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Experimental investigation and Simulation of Friction Stir Welding Process Parameters of Al 5086-HE15, Al 6061-HE20 Joints

Md.Shaker Pasha
M.Tech- Advance Manufacturing Systems,
Department Mechanical Engineering,
Hyderabad Institute of Technology and Management, Telangana, India.

Guntuku Venkatesh
Assistant Professor,
Department Mechanical Engineering,
Hyderabad Institute of Technology and Management, Telangana, India.

V.Venkata Phanibabu
Assistant Professor & HOD,
Department Mechanical Engineering,
Hyderabad Institute of Technology and Management, Telangana, India.

Abstract:
Modern structural concept demand reduction in the weight, cost of production and as well as the fabrication of materials .Therefore welding processed have proven more attractive and program have been set to study their potential. Friction stir welding (FSW) is process is currently considered to be prospective welding process. FWS process received great attention in industry for aluminum alloys; this process is also applicable for other alloys like magnesium, steel etc. Therefore mechanical properties should be controlled to obtain good welded joints. The basic principle of FSW is remarkably simple. A rotating tool with pin and shoulder is inserted in the material to be joined and transverse along the line of joint.

The heating is localized and generated by friction between the tool and the work piece, with the additional adiabatic heating from metal deformation. The pin and shoulder of the tool can be modified in a number of ways to influence material flow and micro structural formation. In this paper dissimilar aluminum alloys will be used for FSW process and the quality of the joint will be tested for mechanical and physical properties. To perform the FSW process four different tool profiles are designed and optimized. FSW process will be performed at different levels of process parameters to develop best set of welding parameters for selected material combination.

I. INTRODUCTION:
Welding, as a technological process, is widely practiced in modern engineering. Welding and joining technology is fundamental to Engineering and Manufacturing. Without the ability to make strong and durable connections between materials it would not be possible to produce the many different items upon which we all rely in our everyday lives, from the very large to the very small. Friction-stir welding (FSW) is a solid-state joining process that uses a third body tool to join two faying surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool.

It then mechanically intermixes the two pieces of metal at the place of the join, then the softened metal (due to the elevated temperature) can be joined using mechanical pressure, much like joining clay, or dough. It is primarily used on aluminum, and most often on extruded aluminum, and on structures which need superior weld strength without a post weld heat treatment. FSW has a wide application potential in ship building, aerospace, automobile and other manufacturing industries. The process proves predominance for welding non-heat treatable and powder metallurgy of aluminum alloys, to which the fusion welding cannot be applied. Thus fundamental studies both on the weld mechanism and on the relation between micro structure with mechanical properties and process parameters have recently been started.

A great advantage is in particular the possibility of joining dissimilar materials, which are not, (or) only with great difficulties wieldable by classical fusion welding technique. Friction stir welding is a relatively simple process as shown in figure 1.

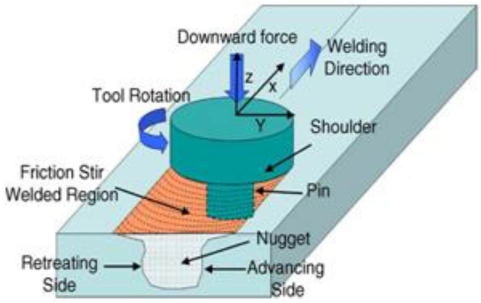

Fig 1: Schematic diagram of FSW process

A typical cross section of the FSW joint consists of a number of zones. This is similar to that in conventional welds although the maximum peak temperature is significantly less than the solidus temperature and pre heat-source is rather diffuse. This can lead to somewhat different micro structures when compared with fusion welding process. The central nugget region containing the "onion ring" appearance is the one which experience the most severe deformation and is a consequence of the way in which a tool deposits material from the front to the back of the weld. The Thermo Mechanical Affected Zone (TMAZ) lies between the Heat Affected Zone (HAZ) and the nugget, the grains of the original micro structures are retained in this region, but after in a deformed state.

II. SELECTION OF BASE MATERIAL AND TOOL SHAPE:

The most common materials used in recent time's are- Steels, Aluminum, Titanium and its alloys and Composite materials. Before starting work on friction welding, it was necessary to do some background work on these possible candidate materials. It was also necessary to choose the dissimilar metal combinations to do the friction welding. Hence, a comprehensive work on identification of possible materials which can be used for friction stir welding was done.

Literature on some of the Materials and their applications is given below.

