Synopsis

An experimental investigation of friction stir welding on AA7108 T79 using counter-rotating twin tool

A synopsis

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By

Maulikkumar Babulal Patel

Enrollment No.159997119020

Guided by

Dr. Komal G. Dave

Professor in L.D. Engineering College

Ahmedabad

GUJARAT TECHNOLOGICAL UNIVERSITY AHMEDABAD

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Thesis Title:

An experimental investigation of friction stir welding on AA7108 T79 using counter-rotating twin tool

Abstract:

In the current research, friction stir welding has been performed on AA 7108 T79 plates and strength has been achieved with the help of a single pass using a counter-rotating twin tool (CRTT). A systematic mathematic approach has been used for the design of a counter-rotating twin tool. The final dimensions of CRTT have been analyzed using three types of materials on ansys design developer 16.0® to find out the best material for the development of CRTT. The en8 material has been finalized as its results for deformation, equivalent strain, equivalent stress, and strain energy are better compared to other tool steel materials such as scm415 and s45c.

In this investigation, two different types of tool pin geometry such as hexagonal and straight cylindrical have been selected based on the output parameters (tensile strength and hardness). The process parameters such as tool feed and tool rotational speed have been taken with its range to performed experimental work. Numbers of pilot runs have been performed with various fixture facilities before applying the design of experimentation. Full factorial design of experiment used for welding. The joints have been found complete without any un-welded zone resulting from smooth material flow. The mechanical properties-tensile strength and hardness, microstructure, results of radiography, and ultrasonic tests have been considered as performance evaluation criteria. Radiography and ultrasonic testing gave the perfect joint of weld without any defect. Multi-objective genetic algorithm used for the optimization in Matlab 2012a. This optimization gives the value of the tensile strength and hardness for two tools. Regression equations put in the ga-multi inbuilt function. This function has been run then gets optimized value. In this work hexagonal tool has been given the maximum tensile strength.

For validation of the work, again experimentation has been performed with use of optimization results, and found less than 5% error. As per the literature, less than 5% error valided for the experimental work.

Introduction:

Friction stir welding is one type of solid-state welding technology. In solid-state welding technology, the joining of surfaces occurs at a thermoplastic state (heat generated) developed by some external tool. Friction stir welding is mostly used in aerospace, shipbuilding construction, automobile industries, and higher strength to lightweight ratio required, such as aluminium, steel, and structure fabrication.

Friction stir welding is a solid-state welding process invented around the world in 1990s the United Kingdom by the welding institute (TWI). Friction stir welding is a solid-state joining method used for aluminium alloys, which are often difficult to be fusion welded without porosity and hot cracking. There are many advantages compared to another welding such as very low distortion, no fumes, porosity, no consumable electrode, and no special surface treatment. There are few disadvantages such as large downward force are required, it is used only continues path for welding, at the end of the welding process an exit hole is left behind when a tool is withdrawn. FSW pin is rotated at a constant speed and feed at a constant traverse rate into a joint line between two aluminium plates shown in figure no.1. Two plates clamped rigidly onto the backing bar in a manner that prevents abutting joint faces from being forced apart. The pin moves against the work-piece that time heat is generated between tool and work-piece, causes the material to soften and forcing force to apply at the plates' two sides. The welding of the material is facilitated by severe plastic deformation in the solid-state involving dynamic recrystallization of the plate [1]. Today in industries very high load is applied on the rotating tool, and the multi-pass process is used. So that concern on the machining tool's high consumption rate that time generates twin tool of welding. With the attempt to extend the tool life and improved welding efficiency [2]. Twin tool welding effect on the microstructure of the welding. Along with the cooling rate is helpful to determine the final weld microstructure. The cooling rate is inversely proportional to the preheat temperature and heat input.

Friction-stir welding (FSW) is a solid-state joining process (meaning the metal is not melted). It is used for applications where the original metal characteristics must remain unchanged as much as possible. It works by mechanically intermixing the two pieces of metal at the join, transforming them into a softened state that allows the metal to be fused using mechanical pressure, much like joining clay, dough, or plasticize. This process is primarily used on aluminium, and most often on large pieces which cannot be easily heat-treated post-weld to recover temper characteristics.

During weld rotating twin tool is driven through the material to be welded, heating the material to a plasticized state and stirring the work-pieces together. While initially performed in aluminium fsw is now achieved in a variety of materials and joint configurations. It offers numerous benefits over conventional forms of welding and with continued work is being applied to an ever-growing number of projects and situations.

