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OPTIMIZATION OF PROCESS PARAMETERS OF FRICTION STIR WELDING

M.Srinivasa Rao, Associate Professor.
Department of Mechanical Engineering,
Sri Indu College of Engineering & Technology
R.R.Dist, Telangana,India
srinu335@gmail.com.

ABSTRACT

Friction Stir Welding (FSW) is a solid state welding process. It is different from fusion welding process and also different from other old solid welding process. It is a way of joining materials without melting them. No melting occurs during friction stir welding. There is no solidification shrinkage when the joined sections solidify. The temperature is lower than fusion welding. The strength of the joint is high. It is relatively a new joining process. Friction stir welding (FSW) produces no fumes; uses no filler material; and can join nonferrous alloys like aluminum alloys, copper, magnesium, zinc, steels, and titanium. FSW sometimes produces a weld that is stronger than the base material. No light is radiated as in fusion welding, no sparks fly, and no smoke is emitted in FSW. FSW is considerably more environmentally friendly than conventional "fusion" welding.

The main objective of this paper is to analyzation of weldment and welding process parameters of Friction stir welding and its properties. Friction stir welding is a new emerging solid state welding process. The weldability of pure aluminium alloys will be evaluated by performing number of experiments. Microstructure and mechanical properties of a number of welds will be done. Number of butt welds is produced under a wide range of welding conditions and the behavior of both base materials and weld bead will be analyzed.The number of experiments are conducted by converting the existing milling machine into Friction Stir Welding machine.

The welds created in this process are used for testing. The weld parameters may be temperature induced between tool and work pieces, spindle speed, transverse speed, thickness of work piece, and work piece material are studied. After welding the weld quality and microstructure is evaluated by means of Metallurgical microscopes. To measure the mechanical properties of weldment, different tests are conducted by using Computerized Universal Testing Machine, Hardness testing machine, Impact testing machine. By varying Tool rotation speed,feed will effects the changes in composition and grain size of weld bead, thermomechanically affected zone and normal zone.

Keywords – Friction Stir Welding, Welding speed, Rotational speed of tool, Stir Zone Temperature

1. INTRODUCTION & LITERATURE

In 1991 a novel welding method was conceived. Friction Stir Welding (FSW) is invented by Wayne Thomas at The Welding Institute (TWI)Ltd at England and patented in 1991[2]. TWI filed successfully for patents in Europe, the U.S., Japan, and Australia. TWI then established TWI Group-Sponsored Project. It is further developed New Friction Stir Technique for Welding Aluminum, “in 1992 to study this technique.

The development project was conducted in three phases. Phase I proved FSW to be a realistic and practical welding technique, while at the same time addressing the welding of 6000 series aluminum alloys. Phase II successfully examined the welding of aerospace and ship building aluminum alloys such as 2000 and 5000 series, respectively. Process parameter tolerances, metallurgical characteristics, and mechanical properties for these materials were established. Phase III developed pertinent data for further industrialization of FSW. Since its invention, the process has received world-wide attention, and today FSW is used in research and production in many sectors, including aerospace, automotive, railway, shipbuilding, electronic housings, coolers, heat exchangers, and nuclear waste containers.FSW has been proven to be an effective process for welding aluminum, brass, copper, and other low-melting-temperature materials. The latest phase in FSW research has been aimed at expanding the usefulness of this procedure in high-melting-temperature materials, such as carbon and stainless steels and nickel-based alloys, by developing tools that can withstand the high temperatures and pressures needed to effectively join these materials.

Radically new joining processes do not come along very often: friction stir welding (FSW) was one such event, being invented by the TWI in 1991.[1,2] Since then research and development in FSW and associated technologies has mushroomed, with many companies, research institutes and universities investing heavily in the process and international conference series dedicated to it's study. By the end of 2007, TWI had issued 200 licences for use of the process, and 1900 patent applications had been filed relating to FSW.[3] The number of research papers has also grown exponentially.

1.1 WORKING PRINCIPLE OF FRICTION STIR WELDING:

In FSW, a cylindrical, shouldered tool with a profiled probe is rotated and slowly plunged into the weld joint between two pieces of sheet or plate material that are to be welded together . The parts must be clamped onto a backing bar in a manner that prevents the abutting joint faces from being forced apart or in any other way moved out of position. Frictional heat is generated between the wear-resistant welding tool and the material of the work pieces. This heat causes the work pieces to soften without reaching the melting point and allows the tool to traverse along the weld line. The resultant plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool probe and is forged together by the intimate contact of the tool shoulder and the pin profile. This leaves a solid-phase bond between the two pieces.