The candidate materials were chosen keeping in mind 3 factors-

- Literature Survey which has been described in the previous chapter
- These materials are not easily weld able by fusion welding techniques and hence scope for friction stir welding exist
- Applicability of these materials in practical applications

Aluminum as FSW Material:

Aluminum is found primarily in bauxite ore .Pure aluminum is soft, silvery, ductile of the poor metal group of Chemical elements, which are corrosion resistant, light weight and high electrical conductivity. It has the symbol Al and atomic number 13. The metal is used in many industries to manufacture a large variety of products and is very important to the world Economy. Structural components made from aluminum and its alloys are vital to the aerospace industry and very important in other areas of transportation and building. It is widely used for foil and conductor cables, but alloying with other elements is necessary to provide the higher strengths needed for other applications.

Aluminum when compared with Steel:

- Aluminum is three times lighter than steel and yet can offer high strength when alloyed with the right elements.
- Aluminum can conduct electricity six times better than steel and nearly 30 times better than stainless steel.
- Aluminum provides excellent corrosion resistance.
- Aluminum is easy to cut and form.
- Aluminum is nontoxic for food applications.
- Aluminum is non-magnetic therefore arc blow is not a problem during welding

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Factors influencing Aluminum Welding:

The reason why aluminum is specified for so many jobs is aluminum alloys can provide unique physical properties.

Weight: Aluminum is three times lighter than steel and yet aluminum can provide higher strength when alloyed with specific elements.

Conductivity: Aluminum can conduct electricity six times better than steel. With alum being more sluggish and less fluid, aluminum can be welded in all positions with spray and pulsed with relative ease. In contrast to Steel the high conductivity of aluminum acts as a heat sink making weld fusion and weld penetration more difficult to achieve.

Non Magnetic: Since it's non-magnetic, arc blow is not a problem during aluminum welding.

Thermal Conductivity: With a thermal conductivity rate that is five times higher than steel and the aluminum has poor fusion properties.

Summary of Materials Selection:

After the preliminary work on these materials was done, feasibility studies for friction welding of the above mentioned materials were undertaken. The following factors were considered before final selection of material

- Earlier research done on the material and literature available
- Cost of the material
- Availability of the material in the local market
- Potential Industrial uses

Considering the above mentioned factors and preliminary results of friction stir welding experiments, the following combination of materials were selected for further work.

- Aluminum 5086
- Aluminum 6061

III. Selection of Probe Shape and Tool Material:

The probe shape plays an important role in friction stir welding process as its provides a proper mixing of the material in the nugget zone. Experiments were carried on using high chromium steel (10% chromium) as tool material and two different probe profiles were developed, one with conical tip and another taper trapezoidal tip profiles. Its is observed that a proper diffusion of material in the weld zone has taken place when using a non cylindrical profiles. This may be due to increase in surface area in contact between the tool and the work-piece and mechanical mixing of the work material. The proper diffusion of the material resulted in better mechanical properties. It is also observed that the surface finish obtained also depends on the probe shape and the shoulder area. Fine surface is obtained when the shoulder is in contact with the work-piece. The tool probe specifications are selected in accordance with that of work-piece. The length of tool probe is generally taken little less than that of work-piece thickness. As a large amount of heat is generated between tool and work-piece it should be properly dissipated to surroundings to prevent any damage to tool and also to prevent melting of work-piece. To achieve this dissipation of heat there should be a proper design of tool and shoulder .The shoulder length and its diameter are so designed so as to provide a convenient rate of heat transfer between work-piece and tool as well as tool and the surrounding.

The specifications of tool

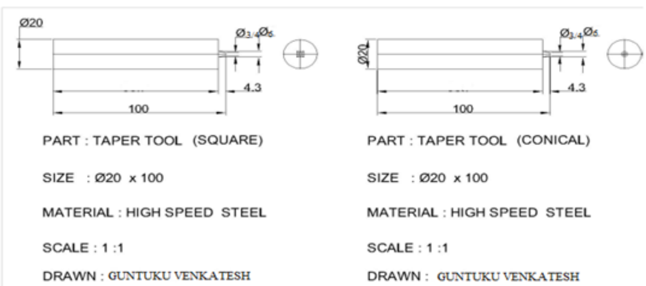

Fig 2: showing the taper tool (square &conical)

Tool Dimensions:

Tool total length: 100mm

Length of shoulder: 20mm

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Probe diameter: 6mm
Length of probe: 5.5 and Pin diameter: ¾ mm

