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Investigation of Mechanical Properties of Dissimilar Friction Stir Welded Joints of AA7075 and AA6061

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ABSTRACT - Friction stir welding (FSW) is a solid-state joining process that uses a non-consumable tool to join two facing work pieces without melting the work piece material. Heat is generated by friction between the rotating tool and the work piece material, which leads to a softened region near the FSW tool. While the tool is traversed along the joint line, it mechanically intermixes the two pieces of metal, and forges the hot and softened metal by the mechanical pressure, which is applied by the tool, much like joining clay, or dough. It is primarily used on wrought or extruded aluminium and particularly for structures which need very high weld strength. FSW is also found in modern shipbuilding, trains, and aerospace applications. Al 6061 series is a precipitation -hardened aluminum alloy, containing magnesium and silicon as its major alloying elements. It is furnished in the T6 temper. .It has the lowest strength and highest ductility. The properties near the conventional weld are those of 6061, a loss of strength of around 80%. Al 7075 series is a commercial aluminium alloys utilizes zinc as the major alloying element and when combined with a smaller amount of magnesium, the result is a heat-treatable alloy which offers very high strength. These materials can become susceptible to stress corrosion cracking after welding. CNC milling machine is used for the Friction Stir Welding (FSW). In which the aluminium plates of series 6061 and 7075 is fitted rigidly in the machine. Tapered pin tool is used for the plates to be welded. And the required inputs like Speed, Feed and tilt angle are given. The welded plates are next proceeded to the tests for evaluating the mechanical properties. The tests conducted are Bending and Impact tests test on pendulum type impact testing machine.

Keywords – Friction Stir, Weld Joints, AA7075, AA6061.

I. INTRODUCTION

An engineering stream has always been on the lookout for wonder-materials which would fit the bills for all types of service conditions. It stem from the need to make progressive discoveries made by scientists, affordable. This affordability quotient has persuaded many researchers to develop such materials which would satisfy various hither to unexplored conditions. In today's world almost all generic materials have been tried for various uses and their limitations have been met. But the never ending quest of civilization requires that materials qualify for harsher environments. This unavoidable situation demands that new materials be created from various combinations of other compatible materials. It is to be noted here that this method is not new; it has been with mankind since ages. In every part of the world, various materials have been combined to achieve some intended properties, i.e. One can create new materials with unique properties, which can be tailor-made and are different from their base ingredients. Friction Stir Welding (FSW) is a relatively new joining process, developed at The Welding Institute (TWI) in 1991 for aluminium alloys, and is presently attracting considerable interest. In this solid state welding technique a rotating tool, cylindrical in shape with a pin of smaller diameter extending from the tool shoulder, is translated along the joint line and produces, during its path, frictional heating and also plastic deformation of the material, due to a stirring effect around the pin. The material along the joint line is heated to a softened condition, transferred around the periphery of the tool, and subsequently solid state welded. Important process parameters include the tool geometry, the rpm and travel speed, as well as the downward force on the tool

1.1 FRICTION STIR WELDING

Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute), and the first patent applications were filed in the UK in December 1991**.**Friction-stir welding is a solid-state joining process (the metal is not melted during the process) and is used for applications where the original metal characteristics must remain unchanged as far as possible. This process is primarily used on aluminum, and most often on large pieces which cannot be easily heat treated post weld to recover

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temper characteristics .The progress of the tool through the joint also showing the weld zone and the region affected by the tool shoulder.

1.1.1 PRINCIPLE OF OPERATION:

The working principle of Friction Stir Welding process is shown. A welding tool comprised of a shank, shoulder, and pin is fixed in a milling machine chuck and is rotated about its longitudinal axis. The work piece, with square mating edges, is fixed to a rigid backing plate, and a clamp or anvil prevents the work piece from spreading or lifting during welding. The half-plate where the direction of rotation is the same as that of welding is called the advancing side, with the other side designated as being the retreating side. The rotating welding tool is slowly plunged into the work piece until the shoulder of the welding tool forcibly contacts the upper surface of the material. By keeping the tool rotating and moving it along the seam to be joined, the softened material is literally stirred together forming a weld without melting .The welding tool is then retracted, generally while the spindle continues to turn. After the tool is retracted, the pin of the welding tool leaves a hole in the work piece at the end of the weld. These welds require low energy input and are without the use of filler materials and distortion. As the tool (rotates and) moves along the butting surfaces, heat is being generated at the shoulder/work-piece and, to a lesser extent, at the pin/work-piece contact surfaces, as a result of the frictional-energy dissipation. The welding speed depends on several factors, such as alloy type, rotational speed, penetration depth, and joint type. Higher tool rotation rates generate higher temperature because of higher friction heating and result in more intense stirring and mixing of material. During traversing, softened material from the leading edge moves to the trailing edge due to the tool rotation and the traverse movement of the tool, and this transferred material, are consolidated in the trailing edge of the tool by the application of an axial force

