two objects together causing friction to provide heat. The standards of this strategy now shape the premise of numerous customary and novel contact welding, surfacing and preparing procedures. The erosion procedure is a productive and controllable strategy for plasticizing a particular range of a material, and thus removing contaminants in preparation for welding, surfacing/cladding or extrusion.

R.S.Mishra *et al* (2005), [2] concentrated on and assessed the advancement of fsw and fsp.Emphasis has been given to the (a) mechanisms responsible for the formation of welds and micro structural refinement, and (b) impacts of FSW/FSP parameters on resultant microstructure and final mechanical properties. The study focusing on the aluminium alloys.

C.A.W.Olea *et al* (2006), [3] were find out "Friction Stir Welding of Precipitate Hardenable Aluminium Alloys: A Review". They taken butt joints of Precipitation hardenable 2xxx (Al-Cu), 6xxx (Al-Mg-Si) and 7xxx (Al-Zn) aluminium alloys. The correlation between microstructure characteristics and strength properties during welding studied. They collect large amount of information about friction stir welding, micro structural properties, mechanical properties, dynamic recovery and recrystallization. Figure shows the temperature distribution during friction stir welding.

A. Heidarzadeh *et al* (2013), [4] were carried out "Prediction of mechanical properties in friction stir welds of pure copper". They taken response surface methodology based on central composite rotatable design with three parameters, five levels and 20 runs to develop the mathematical regression. The optical microscopy and scanning electron microscopy used for microstructure characterization. The increment in welding parameters resulted increase in tensile strength of joints. Hardness of joints decreased with increase in rotational speeds and axial force.

Anjaneya Prasad *et al* (2013), [5] were carried out "Experimental Comparison of the MIG and Friction Stir Welding Processes for AA 6061(Al Mg Si Cu) Aluminium Alloy". They concentrated on mechanical properties like tensile strength, hardness and impact strength for both welding processes for AA 6061.They give conclusion that microstructure of friction stir weld is differ from MIG weld. Tensile strength of weld joints can be increased and HAZ is narrower then MIG weld.

A Scialpi *et al* (2008), [6] were carried out "Micro friction stir welding of 2024-6082 aluminium alloys". The alloys of 2024-T3 and 6082-T6 aluminium starting from 0.8 mm thick plates welded successfully. The conclusions are various zones in microstructure of dissimilar joints base metal, TAZ, TMAZ, Stirred zone for the 2024 and 6082 alloy. The mechanical properties of dissimilar joints are significantly improved in longitudinal direction. The strength of 6082 alloy is higher.

G.cam *et al* (2008), [7] were find out "Mechanical properties of friction stir butt-welded Al-5086 H32 plate". They give emphasis on effect of welding speed on the weld performance of the joints was investigated by conducting optical microscopy, micro hardness measurements and mechanical tests. The maximum ductility performance of the joints was relatively lower. Higher joint performances can also be achieved by increasing the penetration depth of the stirring probe in butt-friction stir welding of Al-5086 H32 plates.

N.camp *et al* (2007), [8] were carried out "Modelling of friction stir welding of 7xxx aluminium alloys". They give modeling approach to predict the behaviour of high strength aluminium alloys. A numerical model and optimized model calibration procedure is presented for 7449 alloy. The robustness of this calibration is subsequently tested by applying the model to a different 7000 series alloy, 7150 in peak-aged condition, after FSW. Microstructure predictions are found to be highly dependent on the peak temperature reached during the weld thermal cycle as well as heating and cooling rates. A range of precipitation sequences involving metastable to equilibrium phase transformation and dissolution/coarsening of precipitates are predicted. The predicted microstructures are found to be in good quantitative agreement with the characterized experimental microstructures. Predicted precipitate distributions are used to estimate the strength of the material. These predictions generally agree well with measured hardness values.

H.J.Liu *et al* (2003), [9] were studied "Tensile properties and fracture locations of friction-stir-welded joints of 2017-T351aluminum alloy". They studied the friction stir weldability of the 2017-T351 aluminium alloy and determine welding parameters. The experimental results showed the tensile properties and fracture locations of the joints are significantly affected by welding process parameters. When the optimum revolutionary pitch is 0.07 mm/rev corresponding to the rotation speed of 1500 rpm and the welding speed of 100 mm/min, the maximum ultimate strength of the joints is equivalent to 82% that of the base material. Though the voids-free joints are fractured near or at the interface between the weld nugget and the thermo-mechanically affected zone (TMAZ) on the advancing side, the fracture occurs at the weld center when the void defects exist in the joints.