IV. EXPERIMENTAL PROCEDURE:

Before starting the friction stir welding, the sample that needs to be friction stir welded was firmly clamped to the backing plate using holding clamps which were bolted to the work table of the machine as shown in the fig 3. Then, a small hole with the same diameter as the pin was drilled at the beginning of the sheet to initiate the penetration of the tool. This drilled hole avoids too much load on the tool for penetration. Then the rotating pin of the FSW tool was forced into the work piece for sufficient time in order to mechanically mix the material around the pin. After adequate mechanical mixing, the tool was moved along the desired direction with a specific translation speed for a single pass. Frictional heating was produced from the rubbing of the rotating shoulder with the work piece, while the rotating pin deformed and stirred the locally heated material and created severe plastic deformation within the sheet. FSW zone is thus formed by dynamic recrystallization with in grain refinement making a new weld joint with continuous homogenized medium between the plates.

Fig 3: Friction stir welding experimental set-up

AA 6061 & AA 5086 aluminum alloys plates in the solution conditions were chosen for the present project work. Specifically designed tool is used in this friction stir welding process. The material of the tool is a non-consumable high speed steel (HSS) with high chromium (about 10%). The tool has conical shaped probe without threads. The FSW tool was subjected to heat treatment to improve its hardness. The hardness of tool after heat treatment is 54 HRC. The FSW is carried out on a CNC milling machine.

Table 1: Showing the Design of Experiments (Selection of Process Parameters)

Tool Description

TOOL 1 TAPRE (3/6) - Probe diameter: 6mm and Pin diameter:3mm
TOOL 2 TAPRE (4/6) - Probe diameter: 6mm and Pin diameter: 4mm
TOOL 3 CONICAL (3/6) - Probe diameter: 6mm and Pin diameter: 3mm
TOOL 4 CONICAL (4/6) - Probe diameter: 6mm and Pin diameter: 4mm

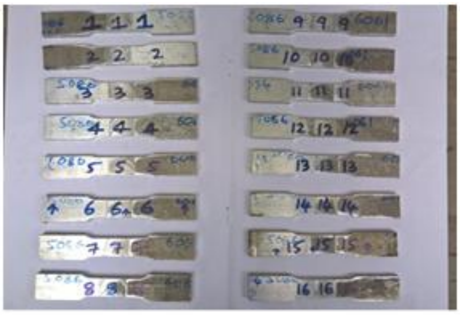

Fig 4: Showing the Al Weld joints after FSW

V. MECHANICAL TESTING

Tensile test:

The samples were designed and manufactured to confirm to ASTM standards. All samples were produced with minimal defects and conformed to specified dimensions with a tolerance of 0.01.

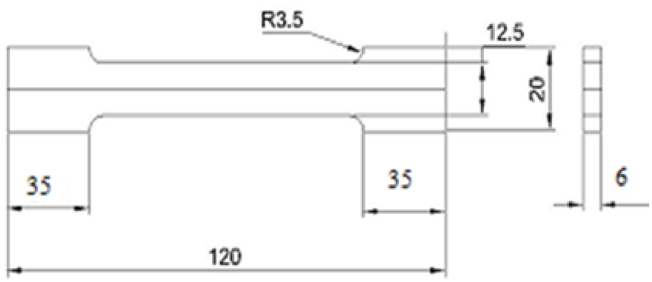

Fig 5: Showing the Dimensions of tensile test specimen as per ASME standard.

The test process involves placing the test specimen in the testing machine and applying tension to it until it fractures.

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During the application of tension, the elongation of the gauge section is recorded against the applied force. The elongation measurement is used to calculate the engineering strain, ε, using the following equation:

$$\varepsilon = \Delta L/L_0 = L - L_0 / L_0$$

Where ΔL is the change in gauge length, L0 is the initial gauge length by L is the final length. The force measurement is used to calculate the engineering stress, σ, using the following equation:

$$\sigma = F_n/A$$

Where Fn is the force by A is the cross-section of the gauge section. The machine does these calculations as the force increases, so that the data points can be graphed into a stress-strain curve.

Fig 6:specimen failed under tension at peak load point

Fig 7: specimens after braking under UTM tension test

Tensile bars were tested on INSTRON mechanical screw machine. All samples were checked visually during testing to ensure that no abnormal failures or sample slippage occurred. A set of properties including ultimate tensile stress (UTS) and elongation of fracture were recorded by the central computer for each test. These values were used to produce stress strain curves. On graph some values were recorded by the computer involved, Slippage and measurement errors in the initial stage of tensile testing.