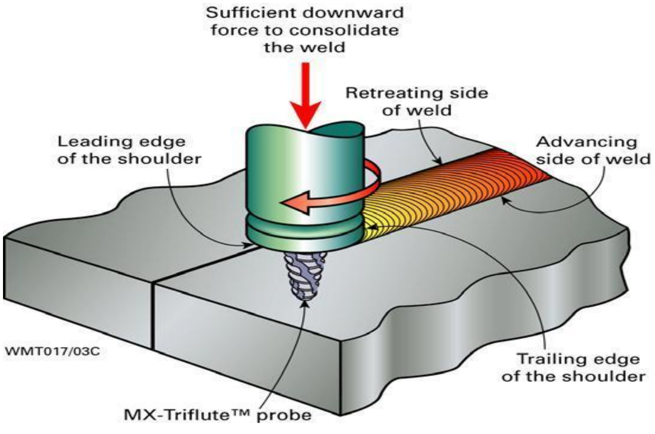

Fig-1 Schematic diagram of the FSW process

1.1.2. Welding Forces:

During welding a number of forces will act on the tool:

- A downwards force is necessary to maintain the position of the tool at or below the material surface. Some friction-stir welding machines operate under load control but in many cases the vertical position of the tool is preset and so the load will vary during welding.
- The traverse force acts parallel to the tool motion and is positive in the traverse direction. Since this force arises as a result of the resistance of the material to the motion of the tool it might be expected that this force will decrease as the temperature of the material around the tool is increased.
- The lateral force may act perpendicular to the tool traverse direction and is defined here as positive towards the advancing side of the weld.
- Torque is required to rotate the tool, the amount of which will depend on the down force and friction coefficient (sliding friction) and/or the flow strength of the material in the surrounding region (sticking friction).

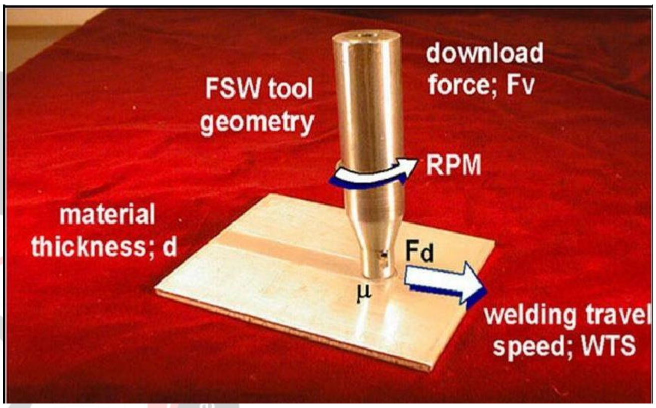

Fig-2 Welding forces

In order to prevent tool fracture and to minimize excessive wear and tear on the tool and associated machinery, the welding cycle should be modified so that the forces acting on the tool are as low as possible and abrupt changes are avoided. In order to find the best combination of welding parameters it is likely that a compromise must be reached, undesirable from the point of view of productivity and weld properties

II. LITERATURE REVIEW

Friction stir welding (FSW) is a recent technology for surface modification and developing surface and bulk reinforcement MMCs and this friction stir processing can be done to aluminium alloys of 7000 series and especially for Al7075. The processing of aluminium and its alloys has always represented a great challenge for researchers and technologists. Aluminium and its alloys mostly used in automotives and aerospace industries because of its low density and high strength to weight ratio.

R.S.Mishra et al. demonstrated that the FSW is a versatile technique with a comprehensive function for the fabrication, processing and synthesis of materials. The microstructure and mechanical properties of processed zone can be controlled by optimizing the tool design and FSW

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parameters. The depth of the processed zone can be adjusted by changing the length of the tool pin, and large volume of materials can be produced by multiple passages. The effect of particle refining, mixing and consolidation of powder mixtures provided by FSW can be investigated without the interference of reaction between reinforcement and matrix.