FU Zhi-Hong *et al* (2004), [10] were find out "Friction Stir Welding of Aluminum Alloys". They studied friction stir welding of aluminium and titanium alloys etc.The processing of FSW, the microstructure in FSW alloys and factors affecting weld quality. They give result that FSW is complex process and many factors affecting processing, main factors are tool‟s materials and configurations, rotating speed, welding speed, press force of tool on work pieces and kind of materials.

K.V.Jata *et al* (2000), [11] were carried out "Continuous Dynamic Recrystallization during Friction Stir Welding of High Strength Aluminium Alloys". They studied basic evolution of microstructure in the dynamically recrystallized region and to relate it to the deformation process variables of strain, strain rate and temperature. Approximate method was employed to estimate the strain and strain rate in the weld nugget. The average grain diameter in the DRX region was 9 µm. Using orientation imaging microscopy, many of the grain boundary misorientations created in the DRX region were observed to be between 15 to 35°.

Tulika garg *et al* (2014), [12] were carried out "Underwater Friction Stir Welding: An Overview". They give a conclusion that it has the ability to join light weight alloys underwater. It also reduces the energy consumption of their joining processes. Cryogenic fuel tanks, military vehicles, rolling stock, and cold plates for thermal management, welding of the latest iMac are the various application of the friction stir welding process.

N.A.Mcpherson *et al*, [13] were carried out "A comparison between single sided friction stir welded and submerged arc welded DH36 steel thin plate". The work described has been put in place to directly compare friction stir welded and submerged arc welded thin plate. The plate thicknesses used were 4, 6 and 8mm thick DH36 grade steel Distortion was found to be lower in friction stir welded steel, but the 4mm thick was still showing significant distortion. No issues were identified with weld metal strength, and toughness at -20OC was found to be comparable but more uniform across the weld area than with the submerged arc welded material. Micro structural observations have been linked to hardness, toughness and fatigue test data. The fatigue data includes the observation of preferential crack initiation relative to the trailing/leading side of the welding process.

Z. Zhang *et al* (2014), [14] were carried out "Influence of water cooling on microstructure and mechanical properties of friction stir welded 2014 Al-T6 joints". They studied effect of friction stir welding parameters on the microstructure and mechanical properties of 5.6 mm thick 2219Al-T6. FSW joints could be obtained under lower rotation rates of 400–800 rpm and welding speeds of 100–800 mm/min; higher rotation rates of 1200–1600 rpm easily led to the tunnel and void defects. The FSW thermal cycle resulted in low hardness zones (LHZs) on both retreating side (RS) and advancing side (AS). The LHZs may be located at the interface between the nugget zone (NZ) and the thermo-mechanically affected zone (TMAZ).

W.F.Xu *et al* (2014), [15] were carried out "Low-cycle fatigue of a friction stir welded 2219-T62 aluminum alloy at different welding parameters and cooling conditions". They studied Cyclic hardening of friction stir welded joints was appreciably stronger than that of the base material. The cyclic stress amplitude increased, and plastic strain amplitude and fatigue lifetime slightly decreased with increasing welding speed from 60 to 200 mm/min but were only weakly dependent of the rotational rate between 300 and 1,000 rpm with air cooling. Friction stir welded joints with water cooling had higher stress amplitude and fatigue life than that with air cooling. Fatigue failure of the joint occurred in the HAZ where the soft zone was present, with crack initiation from the specimen surface or near-surface defect and crack propagation characterized by typical fatigue striations.

H.Farrokhi *et al* (2013), [16] were carried out "Frictions stir welding of copper under different welding parameters and media". They examined friction stir welding of copper plates under different welding medium air and water. The rotation speed 1600 rev/min and traverse speeds of 50 and 100 mm/min.The better microstructure achieved in underwater condition. The welded joints in underwater condition having higher tensile strength.

Basil Darras *et al* (2013), [17] were carried out "Submerged friction stir processing of AZ31 Magnesium alloy". They studied submerged friction stir processing of AZ31 Magnesium alloy. In this work, AZ31 Magnesium samples were friction stir processed while sub-merged in room-temperature and warm water. For comparison, FSP in air medium was also performed. The effects of submerging conditions on thermal fields, power consumption, resulting grain structure and tensile properties were studied. The Formability AZ31 magnesium alloy can be enhanced. The increase in elongation% was achieved.