The process can be regarded as a solid-phase keyhole welding technique since a hole to accommodate the probe is generated, then moved along the weld during the welding sequence.The process originally was limited to low-melting-temperature materials because initial tool materials could not hold up to the stress of "stirring" higher-temperature materials such as steels and other high-strength materials. This problem was solved recently with the introduction of new tool material technologies such as polycrystalline cubic boron nitride (PCBN), tungsten rhenium, and ceramics. The use of a liquid-cooled tool holder and telemetry system has further refined the process and capability. Tool materials required for FSW of high-melting-temperature materials need high "hot" hardness for abrasion resistance, along with chemical stability and adequate toughness at high temperature. Material developments are advancing rapidly in different tool materials, each material offering specific advantages for different applications.

Fabricators are under increasing pressure to produce stronger and lighter products whilst using less energy, less environmentally harmful materials, at lower cost and more quickly than ever before. FSW, being a solid-state, low-energy-input, repeatable mechanical process capable of producing very high-strength welds in a wide range of materials, offers a potentially lower-cost, environmentally benign solution to these challenges. The process uses no outside (filler) material, no shielding gases, and requires low energy input when compared to other welding processes. The solid phase bond between the two pieces is made solely of parent material. The grain structure in the weld zone is finer than that of the parent material and has similar strength, bending, and fatigue characteristics. A constantly rotated non consumable cylindrical-shouldered tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material. The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface.

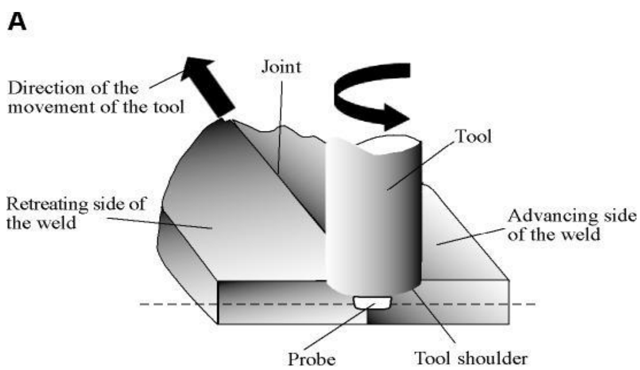


Fig 1

Frictional heat is generated between the wear-resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the pin is moved forward, a special profile on its leading face forces plasticized material to the rear where clamping force assists in a forged consolidation of the weld. This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in severe solid state deformation involving dynamic recrystallization of the base material

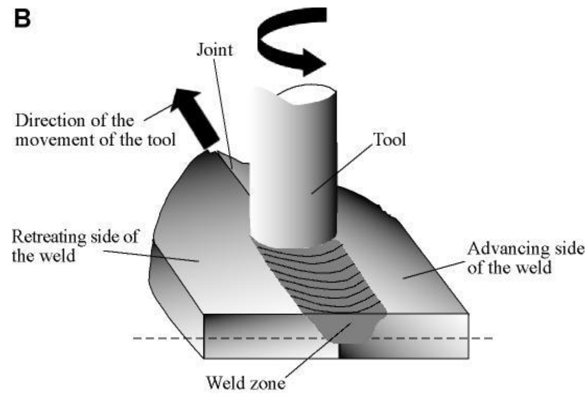


Fig.2

2.2 Advantages:

Provides opportunities for new solutions to old joining problems**:** Friction Stir Welding (FSW) is a leading-edge technology, meaning that MTI is continually identifying new applications for the process and, therefore, new solutions for its customers.

Virtually defect-free welding,Versatile applications by welding all joint geometries including complex contours,Limitless panel length and width, Superior mechanical characteristics, Join dissimilar alloys, "Green"process, Weld Quality, Low distortion, Low shrinkage,No porosity, No lack of fusion, No change in material

2.3 Disadvantages :

The main disadvantages of FSW are thus stated below:It requires very rigid clamping

- Exit hole left when tool is withdrawn.
- Large down forces required with heavy-duty clamping necessary to hold the plates together.
- Less flexible than manual and arc processes (difficulties with thickness variations and non-linear welds).
- Often slower traverse rate than some fusion welding techniques, although this may be offset if fewer welding passes are required.

2.4 Applications:

Aerospace, Automotive, Railways ,Robotics, Personal Computers.

2.EXPERIMENTATION METHODOLOGY

2.1 CARBIDE TOOL:

Tungsten carbide (chemical formula: WC) is a chemical compound (specifically, a carbide) containing equal parts of tungsten and carbon atoms. In its most basic form, tungsten carbide is a fine gray powder, but it can be pressed and formed into shapes for use in industrial machinery, cutting tools, abrasives, armor-piercing rounds, other tools and instruments, and jewelry.