Hardness test:

The Rockwell hardness test method has been used to find out the hardness of the weld joints thus obtained in FSW of Al joints. It consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load F0 usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration.

TYPE OF TOOL	JOB	Test conducted			
		Speed rpm	Feed mm/sec	hardness test at 150 kg load	tensile test KN
TOOL 1 SQUARE(3/6)	1	2300	40	69	9.9
	2	2600	40	67	9.3
	3	2300	60	60	6.8
	4	2600	60	62	6.1
TOOL 2 SQUARE(4/6)	5	2300	40	81	7
	6	2600	40	65	6
	7	2300	60	79	5.4
	8	2600	60	71	8.7
TOOL 3 CIRCLE(3/6)	9	2300	40	60	7.8
	10	2600	40	75	7.2
	11	2300	60	62	6
	12	2600	60	62	5.4
TOOL 4 CIRCLE (4/6)	13	2300	40	65	6.8
	14	2600	40	64	7.8
	15	2300	60	57	7.6
	16	2600	60	66	3.9

Table 2: Results of Hardness Test and Tensile Test

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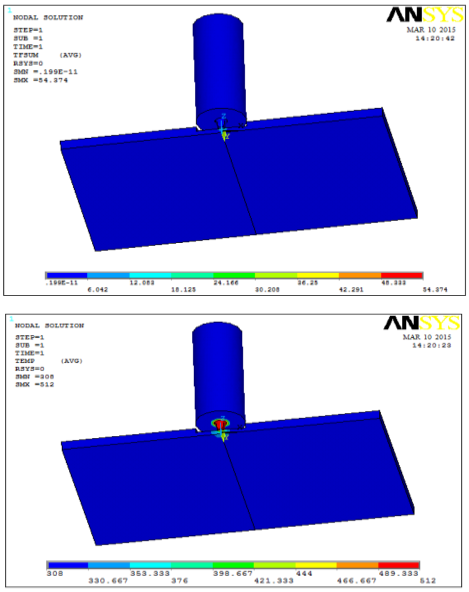
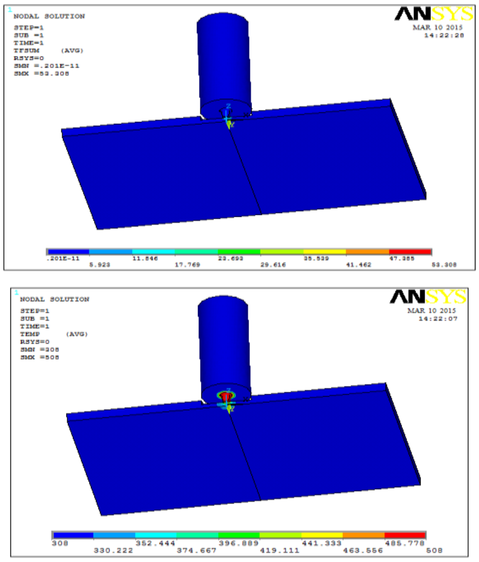
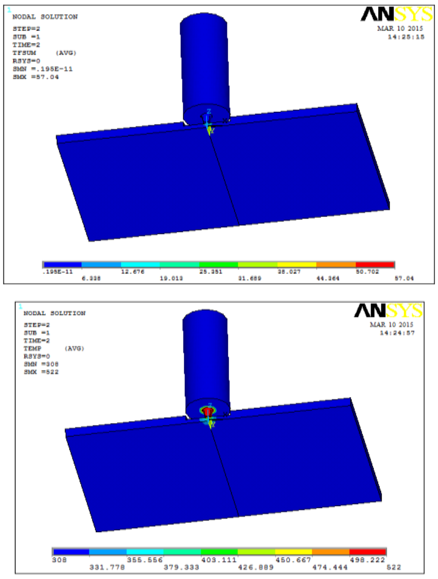
VI. ANALYSIS



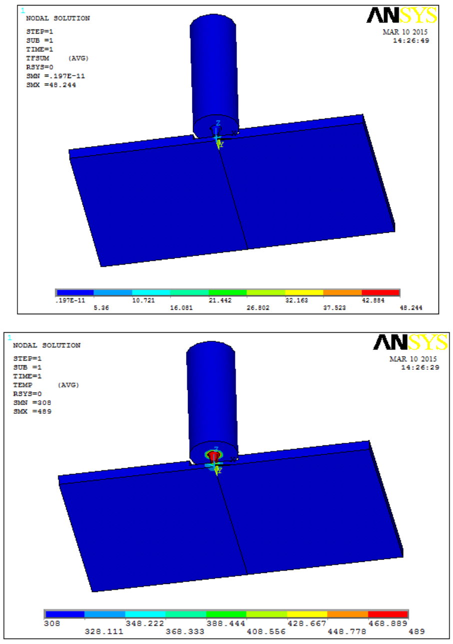
Loads applied for thermal analysis Temperature of the weldment
Fig 8: Tool-Square (3/6), Speed-2300, Feed-40