The side of the weld where the tangential velocity and welding direction are parallel is referred to as the advancing side (as) of the weld; the other side where the vectors point in opposite directions is called the retreating side (rs). In general, Fsw is a stable process: as the temperature of the material around the twin tool rises, the frictional forces and thus, heat input decrease. As the environment near the tool cools, additional heat is generated by increased friction

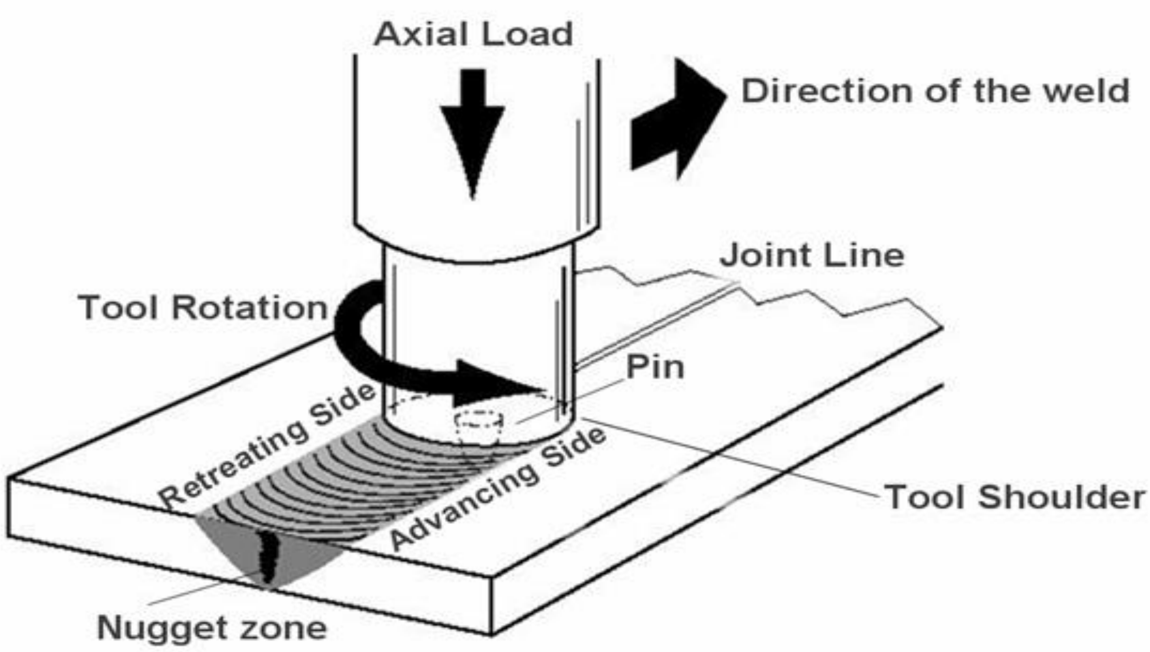


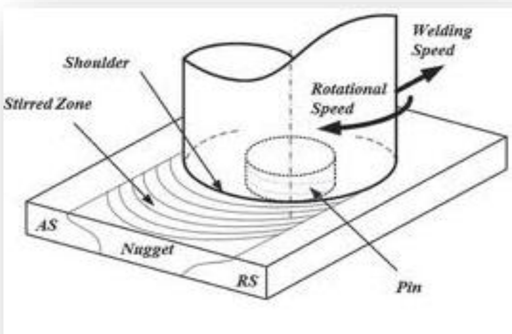
Figure 1 Schematic of typical fsw Process

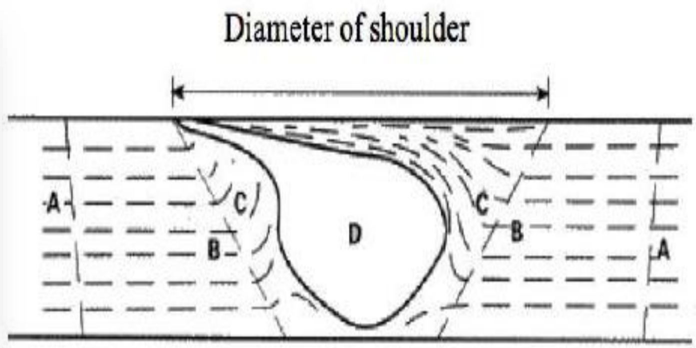
Metallurgical study of fsw

It is also very common to study etched metallurgical cross-sections of single tool friction stir welding. It is mostly divided into four parts:

- Parent material
- Heat affected zone.
- Thermal mechanically affected zone.
- Weld nugget

There are four noticeable regions created by the fsw tool separated by how much heat and deformation the material was exposed to, where the pin has passed in the weld nugget, characterized by the greatest deformation and as a site of recrystallization.