Tool Profile:

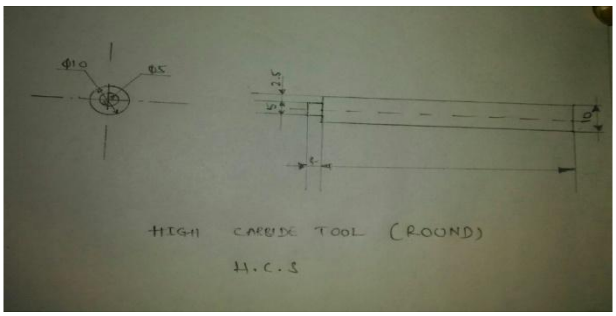


Fig 3

2.2 WELDABLE MATERIALS

The compatibility range extends to welding the following materials.

- Aluminum (all alloys), Copper, Brass, Magnesium, Titanium, Steel Alloys, Stainless Steel, Tool Steel, Nickel & Lead

In those weldable materials we used the Aluminum 6082 T-6 alloy for welding process in F.S.W

2.3 ALUMINIUM:

Aluminium (or aluminum) is a chemical element in the boron group with symbol Al and atomic number 13. It is a silvery white, soft, nonmagnetic, ductile metal. Aluminum is the third most abundant element (after oxygen and silicon), and the most abundant metal in the Earth's crust. It makes up about 8% by weight of the Earth's solid surface. Aluminum metal is so chemically reactive that native specimens are rare and limited to extreme reducing environments. Instead, it is found combined in over 270 different minerals. The chief ore of aluminum is bauxite. Aluminum is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation. Structural components made from aluminum and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. The most useful compounds of aluminum, at least on a weight basis, are the oxides and sulfates.

2.4 ALUMINIUM 6082 ALLOY:

Aluminium alloy 6082 is a medium strength alloy with excellent corrosion resistance.It has the highest strength of the 6000 series alloys.Alloy 6082 is known as a structural alloy.In plate form,6082 is the alloy most commonly used for maching. As a relatively new alloy,the higher strength of 6082 has seen it replace 6061 in many applications. The addition of a large amount of manganese controls the grain structure which in turn results in a stronger alloy. It is difficult to produce thin walled,complicated extrusion shapes in alloy 6082. The extruded surface finish is not smooth as other similar strength alloys in 6000 series. In the T6 and T651 temper, alloy 6082 machines well and produces tight coils of swarf when chip breakers are used.

APPLICATIONS: Aluminium 6082 alloy is typically used in Highly stressed applications ,Trusses,Bridges,Cranes,Transport applications,Ore skips and barrels

2.5 CHEMICAL COMPOSITION ALUMINIUM 6082 ALLOY :

S.NO	ELEMENT	% PRESENT
1	Silicon (Si)	0.70-1.30
2	Magnesium (Mg)	0.60-1.20
3	Manganese (Mn)	0.40-1.00
4	Iron (Fe)	0.0-0.50
5	Chromium (cr)	0.0-0.25
6	Zinc (Zn)	0.0-0.20
7	Titanium (Ti)	0.0-0.10
8	Copper (Cu)	0.0-0.10
9	Others (Total)	0.0-0.15
10	Aluminium (Al)	BALANCE

Table 1

2.6 ALUMINIUM 6082 MECHANICAL PROPERTIES:

Hardness	Ultimate tensile Strength	Yield tensile Strength	% elongation at break
91 BH	300 MPa	240 MPa	9 MIN %

Table 2

2.7 ALUMINIUM 6082 PHYSICAL PROPERTIES :

Thermal conductivity- 180 W/m.k Melting point - 555 deg. centigrade Density - 2.70 gm/cm*3

Thermal Expansion - 24×10^-6/K

Modulus of Elasticity - 70 GPa

Electric Resistivity - 0.038×10^-6 Ω.m

2.8 FRICTION STIR WELDING OF SIMILAR MATERIALS

FSW is a solid state welding process performed at temperatures lower than the melting point of the alloy. The work pieces are rigidly clamped in a fixed position and a specially profiled rotating tool traversed through the joint line produces the friction heating. The tool is crushing the joint line, breaking up the oxide film by a mechanical stirring and forging of the hot and plastic material.

We performed FSW between two aluminium 6082 plates by varying speed and feed. Two aluminum 6082 plates of 150*100*5mm are joined together with the help of heavy clamping devices and a cylindrical, shouldered tool with a profiled probe is rotated and slowly lunged into the weld joint between two pieces of plate material that are to be welded ogether.