Huda Mohammed Abdul-Aziz *et al* (2013), [18] were carried out " Artifitial Aging Time Effect On Corrosion Resistance For Friction Stir Welded Aa6061 T6".They studied effect of heat treatment on the corrosion resistant of friction stir welded joint of AA 6061-T6.The results showed that artificial aging treatment contributed in increasing the corrosion resistance of weld because of presence of precipitate phases occurring in the microstructures of the welding zone but corrosion resistance decreased as increasing ageing time because of the increasing of the precipitating elements. It was found that artificial ageing for 2 hours gives the best corrosion resistance.

Jingqing Zhang et al, [19] were carried out "Investigation on dissimilar underwater friction stir lap welding of 6061-T6 aluminum alloy to pure copper". They studied underwater friction stir lap welding aluminium alloy 6061-T6 to pure copper. The effect of external water on thermal history type thermocouple was utilized to measure the weld temperature. The XRD results demonstrates that the interface of the welds mainly consist of the Al-Cu intermetallic compounds such as CuAl2 and Cu9Al4 together with few amounts of Al and Cu, and it is also found that the amount of the intermetallic in the underwater weld is obvious less than in the classical weld. The SEM images and the EDS line scan results also illustrate that the Al-Cu diffusion layer at the Al-Cu interface of the underwater weld was obviously slender than that of the classical weld.

Mohammad Ammar Mofid *et al* (2012), [20] were carried out "Submerged Friction-Stir Welding (SFSW) Underwater and Under Liquid Nitrogen: An Improved Method to Join Al Alloys to Mg Alloys". They concentrate on friction stir welding plates of AZ31 (Mg alloy) and AA 5083 H34 were joined in three different environment air, water and liquid nitrogen at 400 rpm and 50 mm/min. It is shown that in low temperature FSW, the flow stress is higher, plastic contribution increases, and so adiabatic heating, a result of high strain and high strain-rate deformation, drives the recrystallization process beside frictional heat.

R.D.Fu *et al* (2012), [21] were carried out "Improvement of Formation Quality for Friction Stir Welded Joints". They studied the formation quality of the joints welded underwater clearly improves compared with that of the joints welded in air. Excellent weld joints free from defects are obtained in the present range of the FSW parameters for joints welded underwater and the stir tool rotated in the counterclockwise direction. The investigation of the flow path of the softened metal around the FSW tool reveals that the flow pattern of the softened metal driven by the shoulder and the pin varies with the rotational direction of the FSW tool, weld ambient temperature, and weld parameters. An excessively high weld input is detrimental to sound flow and avoidance of weld defects. By contrast, moderately decreasing the ambient temperature around the weld zone can improve the formation quality of the weld joints, regardless of the other weld conditions.

W.F.Xu *et al* (2012), [22] were studied out "Improvements of strength and ductility in aluminum alloy joints via rapid cooling during friction stir welding". They studied microstructures, tensile properties and strain hardening behaviour of friction stir welding. AA2219 aluminum alloy under optimized welding parameters and varying cooling conditions (air cooling and water cooling) were investigated with three slices (top, middle and bottom) through the plate thickness. While the yield strength was lower in the FSW joints than in the base metal, the ultimate tensile strength of the FSW joints with water cooling reached nearly that of the base metal. In particular, FSW resulted in a significant improvement in the ductility of the alloy due to the presence of recrystallized fine grains with fragmented and uniformly dispersed second-phase particles in the weld nugget zone.

X.Chen *et al* (2011), [23] were studied out "Compression Behaviors of Thickness-reduced Steel Pipes Repaired with Underwater Welds" .They studied the weld model was firstly validated against a theoretical shear stress distribution in a longitudinal fillet weld and then further validated against experimental results of thickness-reduced steel pipes repaired with welded patch plates under compression. The proposed model was then applied to thickness-reduced steel pipes repaired by welded patch plates with different weld patterns that have the minimum required weld length. Behaviors of these repaired pipes under a compressive load were examined with respect to stiffness, load-carrying capacity, load share of patch plates, and failure modes. It was found that stiffness and load-carrying capacity of the thickness-reduced steel pipes under compression cannot be fully recovered by the welded patch plate repair when a patch plate thickness is the same as the thickness reduction of the damaged pipe. Among different weld patters, the one with four slits was found to show better performance.