Loads applied for thermal analysis Temperature of the weldment
Fig 9: Square (3/6), Speed-2600, Feed-40



Loads applied for thermal analysis Temperature of the weldment
Fig 10: Square (3/6), Speed-2300, Feed-60



Loads applied for thermal analysis
Temperature of the weldment
Fig 11: Square (3/6), Speed-2600, Feed-60

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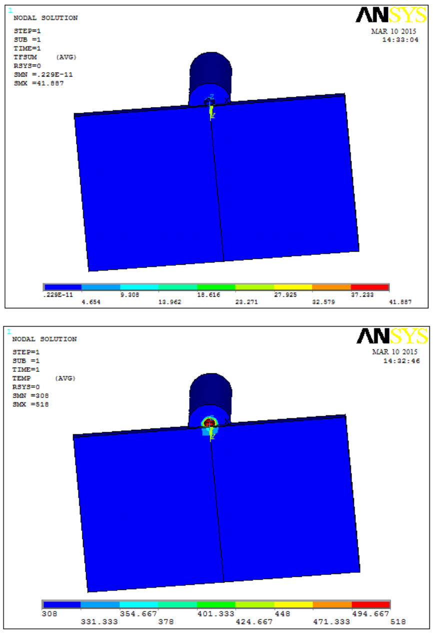
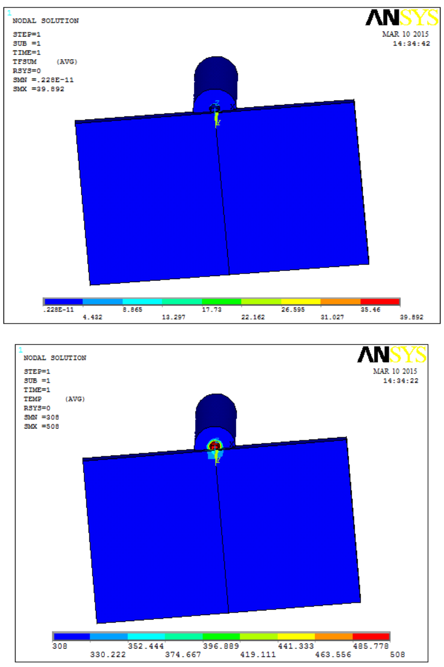


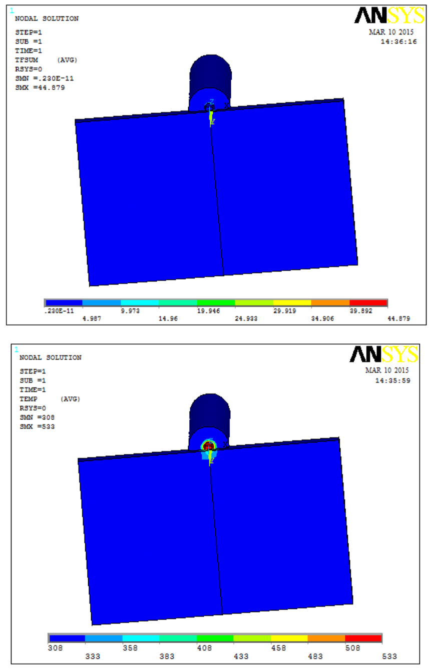
Loads applied for thermal analysis Temperature of the weldment

Fig 12: Square (4/6), Speed-2300, Feed-40



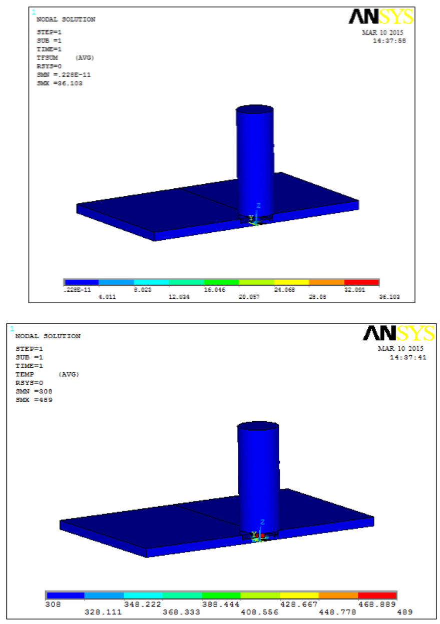
Loads applied for thermal analysisTemperature of the weldment