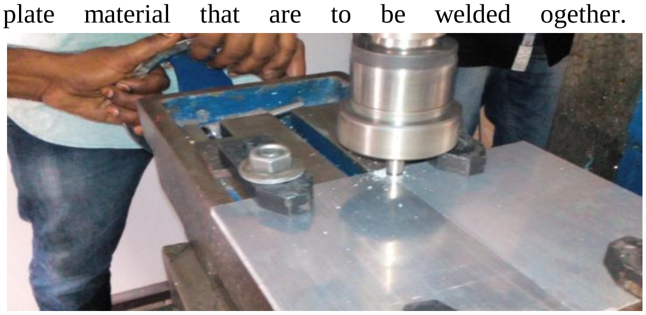


Fig 4

3. Results & Discussion

The aluminum plates were welded using rounded profile tool at a speed of 1900rpm to 1100 rpm with different feeds. The welded plates were first sectioned according to the specific test specimen dimensions as mentioned below, the following tests which were performed on the welded plates are as given below:

Destructive Testing is conducted as below

- UTM (Universal Testing Machine)
- Hardness Testing
- Impact Testing

3.1 UNIVERSAL TESTING MACHINE: A universal testing machine (UTM) of 60Tonnes, also known as a universal tester, materials testing machine or materials test frame, is used to test the tensile strength and compressive strength of materials. It is named after the fact that it can perform many standard tensile and compression tests on materials, components,and structures.

Fig 5

3.2 Procedure of U.T.M:

- At first the welded aluminum plates are thus sectioned according to the universal tensile testing machine standard dimensions as per ASTM. There are two types one is longitudinal sectional part and the other is transverse section. These two are just sectioned in the form of "I" section and the longitudinal I section and transverse I section are thus stated below.

Fig 6

- Now measure the gauge length and the diameter of the specimen
- Insert the specimen into grips of the test machine
- Begin the load application and record load v/s elongation data
  - Take the readings more frequently as yield point is approved
  - Measure the elongation values
  - Continue the test till fracture occurs
  - By joining the two broken halves of the specimen together, measure the final length and diameter of specimen at fracture

3.3 At Longitudinal I Section:

- The sectioned "longitudinal I section" work piece is then fitted in to the grips.
- By conducting this test in this ultimate testing machine we can get the following:
  - Ultimate Tensile strength ,Elongation,Ultimate load,0.2% proof stress
- 0.2% proof strain,Load v/s displacement graph
- The input that was given to the UTM is stated below:

Specimen type : Flat
Specimen width : 19.00mm
Specimen thickness: 5.00mm
Cross sectional area: 95.00mm^2
Original Gauge length : 52.63mm
Extensometer gauge length :50mm

Test procedure was conducted as IS 1608-2005 standards pattern.

The sectioned work piece that was fitted into grips of UTM as mentioned in below fig:

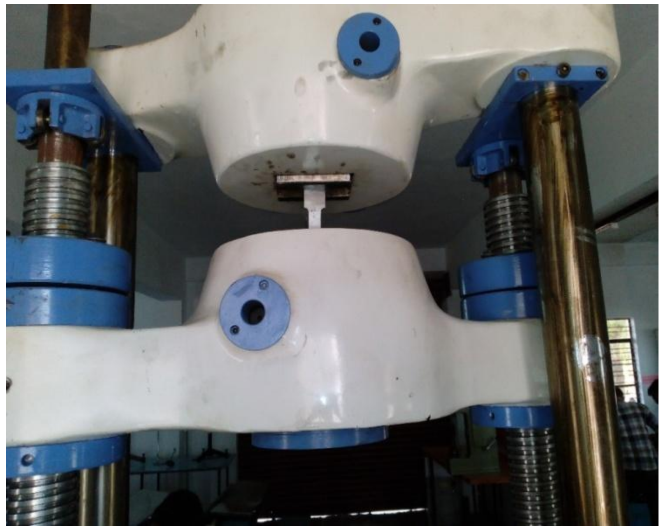


Fig 7

- The results of the conducted test are as follows:

3.4 Ultimate Tensile Test Results :

	ULTIMATE TENSILE LOAD	ULTIMATE TENSILE STRENGTH	MAXIMUM DISPLACEMENT	YIELD LOAD	YIELD STRRESS	BREAKING STRESS
H1	14.160 KN	149 MPa	2.00 mm	11.58KN	122 MPa	83 MPa
H2	14.340 KN	151 MPa	2.200 mm	9.480KN	100 MPa	83 MPa
H3	14.340 KN	151 MPa	2.000 mm	8.520KN	90 MPa	89 MPa
M1	15.240 KN	160 MPa	2.400 mm	9.780KN	103 MPa	83 MPa
M2	18.720 KN	197 MPa	1.600 mm	10.440KN	110 MPa	144 MPa
M3	13.080 KN	138 MPa	2.400 mm	8.520 KN	90 MPa	81 MPa

Table 3

3.5 Izod Impact testing machine:

Izod Impact testing machine of 18Kg Rammers weight is used. Impact is the property of the material to receive and to observe the energy of load when sudden energy impact upon & it can be designed and impacted on an area and load

Impact = load/area

Fig 8

The welded part which is to be tested must be sectioned according to the dimensions of the notch which is used to hold specimen to conduct impact test.