Adem Kurt et al.[1] It has been demonstrated that FSW was an appropriate method to modify the microstructure and mechanical properties of Al-alloy. In general, FSW decreased the grain size and increased the hardness of processed material. Increased rotation speed and low travelling speeds caused more heat input which affects the thickness of the surface layer, grain size and distribution of the precipitates and reinforcing particles. A good dispersion of SiCp can be obtained for the composite layer produced by ω= 1200rpm and v = 20 mm/min. Good interfacial conditions between particles and base metal can be formed during this solid-state process which avoids the chemical reactions on the interface. The micro-hardness of the plain surface of Aluminium increased significantly with increasing travelling speeds. With further research efforts and increased understanding, FSW could be conducted for mechanical behavior of these composites, like fatigue and creep response and new tool design for uniform distribution of reinforcement particles into the matrix materials.

III. FSW TOOLING& MECHANICAL PROPERTIES

3.1 INTRODUCTION TO FSW TOOLS:

Ever since the invention of the FSW the tools used to perform the process have advanced considerably. Early tools used simple cylindrical extrusions with a profiled end, when this is compared to modern tool such as retractable pin tools the advancement of the technology is clearly evident.

3.1.1 TOOL REQUIREMENTS:

The friction stir processing is advancement on traditional rotation friction stir welding described above in introduction. The tool must be designed to generate sufficient heat, through means of rotational surface contact, to create a plasticized region beneath the tool.

3.1.2 BASIC FORM AND CONSTRUCTION:

It was realized early on in the development of FSW that the tool's design is critical in producing strong nugget. A basic and conventional design for a FSW tool is shown in the Fig. 1.2. This tappered probe design will be compared to other more complex and still emerging tool variants. FSP tools follow the same basic trends in terms of their shapes and geometries. They are generally comprised of three generic features: 1.A shoulder section, 2.A probe (also known as a pin), 3.Any external features on the probe.

3.1.3 TOOL SHOULDER:

The shoulder is designed as a relatively large, when compared to the probe, profiled surface. Although the probe makes the initial contact with the pre-welded material the shoulder has a large contact area and produces more friction.

3.1.4 SHOULDER DIAMETER:

The diameter of the shoulder will determine the amount of contact area applied to the weld material's surface. A shoulder diameter which is too small could result in insufficient heat being applied to the process through an inadequate contact area between tool and material to be processed and therefore a failed weld or broken tooling. To generate sufficient heat during the process the shoulder diameter should be a minimum of 50% larger than the root diameter of the probe with contact areas up to three times larger deemed to be satisfactory. The diameter of the tooling determines the width of the plasticized region beneath the shoulder and the width of the thermo-mechanical affected zone (TMAZ).

3.1.5 FRICTIONAL HEATING AND DEFORMATION:

The shoulder of the tool generates the majority of the heat required for the process due to its longer contact area the rotating surface of the tool contacts the top surface of the material causing friction. The softened material beneath the tool is said to be plasticized. The material doesn't melt, but is heated to become softer and more malleable. The plasticized region extends down through the weld directly beneath the shoulder has it is translated through the material. The plasticized region of material undergoes heating from the friction and also deformation from the rotation of the tool. As the tool shoulder heats the material it is deformed and stirred by the tool's rotation. As the tool's are traversed through the weld material it compress the joint, stopping any plasticized material from being expelled from the top of the weld.

3.2 TOOL PROFILE:

The probe makes the initial contact with the material before plunged through the material, for a typical Butt weld the probe stops when the tool shoulder contacts material in the region of 0.1 mm below that of surface of the material. The probe rotates with the shoulder as it is pulled through the weld material. There are some types of profile they are

- **a.** Cylindrical pin.
- **b.** Taper cylindrical pin
- **c.** Triangular pin
- **d.** Square pin
- **e.** Pentagonal Pin
- **f.** Hexagonal pin