(I) (II)

Figure 2 (I) Fsw cross section view (II) schematic of a typical fsw cross-section (A) parent material (B) heat affected zone (C) thermal mechanically affected zone (D) weld nugget [4]

In figure 2 (I) shows the side view of the friction stir welding with the different zones. Surrounding the nugget is the TMAZ (Thermal mechanically affected zone). In the case of material, it is possible to get significant plastic strain without recrystallization in this region. There is generally a distinct boundary between the recrystallized zone and the deformed zones of the TMAZ, which contains grains of the original material in a deformed state. The third layer, affected by the heat of the weld but lacking the deformation of the more central zones, is referred to as the heat-affected zone (HAZ), similar to conventional fusion welding. Finally, the unaffected original material is often called the parent material or the unaffected zone; both names are relatively descriptive.

Figure no.2 (II) shows a schematic cross-section of these four zones in a typical fsw arrangement. The asymmetrical nature of the nugget and surrounding zones are result of different flows between the AS and RS of the weld. Fsw offers several advantages over conventional fusion welding techniques. Fsw used with materials and alloys considered hard or impossible to weld by conventional means; it is also join different materials and different material thicknesses.

Problem statement

The conventional fusion welding of aluminium alloys leads to the melting and resolidification of the fusion zone, which results in the formation of the eutectic phase and brittle structure. The formation of brittle structure in the weld zone leads to decrease mechanical properties such as strength, hardness and ductility. Friction stir welding is a solid-state metallic alloy joining process and thus emerged as an alternative technology used in high strength alloys that are difficult to join with conventional techniques. In this process the relative motion between tool and work piece produce heat which helps the material of two edges being joined by plastic diffusion. Hybrid friction stir welding improves mechanical properties. It consumes less energy. It produces welds which are high in quality, strength, and inexpensive.

The twin tool enables the cost reduction for multipass since it consumes time in the process of welding. The twin tool works as a stress-relieving process for the work piece so tensile strength to be increased. It also provided preheating of the welding joint.

So above discussion, we make a statement "An experimental investigation of friction stir welding on AA7108 T79 using counter-rotating twin tool".

Objectives of fsw and scope of research

Today in a modern era mostly software, to direct the computer's strength of rapid, linear computation on the task of building a numerical model that requires only a small amount of time and it is capable of analyzing experimental results from friction stir welding. Even mostly improvement in simulation and simulation is required on time to reduce a work time .Team work is useful and it helps to reducing time. Any problem creates that time in the simulation all of the persons have different knowledge and get a sign of courage to solve the problem.

This states that as the number of workers and processors increases, the incremental reduction in price and processing time decreases if there is not also an improvement in how they work together.

Objectives of research work:

- To design a twin tool with the help of the different software and analyses (finite element method) as a gear meshing and different force on the twin tool.
- Fabrication of twin tool as per the design.
- To develop fsw set up on a vertical milling cnc machine (VMC 800) and welding as per the design of experiments (D.O.E).Welding of Al 7108 T79 alloys for different input parameters.
- To conduct characterization, analyses, testing and validation of weldment joint.

Methodology of research

In general, ‘methodology’ is the strategy that outlines the way in which research work is to be undertaken and identifies the methods used in it. It does not define a specific method but conveyed the nature of the processes followed by the objectives.

This section describes the methodology used for carrying research work

1. Define the problem
2. Review of the available literature
3. Prepare the research design
    - In this research design of the twin tool (CREO PARAMETRIC 3.0®) and analysis in ANSYS WORKBENCH 16.0®.
    - Development of twin tool (EN 8) then after creating a welding
    - Selection of the material (AA7108T79)
    - Exhaustive experimental pilot test varying with process parameters and fixture
    - Collection and interpretation of the data for final experiment work
4. Experimental work
    - Preparation of the final experiment setup
    - The final experiment runs with D.O.E.