Fig 9

Fig 10

367

4. EXPERIMENTAL RESULTS

The following are the results of conducted tests with the welded specimens:

4.1 SPECIMENS: H: HIGH SPEED PIECE ,M: MEDIUM SPEED PIECE

	H-1	H-2	H-3	M-1	M-2	M-3
ROTOR SPEED (S) in rpm	1843	1748	1802	1164	1156	1167
FEED (F) in mm/sec	0.5	0.72	0.92	0.302	0.44	0.66

Table 4

4.2 BRINELL HARDNESS TEST RESULT : Brinell Hardess Test of weight 60Kg(f) is used to know the hardness on the welded specimens.

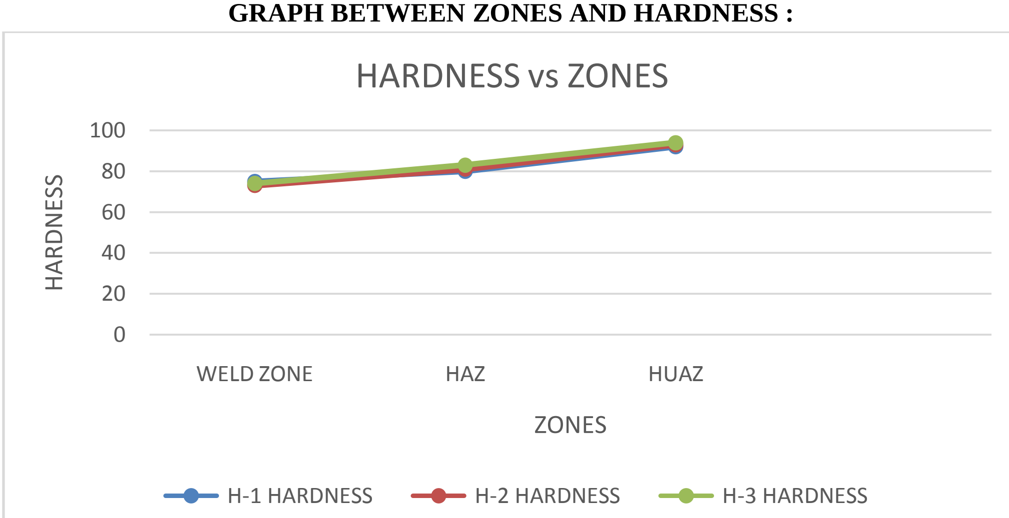
	H-1	H-2	H-3	M-1	M-2	M-3
Rotational speed of Tool(rpm)	1843	1748	1802	1164	1156	1167
Feed(mm/sec)	0.5	0.72	0.92	0.302	0.44	0.66
Weld Zone	75	73	74	76	80	78
Heat Affected Zone	80	81	83	80	85	82
Heat Unaffected Zone	92	93	94	92	93	93

Table 5

H: HIGH SPEED PIECE; S-ROTOR SPEED in rpm ; F-FEED in mm/sec
M: MEDIUM SPEED PIECE

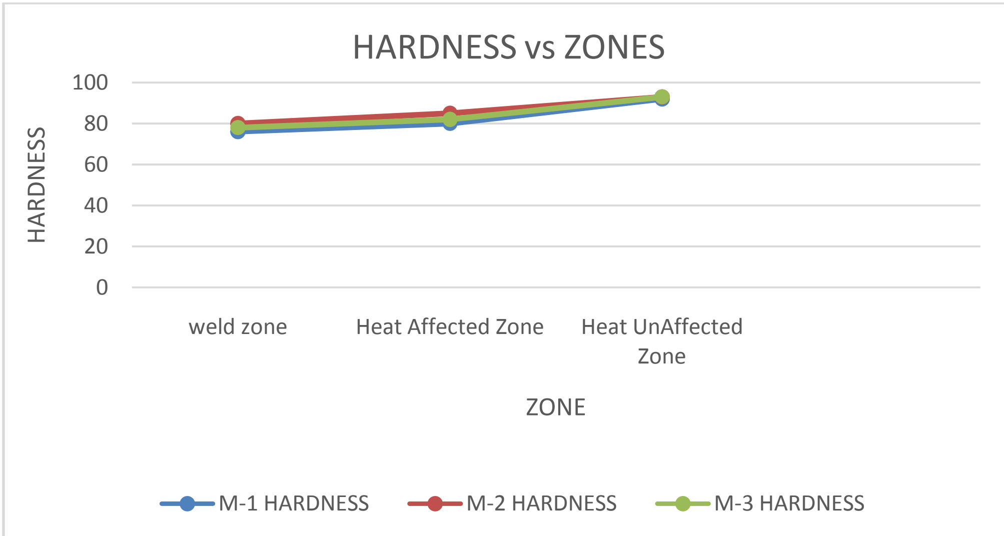
Graphs are drawn between hardness versus different zones for different specimens as given below