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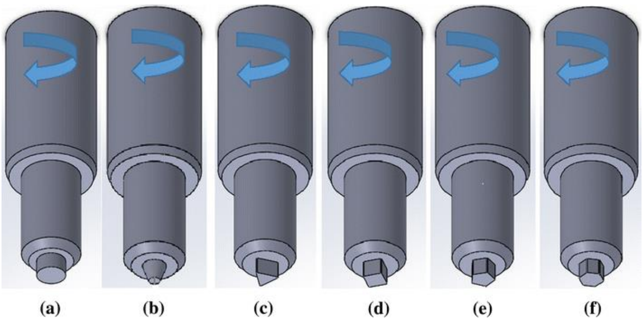

Fig-6 Types of Tool Profiles

3.2.1 PROBE LENGTH:

The probe length must be designed for the desired weld depth. The probe must not contact the backing plate as it would cause potential failure in the weld such as root plaws caused by impurities included in the weld from the backing plate, damage to the tool as a result of it being plunged into the backing plate or an unsatisfactory weld root. This means that roughly speaking the tool's probe should be design to be in the region of 0.2mm less than the thickness of the material to be welded.

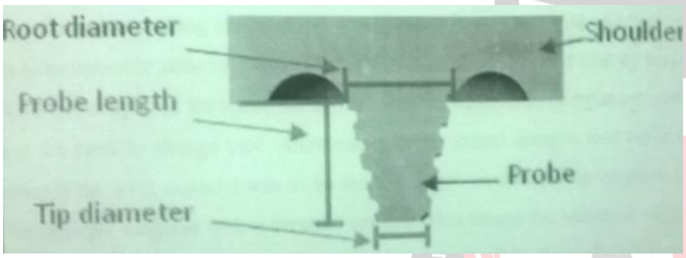

Fig-7 Showing Probe Dim

IV. EXPERIMENTATION

4.1 SELECTION OF TOOL MATERIALS:-

- **<u>Aluminium 6061- T6 plate 6.35mm X 100mm X 100mm :</u>**

Al 6061 is a precipitation -hardened aluminum alloy, containing magnesium and silicon as its major alloying elements. It is furnished in the T6 temper. .It has the lowest strength and highest ductility. The properties near the conventional weld are those of 6061, a loss of strength of around 80%. In order to weld aluminum one needs to remove the oxide layer. The easiest method is stir weld the component. The problem with the electrodes are eliminated.

4.1.1 CHEMICAL COMPOSITION:

Table-5 Chemical Compositions Of 6061 T6

Magnesium	Silicon	Copper	Zinc	Manganese	Titanium	Chromium	Iron
0.8-1.2	0.4-0.8	0.15-0.4	0.25	0.15	0.15	0.04-0.35	0.7

- **<u>Aluminium 7075-T6 plate 6.35mm X 100mm X 100mm :</u>**

7075 series commercial aluminium alloys utilizes zinc as the major alloying element and when combined with a smaller amount of magnesium, the result is a heat-treatable alloy which offers very high strength. These materials can become susceptible to stress corrosion cracking after welding. This phenomenon is particularly dangerous because it is not detectable immediately after welding, and usually develops at a later date when the component is in service. The completed weld joint can appear to be of excellent quality immediately after welding 7075.

4.1.2 CHEMICAL COMPOSITION:

Table-6 Chemical Compositions Of 7075 T6

Zinc	Magnesium	Copper	Chromium	Silicon	Titanium
5.6 - 6.1	2.1-2.5	1.2-1.6	0.23	0.40	0.20

4.2 EXPERIMENTAL SETUP:

A retrofitted milling machine was used for friction stir welding (FSW) of aluminium alloy. The machine was a maximum speed of 1800rpm and 5.5 kW/rpm. The materials used in this work are commercial Al 7075 alloy and Al 6061 (tempered condition) rolled plates with nominal composition as shown in table. The surface plates were grinded at the place welding to be performed before processing. Work pieces were prepared with respective length, width, thickness. The alloy plates are fitted in the machine rigidly. A hardened HSS tool was used that consists of a shoulder with diameter of 16mm, pin with a tapper diameter of (2 x 3)mm and length 2mm respectively. This tool is fitted into the tool holder and work piece is rigidly clamped to machine table using fixtures.

Fig 10 CNC MILLING MACHINE

At first the tool is fixed in arbor and after setting the process parameters the rotating tool pin is made to plunge into the work piece dwell time is maintained for some

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time to develop heat. Then the tool is traversed along the groove. If the tool moves from one end to other end then it is one pass. The tool get stop at the 5mm before of the end of the specimen. The same process is repeated for the remaining experiments. The FSW was conducted with different speeds, Feed and tilt angle.