Fig 13: Square (4/6), Speed-2600, Feed-40



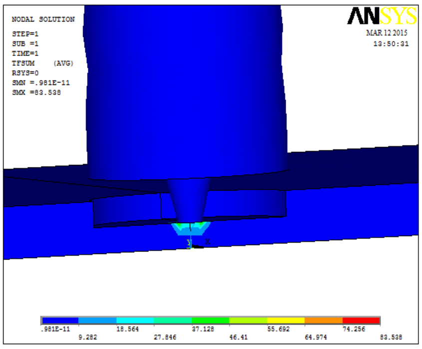
Loads applied for thermal analysis Temperature of the weldment

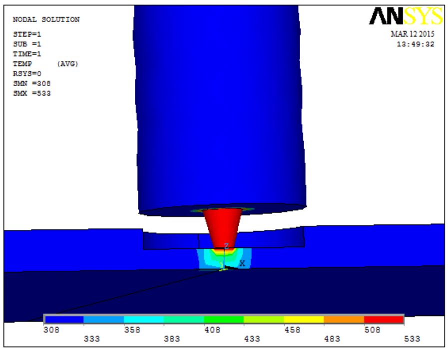
Fig 14: Square (4/6), Speed-2300, Feed-60



Loads applied for thermal analysis Temperature of the weldment

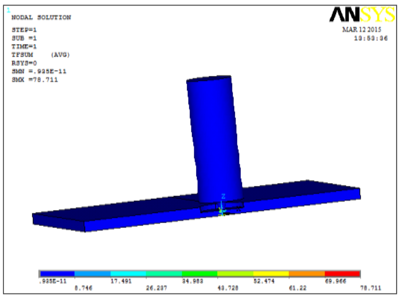
Fig 15:Square (4/6), Speed-2600, Feed-60

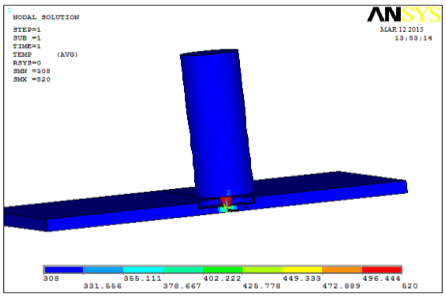




Loads applied for thermal analysis Temperature of the weldment

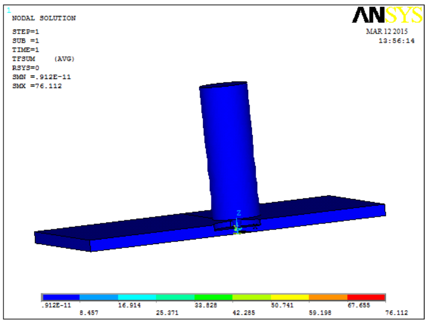
Fig 16: Circle (3/6), Speed-2300, Feed-40

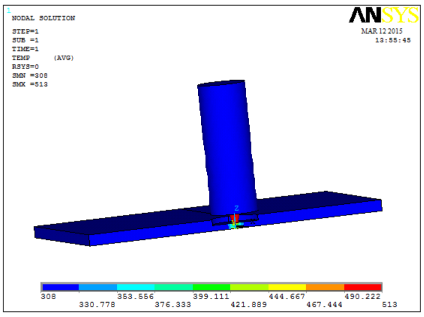




Loads applied for thermal analysis Temperature of the weldment

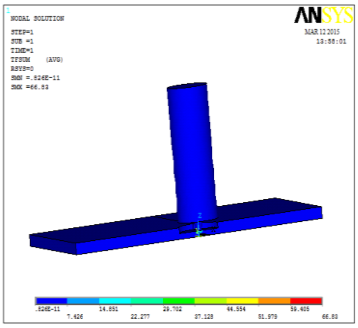
Fig 17: Circle (3/6), Speed-2600, Feed-40