GRAPH BETWEEN ZONES AND HARDNESS :



HAZ- Heat Affected Zone

HUAZ-Heat Unaffected Zone



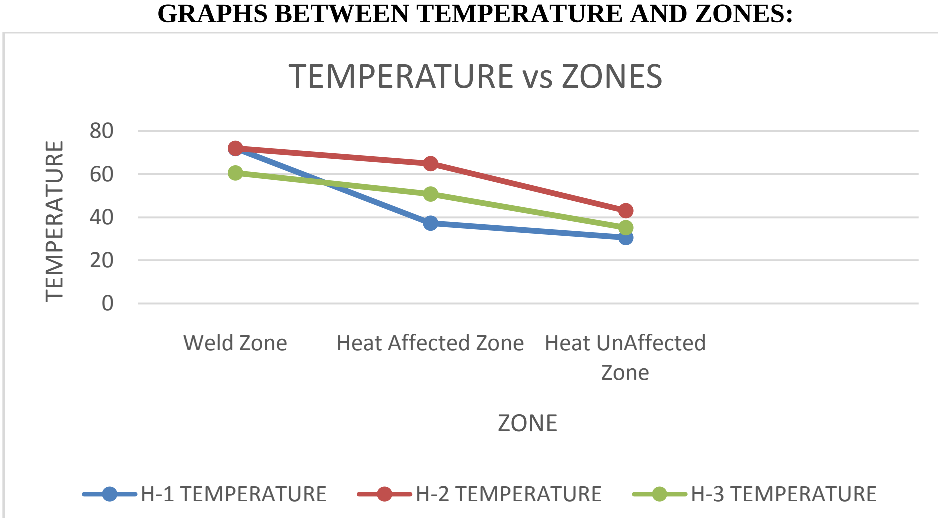
Temperature Induced at different speeds, feeds at different zones are given below

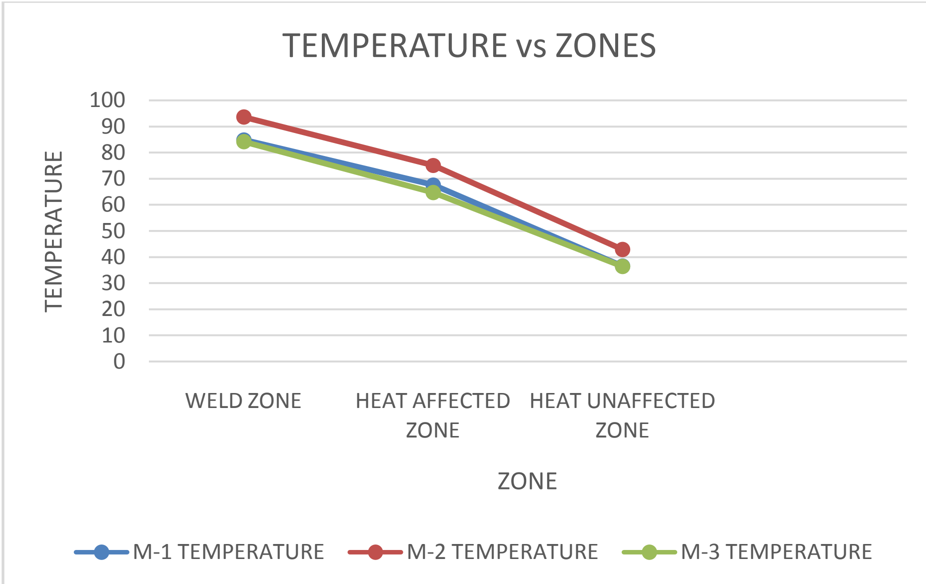
Specimen	**H-1**	**H-2**	**H-3**	**M-1**	**M-2**	**M-3**
Rotational speed of Tool(rpm)	1843	1748	1802	1164	1156	1167
Feed(mm/sec)	0.5	0.72	0.92	0.302	0.44	0.66
Weld Zone	71.93	71.96	60.52	84.9	93.7	84.17
Heat Affected Zone	37.26	64.86	50.70	67.62	75.1	64.72
Heat UnAffected Zone	30.53	42.98	35.12	36.55	42.87	36.47