4.2.1 SPECIFICATIONS:

Table-7 Specifications

DESCRIPTION	DEMENSIONS
Machine type	Semi automatic(FN2 V)
Overall Dimensions (LxW)	1520 x 310 mm
Clamping Length (LxW)	1350 x 310 mm
Power operated table tranverse	800 mm
Power operated table longitudinal	400 mm
Power operated table cross vertical	265 mm
Number of speeds	18
Speed range	35.5 - 1800
Main motor	5.5/1500 kW/rpm
Feed motor	1.5/1500 kW/rpm
Space required (LxBxH)	255 x196 x197 mm

4.2.2 OBSERVATIONS:

Table-8 Observations

S.NO.	INPUT PARAMETERS			OUPUT PARAMETERS	
	SPEED (rpm)	FEED (mm/min)	TILT ANGLE	BENDING TEST (KN)	IMPACT TEST (J/M)
1	560	20	1^0	3.2	14.00
2	560	30	2^0	2.84	8.00
3	560	40	3^0	2.72	10.00
4	1120	20	2^0	2.88	2.00
5	1120	30	3^0	2.72	4.00
6	1120	40	1^0	2.84	6.00
7	1680	20	3^0	3.04	4.00
8	1680	30	1^0	2.8	10.00
9	1680	40	2^0	2.76	10.00

V. MECHANICAL TESTINGS

5.3.1 BENDING TEST EQUIPMENT:

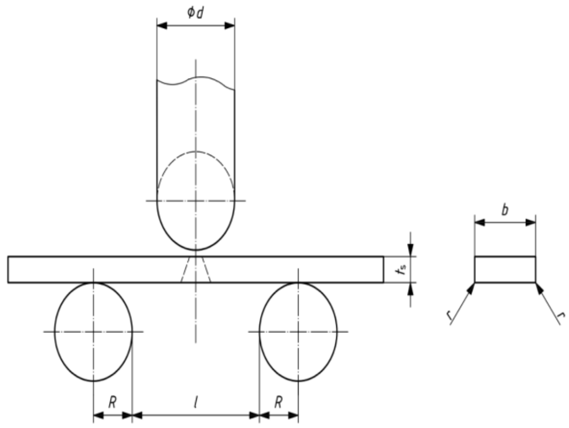

Fig- 11 Principle of bending Equipment

5.3.2 STAGES OF TEST:

5.3.2.1 Centering the weld:

It is essential that the weld is placed in the centre of the bend zone. Unless the position of the weld is clearly marked or displayed, the position of the weld can be determined by lightly macro etching the surface of the test piece.

Fig-12 Bending test machine

5.3.2.1 Testing with a former:

The test shall be carried out by placing the test piece on two supports consisting of parallel rollers or U-type jig, with the weld at the midpoint between the rollers. The piece is bent by loading gradually and continuously in the middle of the span, on the centre of the weld, with a former (three-point bending) perpendicular to the test surface. The bending continues until a bend angle of 180° is achieved. The test is carried out by placing the test piece on parallel support rolls with the weld centered between the rollers. The diameter of the former shall be 4´ the thickness of the test piece. For materials with a metal elongation of less than 20%, the diameter of the former is calculated as:

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$$diameter = \frac{100 \times test\ piece\ thickness\ (mm)}{minimum\ elongation\ (\%)} - test\ piece\ thickness$$

Fig-13 Specimens after Testing (bending)

5.3.3 OBSERVATIONS FOR BENDING TEST:

Table-7 Observations for Bending Test

S. NO	Specimen Type	Specimen Width (mm)	Specimen Thickness (mm)	c/s Area (mm²)	Original Gauge length	Final Gauge Length	RESULTS (Ultimate Load) KN
1	FLAT	35	6.1	213.5	0	0	3.2
2	FLAT	35.07	6.15	215.681	0	0	2.84
3	FLAT	35.2	6.11	215.072	0	0	2.720
4	FLAT	35.16	6	210.96	0	0	2.88
5	FLAT	35.04	6.04	211.642	0	0	2.72
6	FLAT	35.1	6	210.6	0	0	2.84
7	FLAT	33.97	6	203.82	0	0	3.040
8	FLAT	35.2	6.15	216.48	0	0	2.8
9	FLAT	35.15	6.04	212.306	0	0	2.76

5.4 IMPACT TESTING (CHARPY):

CALCULATIONS:

Impact energy(j/m) = energy required in breaking the sample(j)/Thickness(m)

Fig-15 Specimens after Testing (Impact)

5.5.OBSERVATIONS OF IMPACT TEST:

A higher toughness material will absorb more energy upon impact and will therefore result in a low height to which the pendulum arm will swing to following impact.