Rui-dong Fu *et al* (2011), [24] were carried out **"**Improvement of weld temperature distribution and mechanical properties of 7050 aluminium alloy butt joints by submerged friction stir welding" They studied friction stir welding in cold and hot water, air condition carried out for 7050 aluminium alloys. The peak temperature during welding in air was up to 380.c and during hot and cold water about 300.c and 220.c. The distributions of micro hardness exhibited a typical „„W"" shape. The width of the low hardness zone varied with the weld ambient conditions. The minimum hardness zone was located at the heat affected zone (HAZ) of the weld joints. Better tensile properties were achieved for joint welded in hot water, and the strength ratio of the weld joint to the base metal was up to 92%. The tensile fracture position was located at the low hardness zone of the weld joints. The fracture surfaces exhibited a mixture of dimples and quasi-cleavage planes for the joints welded in cold and hot water, and only dimples for the joint welded in air.

LIU Hui-jie *et al* (2010), [25] were carried out "Mechanical properties of underwater friction stir welded 2219 aluminum alloy". They studied that tensile strength of the joint can be improved from 324 MPa by external water cooling action in normal to 341 MPa. However, the plasticity of the joint is deteriorated. The underwater joint tends to fracture at the interface between the weld nugget zone and the thermal mechanically affected zone on the advancing side during tensile test, which is significantly different from the normal joint.

P. Upadhyay *et al* (2010), [26] were carried out "Effects of thermal boundary conditions in friction stir welded AA7050-T7 sheets". They take a series of friction stir welds was made in laboratory air and with the plates submerged in water to investigate how the quenching rate affects properties of the joint and some weld response parameters. Select welds were also made at a sub-ambient temperature of −25 ◦C. Temperature measurements were made in the probe center and at the minimum hardness location of the weld.

Weld response variables, hardness distributions, joint strength and nugget grain size were measured and correlated with boundary conditions and welding parameters. A consistent decrease in the peak temperature and increase in cooling rate were observed in the submerged welds. Submerged welds show improvement in tensile strength and elongation throughout the range of parameters tested.

III. EXPERIMENTAL SETUP

In our project work, we choose three factors at range of three levels for two different cases as dry and water sprinkling medium.

Table.1 Values of Process parameters for L9 Orthogonal Array

		Parameters		
Sr no.	Level	Tool Rotational Speed (RPM)	Tool Geometry	Welding Speed (mm/min)
1	Level-1	1000	C (Cylindrical)	18
2	Level-2	1200	T (Taper Straight Flute)	29
3	Level-3	1400	TR (Triangle)	45

From the above table according to design of experiments with taguchi's orthogonal array by using Minitab_16 statical tool have produced total numbers of 9 experiments to be performed in deep drawing process as shown in below table.2.

Table.2 Experimental runs as per L9 Orthogonal Array

Experiment no	Tool Rotational Speed (RPM)	Tool Geometry	Welding Speed (mm/min)
1	1000	C	18
2	1200	C	29
3	1400	C	45
4	1000	T	18
5	1200	T	29
6	1400	T	45
7	1000	TR	18
8	1200	TR	29
9	1400	TR	45

Finally we take total 9 number of experimental run to perform AA 6061-T6 with the help of vertical milling machine for two different cases.

Fig.4: Experimental Setup for Different Parameters

MATERIAL SELECTION

The base material for the investigation is AA6061-T6. The composition of the metal is shown in following table. The size of the base plate is 150mm x 80mm x 6mm with square edges.

Table.3 Chemical Composition of AA 6061-T6

Composition	Amount (wt %)
Aluminium	Balance
Magnesium	0.8-1.2
Silicon	0.4-0.8
Iron	Max.0.7
Copper	0.15-0.40
Zinc	Max.0.25
Titanium	Max.0.15
Manganese	Max.0.15
Chromium	0.04-0.35
Others	0.05

TOOL SELECTION

Stresses developed by the tool are dependent on the strength of the work piece at high temperatures under the FSW conditions. Three different tool pins of H13 Steel are selected. Straight Cylindrical Pin, Triangular Pin, Tapered Straight Flute Pin. Weld quality and tool wear are two important considerations in the selection of tool material, the properties of which may affect the weld quality by influencing heat generation and dissipation. The weld microstructure may also be affected as a result of interaction with worn tool material.

IV. RESULTS & DISCUSSIONS

TENSILE STRENGTH

Tensile tests were performed to determine the tensile properties of the weld material such as tensile strength and percentage of elongation. Transverse tensile test samples were prepared from joints according to ASME Sec-IX. The result of specimen measured and noted. The tensile test of the welded joints was carried out on MTS System Corporation manufactured.