- Testing of weldment specimens
- Analysis of data
- Interpretation and characterization of the data

5. Results and discussions
6. Validation of research work
7. Conclusion
8. Future scope

Design and development of twin tool

The approach towards the making of twin tool has been split into different steps which go like design and development, and check different materials for twin tool. Figure no.3 shows the steps of the methodology of the development twin tool. The first step is to identify the problem. The second aware is developing the idea to overcome the problem which has been defined in the first step. Once the concept is willing for the recognized problem, the different possibilities generate and various mathematical calculations are used for gear. The next step is to develop the conceptual idea of a 3-D model generate with the help of modeling software by cad model (CREO PARAMETRIC 3.0®). The next step is to generate grid generation (ANSYS DESIGN MODELER 16.0®). Following analyses on twin tool with different materials and different properties with the help of static structure solver and post-process (ANSYS WORKBENCH 16.0®). The next stage is to develop a twin tool.

Identify the problem

↓

Generate mathematical calculation for gear

↓

3-D CAD model generate of twin tool (CREO 2.0)

↓

Grid generation of computational domain (ANSYS design modeler 16.0®)

↓

Static structure solver (ANSYS design modeler 16.0®)

↓

Comparative analysis of twin tool with different material (SCM415, S45C, EN8)

↓

Development of twin tool

Figure 3 Solution methodology for finite element analysis (FEA)

Mathematical calculation:

M_t =Torque transmitted by gears

KW= Power transmitted by gears(KW)

N_p = Speed of pinion (rpm)

M = Module

C_s=Service factor (1.5)

C_v =Velocity factor

P_{eff} =Effective load on the gear

D_p= Pitch circle diameter of pinion

S_b =Beam strength of gear tooth

σ_b =Permissible bending stress

P_t = Tangential components of resultant tooth force

- **Torque transmitted by gears**

$$\mathrm{Mt} = \frac{60 * 10^6 * \mathrm{KW}}{2 * \pi * \mathrm{Np}}$$

$$= \frac{60*10^6*10}{2*\pi*1500}$$

$$= 63622\ N.mm$$

- **A module of gear:**

$$\mathrm{M} = \left[\frac{60 * 10^6}{\pi}\left[\frac{\mathrm{KW} * \mathrm{cs} * \mathrm{fs}}{\mathrm{Zp} * \mathrm{N} * \mathrm{Cv}\left(\frac{\mathrm{B}}{\mathrm{m}}\right) * \left(\frac{\mathrm{Sut}}{3}\right) * \mathrm{Y}}\right]\right]^{\frac{1}{3}}$$

$$= \left[\frac{60 * 10^6}{\pi}\left[\frac{10 * 1.5 * 1}{20 * 1500 * 10 * (\frac{3}{8}) * \left(\frac{565}{3}\right) * 0.34}\right]\right]^{\frac{1}{3}}$$

=3.44= 3.5 mm

Dp′= 3.5×20 =70 mm

Dg′= 3.5×20 =70 mm

b = M×10=3.5×10 = 35 mm

- **Tangential components of resultant tooth force:**

$$\mathrm{Pt} = \frac{2\times Mt}{Dp'}$$

$$= \frac{2 \times 63662}{70} = 1818.91\ \mathrm{N}$$

$$\mathrm{v} = \frac{\pi * \mathrm{Dp}' * \mathrm{Np}}{60000} = 5.49\mathrm{m/s}$$

$$\mathrm{Cv} = \frac{3}{3 + \mathrm{v}} = \frac{3}{3 + 5.49} = 0.3531$$

- **Effective load on the gear:**

$P_{effect} = \frac{Cs}{Cv} * Pt$

$$=\frac{1.5}{0.35} * 1818.91 = 7795.32$$

- **Beam strength of gear tooth :**

$S_b = M*b*\sigma_b*Y$

$= 3.5*(\frac{565}{3})*35*0.34$

$= 7844$ N

$S_b \geq P_{eff}$ (satisfy)

- **The factor of safety:**

$F_s = (\frac{Sb}{Peff})$

$= \frac{7844}{7795.32}$

$= 1.06$

3-D model generation:

A numerical investigation of the twin tool physical domain in 3-D is prepared using CREO 2.0 software. The figure no.4 shows the computational domain for FEA consisting of a shafts, gears, arbors, and twin tool.