Table-9 Observations Of Impact Test

S.No	Location of Sample	Impact -1	Impact -2	Impact -3	Average
1	SL NO: A	14	0	0	14.00
2	SL NO: B	8	0	0	8.00
3	SL NO: C	10	0	0	10.00
4	SL NO: D	2	0	0	2.00
5	SL NO: E	4	0	0	4.00
6	SL NO: F	6	0	0	6.00
7	SL NO: G	4	0	0	4.00
8	SL NO: H	10	0	0	10.00
9	SL NO: I	10	0	0	10.00

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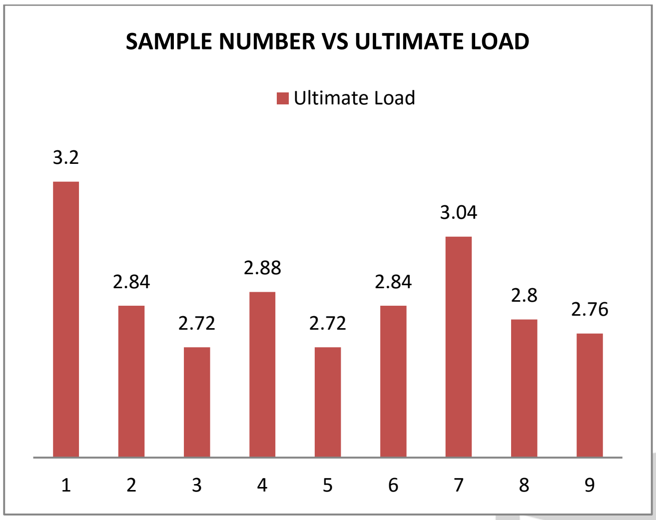
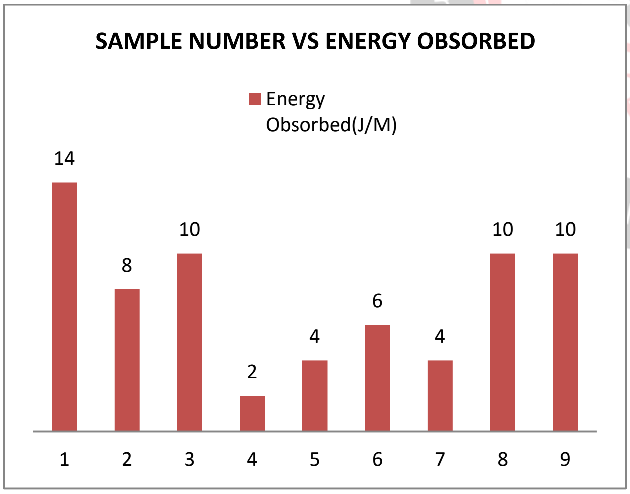
VI. RESULTS AND DISCUSSIONS

6.1 BENDING TEST REULTS:



From the above graph, it is observed that, Sample number-1 with a width of 35mm and cross section area of 213.5 sq.mm has an highest ultimate load of 3.2 kN and the input parameters taken for the sample-1 are speed-560rpm, Feed-20mm/min, Tilt angle-2^o.

IMPACT TEST RESULTS:



From the above graph, it is observed that, Sample number-1 with size 10x5x55mm and a notch depth of 2mm and notch angle of 45 has an impact energy of 14 j/m and the input parameters taken for the sample-1 are speed-560rpm, Feed-20mm/min, Tilt angle-2^o.

VII. SCOPE OF FUTURE WORK

It would be useful to extend the present work on FSW in the following areas:

- The effect of post heat treatment of FSW joints with different ageing treatments to improve the tensile strength can be studied.
- More experiments with different tool materials and geometries should be attempted in order to improve the tensile strength and make the process acceptable to the welding industries.
- Study of heat transfer analysis can be extended to butt friction stir welded joints.

By using different Tools we can achieve more good results

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