Table.4 Tensile Strength for Case-1 Dry Medium

Experiment No	Tool Geometry	Tool Rotational Speed(rpm)	Welding Speed (mm/min)	Ultimate Tensile Strength MPa	Ultimate Tensile Load(KN)	Elongation (%)
1	Straight Cylindrical Tool Pin(C)	1000	18	107.780	10.400	13.220
2		1200	29	87.553	8.910	9.5
3		1400	45	90.278	9.750	11.750
4	Triangular Tool Pin(TR)	1000	18	102.500	11.070	18.750
5		1200	29	105.556	11.400	10.750
6		1400	45	110.526	12.600	15.250
7	Tapered Straight	1000	18	121.389	13.110	12.000

8	Flute Tool Pin(T)	1200	29	105.833	10.800	13.250
9		1400	45	100.294	10.230	15.500

Table.5 Tensile Strength for Case-2 Water Sprinkling

Experiment No	Tool Geometry	Tool Rotational Speed(rpm)	Welding Speed (mm/min)	Ultimate Tensile Strength MPa	Ultimate Tensile Load(KN)	Elongation (%)
1	Straight Cylindrical Tool Pin (C)	1000	18	117.940	12.030	14.500
2		1200	29	95	10.260	12.500
3		1400	45	98.889	10.680	7.750
4	Triangular Tool Pin (TR)	1000	18	105.880	10.800	28.500
5		1200	29	106.410	11.250	13.250
6		1400	45	118.347	13.560	10.113
7	Tapered Straight Flute Tool Pin (T)	1000	18	131.000	13.410	14.500
8		1200	29	106.940	11.550	11.250
9		1400	45	102.059	10.410	18.750

HARDNESS

The hardness of the welded joints was measured on a Rockwell hardness tester. The hardness tester has an indicator and a rhombus shaped indenter to measure the hardness of the material. Aluminium material ball diameter 1/16 and load on the 100kg will be set on the buttons. The load on the indenter can be set using a knob on the hardness tester. It shows the dial indicator and load and unload knob. The indicator load can be set by using the button on the side panel of the hardness tester.

Table.6 Hardness for Case-1 Dry Medium

Experiment No	Tool Geometry	Tool Rotational Speed(rpm)	Welding Speed (mm/min)	Hardness(HRB)
1	Straight Cylindrical Tool Pin (C)	1000	18	63
2		1200	29	59
3		1400	45	60
4	Triangular Tool Pin (TR)	1000	18	58
5		1200	29	60
6		1400	45	61
7	Tapered Straight Flute Tool Pin (T)	1000	18	62
8		1200	29	60
9		1400	45	58

Table.7 Hardness for Case-2 Water Sprinkling

Experiment No	Tool Geometry	Tool Rotational Speed(rpm)	Welding Speed (mm/min)	Hardness(HRB)
1	Straight Cylindrical Tool Pin(C)	1000	18	68
2		1200	29	64
3		1400	45	61
4	Triangular Tool Pin(TR)	1000	18	60
5		1200	29	63
6		1400	45	67
7	Tapered Straight Tool Pin(T)	1000	18	63
8		1200	29	62
9		1400	45	60

BEND TEST

The Bending experiment is also conducted on the same machine as the tensile test, the hydraulic grippers are replaced by the rollers forming die to transform the machine to perform the bending. Bending test specimens created as per the **IS-4598- 1968** for aluminium (1mm to 7mm thickness).

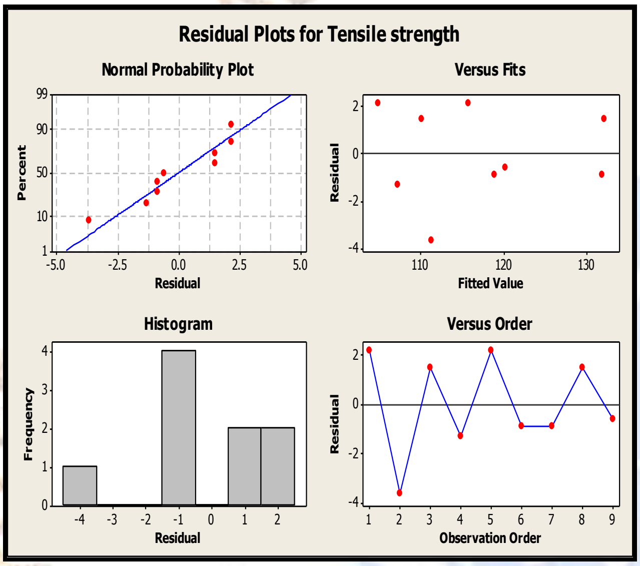
Table.8 Bending Test Result for Case-1 Dry Medium