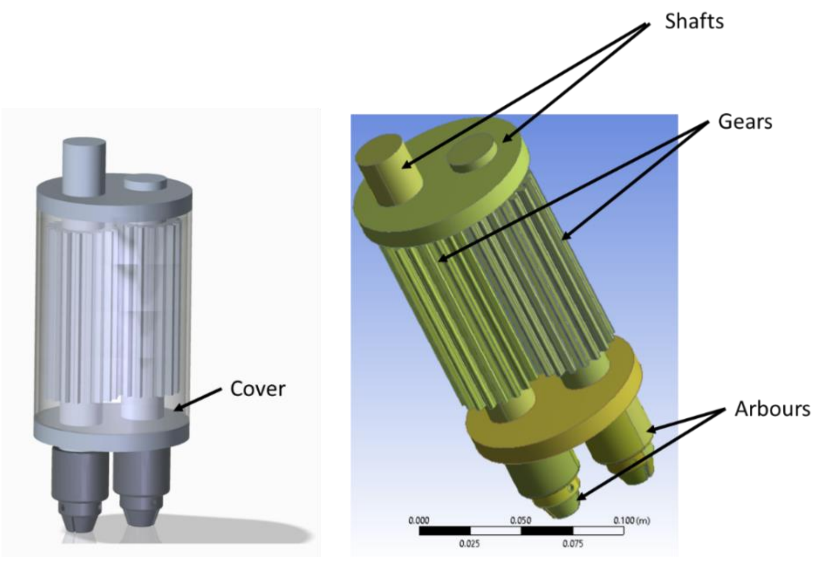


Figure 4 3-D CAD model

Result and discussion of twin tool

For static structure FEA, ANSYS Workbench solver 16.0 is carried for the performance of a twin tool with a prescribed torque range and different materials. The objective of the simulation is to evaluate the effect of torque on different materials on twin tool and find out an optimum tool material from the listed materials. For that, results are shown for all fifteen runs with different torque and tool materials. Figure no.5 shows total deformation contours at a torque of 7.5 N.m for SCM415, S45C, and EN8. Also, comparative analysis of total deformation with torque ranges from 7.5 to 90 N.m. Negligible deformation of EN8 is observed in comparison with SCM415 and S45C.

For further justification for optimum tool material, equivalent strain, equivalent stress, and strain energy of all three materials are compared with the prescribed torque range. The equivalent strain is minimum for EN8 which is 0.0027 for elevated torque. The equivalent strain for EN8 is about 10% less compared with SCM415 and 7% less compared with S45C. For further justification for optimum tool material, equivalent strain, equivalent stress, and strain energy of all three materials are compared with the prescribed torque range. The equivalent strain is minimum for EN8 which is 0.0027 for elevated torque. The equivalent strain for EN8 is about 10% less compared with SCM415 and 7% less compared with S45C. Similarly, equivalent stress for EN8 is about 8.7% less compared with SCM415 and 8.5% less compared with S45C. A tremendous difference in Strain Energy is observed. For EN8, the difference is observed 73% less compare with SCM415 and 74% less compared with S45C.