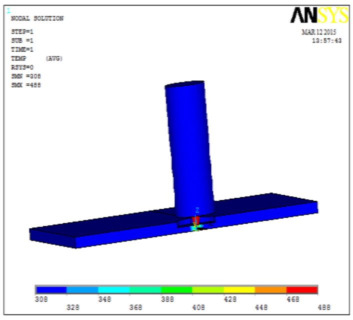




Loads applied for thermal analysis Temperature of the weldment

Fig 18: Circle (3/6), Speed-2300, Feed-60





Loads applied for thermal analysisTemperature of the weldment

Fig 19: Circle (3/6), Speed-2600, Feed-60

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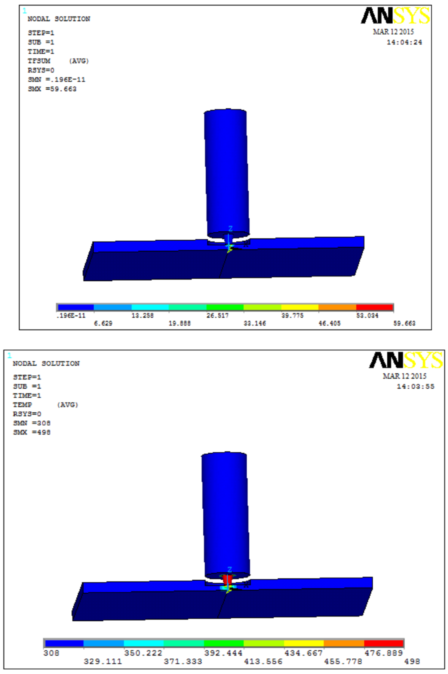
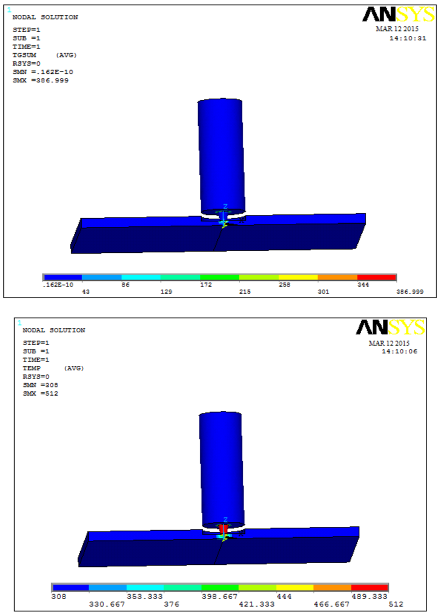


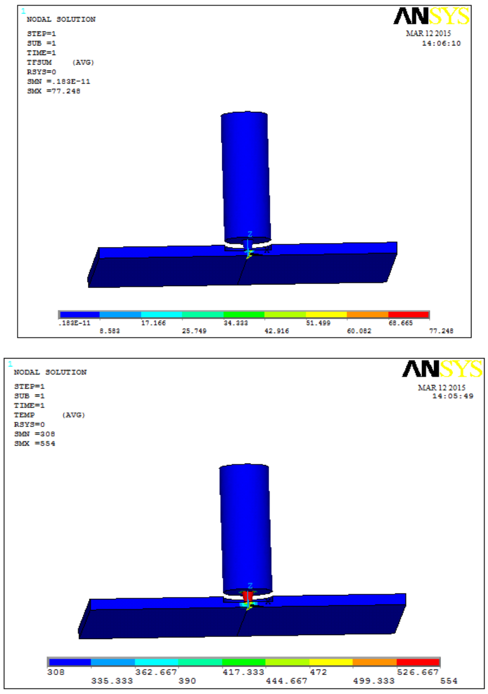
Loads applied for thermal analysis Temperature of the weldment

Fig 20: Circle (4/6), Speed-2300, Feed-40



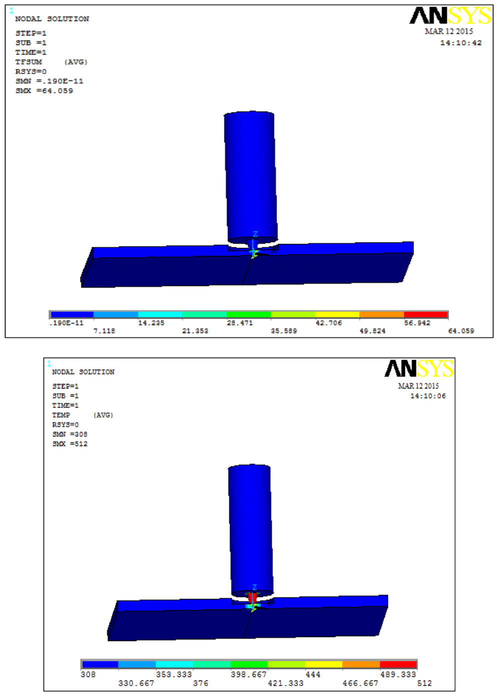
Loads applied for thermal analysis Temperature of the weldment