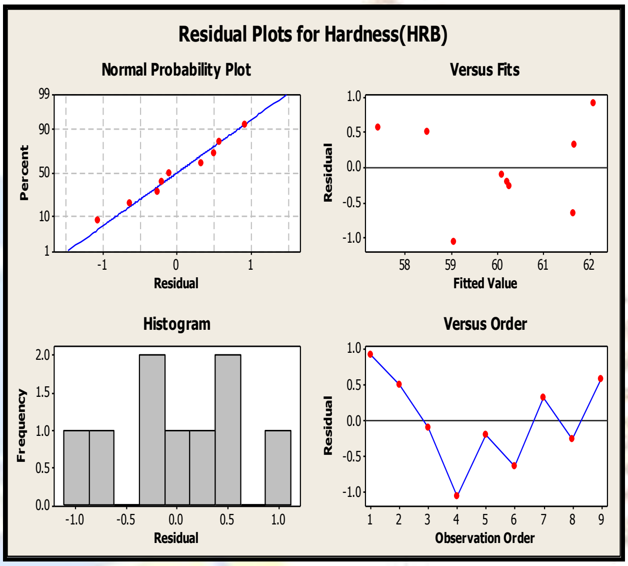
No	No Crack	Crack	Before 90°	After 90°
1	Yes			
2	Yes			
3		Yes		Yes

4	Yes			Yes
5	Yes			
6	Yes			
7	Yes			
8	Yes			
9		Yes		

Table.9 Bending Test Result for Case-2 Water Sprinkling

No	No crack	Crack	Before 90°	After 90°
1	Yes			
2	Yes			
3	Yes			
4	Yes			
5		Yes	Yes	
6		Yes		Yes
7	Yes			
8	Yes			
9	Yes			





V. CONCLUSIONS

The Following conclusion have been arrived at after the present study involving friction stir welding of aluminium alloys (AA 6061-T6).

✓ In this research AA 6061-T6 Alloy was welded by using FSW process. Three Different friction stir profiles were designed to study the influence of pin geometry on the weld shape and mechanical properties. Also the effect of different tool rotation speed, welding speed and two different cases dry and water sprinkling is investigated.

✓ The effect of tool pin profile, rotational speed and welding speed on the appearance of the weld is presentated and no obvious defect was found for both cases. The surface finish of weld sample welded at 1400 rpm was better than weld sample welded at 1000 rpm.This shows that as the tool rotation speed increases smooth surface is produced at the weld ment.

✓ The results indicate that the pin profile effect on mechanical properties.

✓ Among the joints welded in this experiment, the joints produced using tapered straight flute tool shows more strength and ultimate load compared to another tool. The joints produced using tapered straight flute tool pin at tool rotational speed 1000 rpm and welding speed 18 mm/min shows best tensile properties for both cases.

✓ Straight cylindrical tool pin shows higher strength at lower rotational speed and welding speed. Triangular tool pin shows higher strength for medium to high rotational speed and welding speed.

✓ The Joints welded using straight cylindrical tool pin at tool rotational speed 1000 rpm and welding speed 18 mm/min shows best hardness for both cases.

✓ Triangular tool joints fabricated at tool rotational speed 1400 rpm and welding speed 45 mm/min have shown higher hardness compared to 1200 rpm, 1400 rpm and welding speed 29 mm/min, 45 mm/min for both cases.

✓ Tapered straight flute tool joints fabricated at tool rotational speed 1000 rpm and welding speed 18 mm/min shows higher hardness than tool rotational speed 1200 rpm,1400 rpm and welding speed 29 mm/min,45 mm/min for both cases.

✓ The tensile strength of tapered straight flute tool pin reaches 41.12% of base metal tensile strength. The tensile strength of straight cylindrical tool pin reaches 37.02% of base metal tensile strength and triangular tool pin reaches 33.24% of the base metal tensile strength.

✓ The results show that tensile strength and hardness for water sprinkling case is more than conventional case. It improves mechanical properties and consumes less energy.

- ✓ The microstructure image shows the grain structure. This image shows the porosity in some welding.

VI. References

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