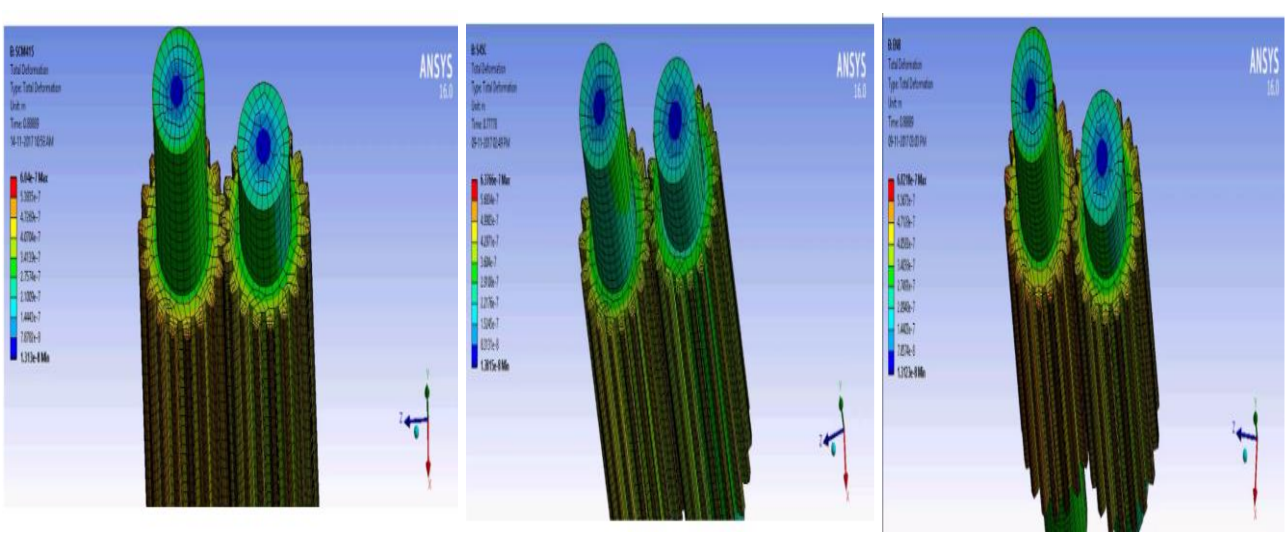


Figure 5 Total Deformation of SCM415, S45C, and EN8

Tool Pin design

This research used a two-tool pin profile as straight hexagonal and straight cylindrical tool design shown figure no. 6 and 7.

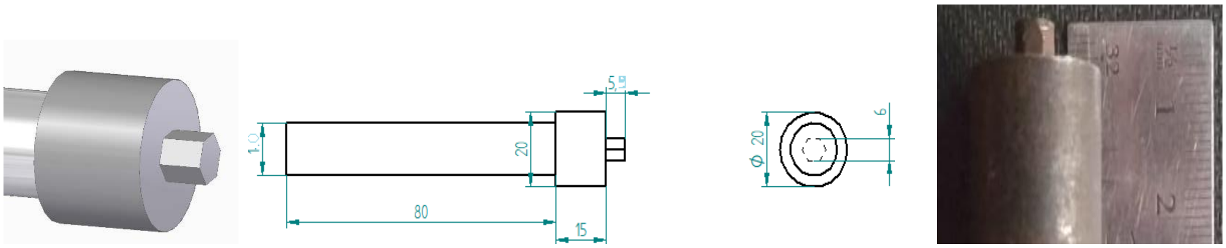


Figure 6 straight Hexagonal pin design

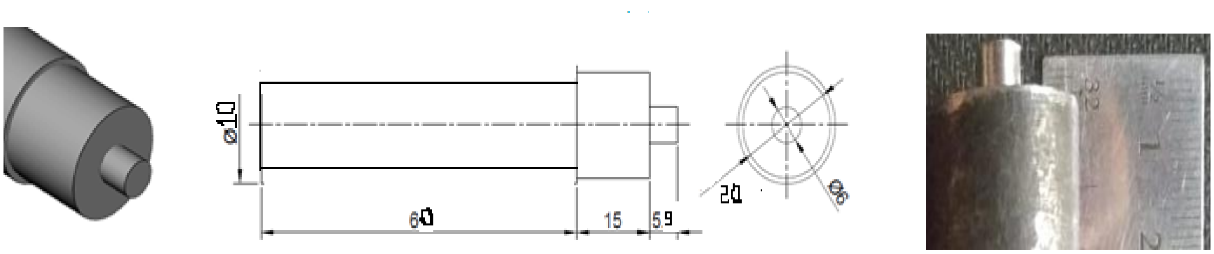


Figure 7 straight Cylindrical pin design

Pilot test:

After the selection of the tool geometries table no.5 shows different clamping and input parameters used for the pilot tests. The pilot tests found the perfect clamping arrangement and tool rotational speed and feed. Also, generated a joint with-out any defect.

Table 5 Pilot tests

Pilot Test no	Tool rotational speed (rpm)	Tool feed (mm/min)	Clamping	Remarks
1	900	50	Vice	Tunnel dsefect
	1200			
	1500			
2	1200	50	Clamping	No defect
3	900	50	Clamping	Small
	1200			
	1500			

	1800			
4	900	30	Developed fixture	No defect
	1200			
	1500			
	1800			
5	900	50	Developed fixture	No defect
	1200			
	1500			
	1800			
6	900	70	Developed fixture	No defect
	1200			
	1500			
	1800			
7	900	90	Developed fixture	No defect
	1200			
	1500			
	1800			

Testing

Radiography testing

Radiography test performs on the radiotech NDT test PVT. Ltd. At 87-90 bhagwati estate b/h. uttam dairy, amraiwadi Road, Ahmedabad. This test was performed as per the ASTM-12 1A standard.