Table 6

Graphs are drawn between temperature versus at different zones as given below

GRAPHS BETWEEN TEMPERATURE AND ZONES:





4.3 IZOD IMPACT TEST RESULTS:

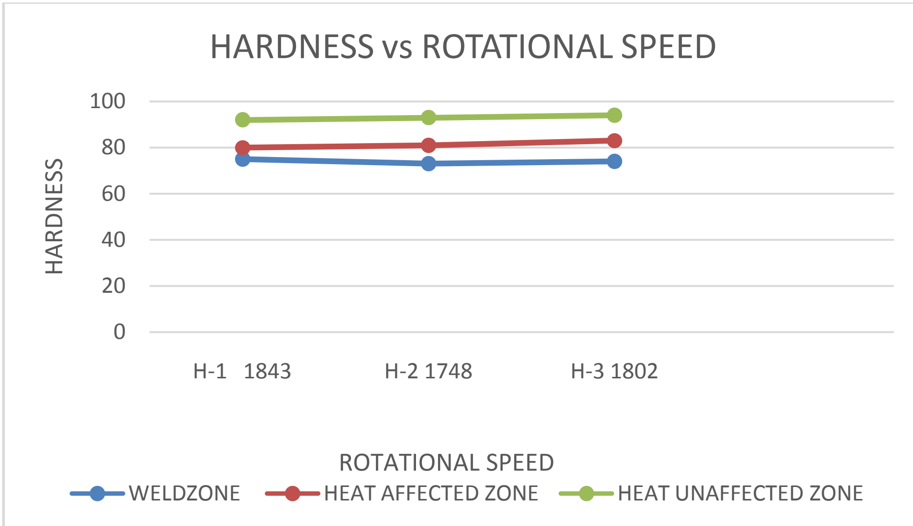
SPECIMEN	H-1	H-2	H-3	M-1	M-2	M-3
IMPACT ENERGY	96 J	96 J	98 J	104 J	106 J	96 J

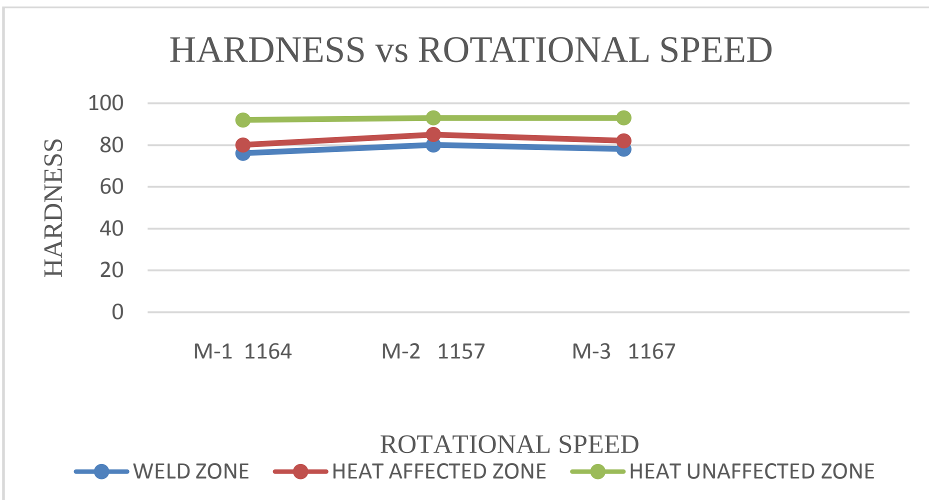
Table 7 J-Joules

Hardness measured values at different zones for different rotational speed of the tool as given below:

Specimens	**H-1**	**H-2**	**H-3**	**M-1**	**M-2**	**M-3**
Rotational speed of Tool(rpm)	1843	1748	1802	1164	1156	1167
Weld Zone	75	73	74	76	80	78
Heat Affected Zone	80	81	83	80	85	82
Heat Unaffected Zone	92	93	94	92	93	93