Fig 21: Circle (4/6), Speed-2600, Feed-40



Loads applied for thermal analysis Temperature of the weldment

Fig 22: Circle (4/6), Speed-2300, Feed-60



Loads applied for thermal analysis Temperature of the weldment

Fig 23: Circle (4/6), Speed-2600, Feed-60

Summary of Analysis:

- In friction stir welding process heat is generated. Here we have defined weather the generated heat is going to affect the tool and working plates.
- No other external load is applied in this process; only the friction load is applied.
- Plates should have minimum allowance to escape the heat generated.
- Heat generated in FSW will not be beyond the melting point of the aluminium plates.
- Aluminium plates should be re-crystallized in solid form.
- Mechanical mixing should be done with not effecting melting point temperature of aluminium plates.
- Tool sholder should meet the surface of the plates to generate the friction .
- The height of tool pin should be less compared to the thickness of the plates.
- Tool shoulder and pin is depends on the aluminium plates.
- Four different types of the tools are taken to differentiate them.
- Two speed and feed, is taken to check the performance of the tool.
- Tool life is matters so check the safe condition of the tool at higher speed and higher feed conditions.
- Higher speed and higher feed are used to find the geometric conditions of tool

TYPE OF TOOL	JOB	Temperature in centigrade						
		Speed Rpm	Feed mm/sec	surface	joint	inner	point of contact	pin
TOOL 1 SQUARE(3/6)	1	2300	40	353	376	398	444	489
	2	2600	40	352	374	396	441	485
	3	2300	60	355	379	403	450	498
	4	2600	60	348	368	388	428	468
TOOL 2 SQUARE(4/6)	5	2300	40	354	378	401	448	494
	6	2600	40	352	374	396	441	485
	7	2300	60	358	383	408	458	508
	8	2600	60	348	368	388	428	468
TOOL 3 CIRCLAR(3/6)	9	2300	40	358	383	408	433	508
	10	2600	40	355	378	402	449	496
	11	2300	60	353	376	399	444	490
	12	2600	60	348	368	388	428	468
TOOL 4 CIRCLAR(4/6)	13	2300	40	350	371	392	434	476
	14	2600	40	353	376	398	444	489
	15	2300	60	362	390	417	472	526
	16	2600	60	353	376	398	444	489

Table 3: Temperature reading by using ANSYS software

TYPE OF TOOL	JOB	temperature in centigrade			
		Speed rpm	Feed mm/sec	experimental	ANSYS
TOOL 1 SQUARE(3/6)	1	2300	40	349	353
	2	2600	40	347	352
	3	2300	60	349	355
	4	2600	60	347	348
TOOL 2 SQUARE(4/6)	5	2300	40	353	354
	6	2600	40	351	352
	7	2300	60	355	358
	8	2600	60	347	348
TOOL 3 CIRCLAR(3/6)	9	2300	40	350	358
	10	2600	40	352	355
	11	2300	60	350	353
	12	2600	60	345	348
TOOL 4 CIRCLAR(4/6)	13	2300	40	348	350
	14	2600	40	349	353
	15	2300	60	361	362
	16	2600	60	348	353

Table 3: Temperature comparisons of experimental and ANSYS software

VII. CONCLUSION:

In this paper analysis on square, circular tools has been conducted. In this research, the friction welding process was improved by reversing the progression of welding by designing a new joint geometry. In new joint geometry welding is initiated from the inner region and it progresses to outer region. The shape of new joint geometry helps in uniform heat generation at the weld interface and it facilitates in destruction and removal of oxides and other contaminations from the inner region of weld interface. The uniform temperature, removal of oxide layer, and progression of welding from inner to outer region, helped in preventing the formation of unbound zone at the inner region of the weld interface which results in better weld strength. In the first stage literature survey on welding and welding parameters and types of tools are done. In the next stage experiment depending on speed, feed has been done. No other external load is applied in this process; only the friction load is applied. Aluminum plates should be re-crystallized in solid form. No deformation of tool has taken place, so tool geometry is safe at higher speed and feed.

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Thermal analysis is conducted on assembly of tools and work piece with different tool profiles in ANSYS. As per the analytical results this project work concludes that tapered square tool is more effective for friction stir welding 9.9 KN. Tapered square tool is more effective while comparing temperature, thermal gradient, flux, displacement.

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