Table 8





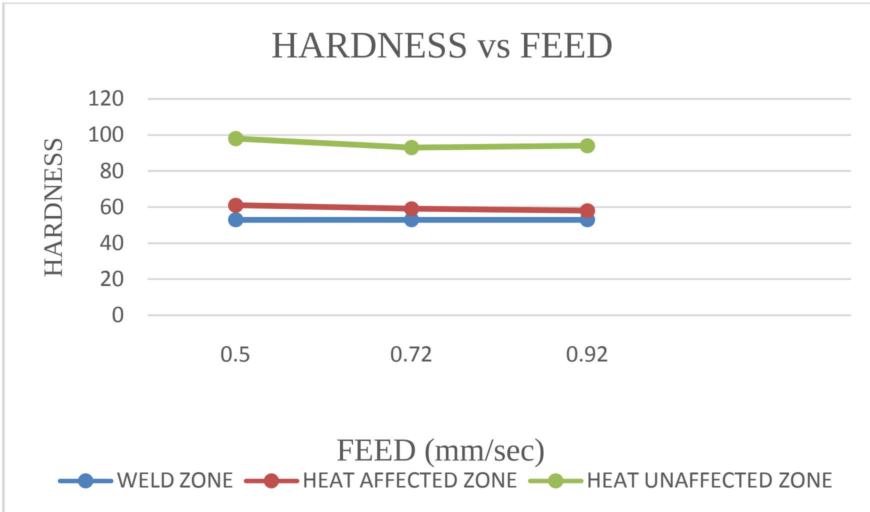
Hardness measured values at different zones for different feeds as given below:

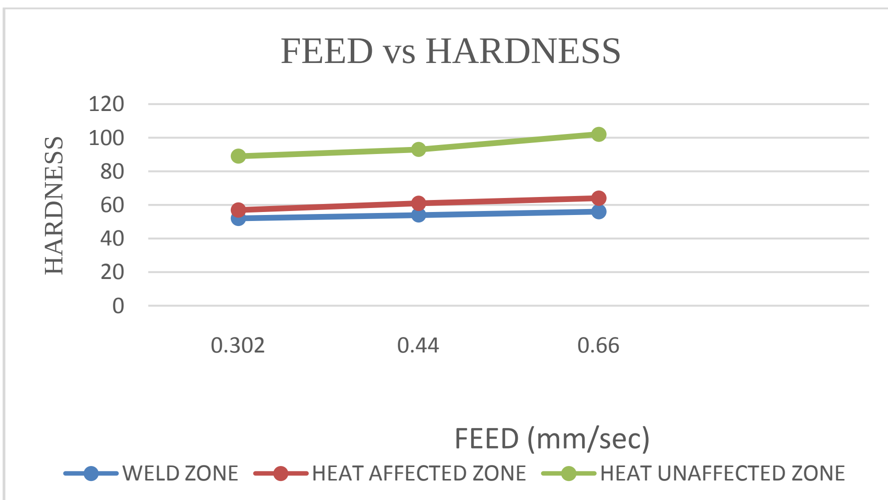
Specimens	**H-1**	**H-2**	**H-3**	**M-1**	**M-2**	**M-3**
Feed(mm/sec)	0.5	0.72	0.92	0.302	0.44	0.66
Weld Zone	75	73	74	76	80	78
Heat Affected Zone	80	81	83	80	85	82
Heat Unaffected Zone	92	93	94	92	93	93

Table 9

Graphs are drawn between feed versus hardness as given below

GRAPH BETWEEN FEED AND HARDNESS:





5.CONCLUSION & FUTURE SCOPE

Among all these experiments the work piece M2 specimen at medium rotational speed of tool, feed (i.e rotational speed of tool = 1156 rpm, Feed = 0.44 mm/sec) is shows optimum

ultimate strength, hardness, Impact strength proof stress, breaking stress are good at so good joint is obtained compare to the other rotational speed of tool, feed. The rotational speed of the tool, feed does effect the hardness in welding zone and at other zones also. At the medium speed of the tool (1156 rpm), Feed (0.44 mm/sec) is directly proportional the hardness, tensile strength at the weld zone. Properties look good in most of the cases. Welding will be done below the melting point of metals and alloys. The invention of FSW process has revolutionized the entire welding industry. Low distortion, no spatter, no fumes, it creates high strength welds in hard to weld metals. Ultimate tensile strength increases upto some speed & feed and then decreases. From the above results it is observed that the ultimate tensile strength and breaking stress of the welded part is directly proportional to the probe depth .speed and feed is increase tensile strength and proof stress up to some extent and then decrease.

It can be extended to similar and dissimilar and combination of both the materials like Aluminum (all alloys), Copper, Brass, Magnesium, Titanium, Steel Alloys, Stainless Steel, Tool Steel, Nickel & Lead and so on.

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