Figure 8 Radiography strip view on the radiographic viewer

The above figure no. 8 shows radiography film. This film shown on the radiographic viewer in L.D. engineering college. A radiography test has been used to find any defect between the two plates, but from the all joint no one any cracks or porosity found.

Ultrasonic testing

Ultrasonic test perform at the keepsake engineering consultancy Pvt. Ltd. in the L. D. engineering college Ahmedabad. This test found the thickness of the plate for the base metal as well as weld joint and easily found if any crack or porosity inside the weldment. So machine display value shows the thickness of the plate decreased. In this ultrasonic testing use, a double probes sensor used for the testing for the accuracy work shown in the below figure no 9.

Figure 9 Ultrasonic testing

Tensile strength

The tensile tests performed according to the standards given by the **ASTM E8M-04**, the beginning and the end of the welds with holes are sheared and not used for research purposes. The welded plates are marked for the right dimensions cuts from each welded joint to ensure accuracy. The specimens are marked for identification, the center of the weld is identified and a 40 mm mark is made to facilitate the measurement of elongation after the test sample breaks under tension the specimens with the marking are shown in figure no. 10.

Figure 10 (i) tensile test specimens before testing (ii) after tensile test specimen

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 100kgf set on the buttons. The load on the indenter set using a knob on the hardness tester. Hardness tester shows the dial indicator and load-unload knob. The indicator load set by using the button on the side panel of the hardness tester.

The hardness test was tested on **Zen air tech Pvt. Ltd.** At GIDC, naroda, Ahmedabad. The sample whose hardness is to be measured mount on a round plate and fixed securely on the table, the indicator is used to locate the point where the measurement is to be taken and the height of the table is adjusted until the clear indicator shows a small meter is 3 point. The below figure no. 11 shows indent on welded specimen.

Figure 11 Hardness specimen

Microstructure

The mounted samples are polished on polishing paper of grit no. 150,320,600,800,1000and 1200 with a combination of water and diamond paste (3-OS-40) for a smooth finish, the final stage of polishing is on smooth cloth with a diamond suspension liquid for a smooth finish. The samples are etched after polishing to reveal the microstructure clearly; the acids in the etchant attack the grain boundaries and give a clear image of the size of the grains. The etchant used for aluminum alloys is keller’s etchant which is prepared by adding 1 percent of hydrofluoric acid by volume, 1.5 percent of hydrochloric acid by volume, 2.5 percent of nitric acid by volume, and 95 percent of distilled water by volume. The samples are etched for 1 min according to the Boeing company standards, but over etched for one more minute if the microstructure is not revealed. The etched samples are washed thoroughly to remove the carbon deposits and pat dry to study the microstructure under the optical microscope.

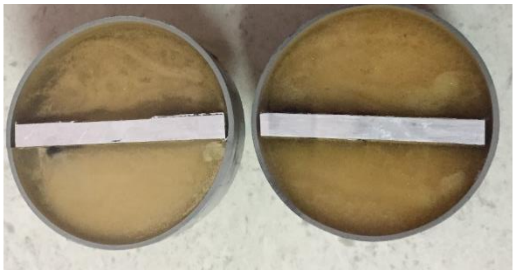
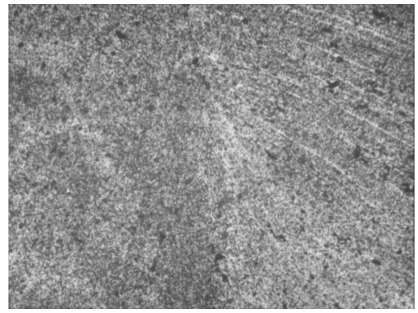
 

Figure 12 microstructure specimen and microstructure

Result and discussion

The below table no.6 and 7 shows the result of tensile strength and hardness values of cylindrical tool and hexagonal tool.

Table 6 Experimental value for the cylindrical tool

Sr. no	Tool rotational speed (rpm)	Tool feed (mm/min)	Tensile strength (MPa)	Hardness (HRB)
1	1800	30	184.00	44
2	1800	70	190.00	42
3	1500	30	135.89	45
4	1200	50	154.70	41
5	900	90	159.00	42
6	1200	30	149.92	43
7	900	70	174.12	39
8	900	30	162.22	42
9	1500	50	153.00	43
10	1800	90	180.00	45
11	1500	90	144.52	45
12	1500	70	150.94	42
13	1800	50	198.00	42
14	1200	90	146.00	43
15	1200	70	161.39	41
16	900	50	167.63	40

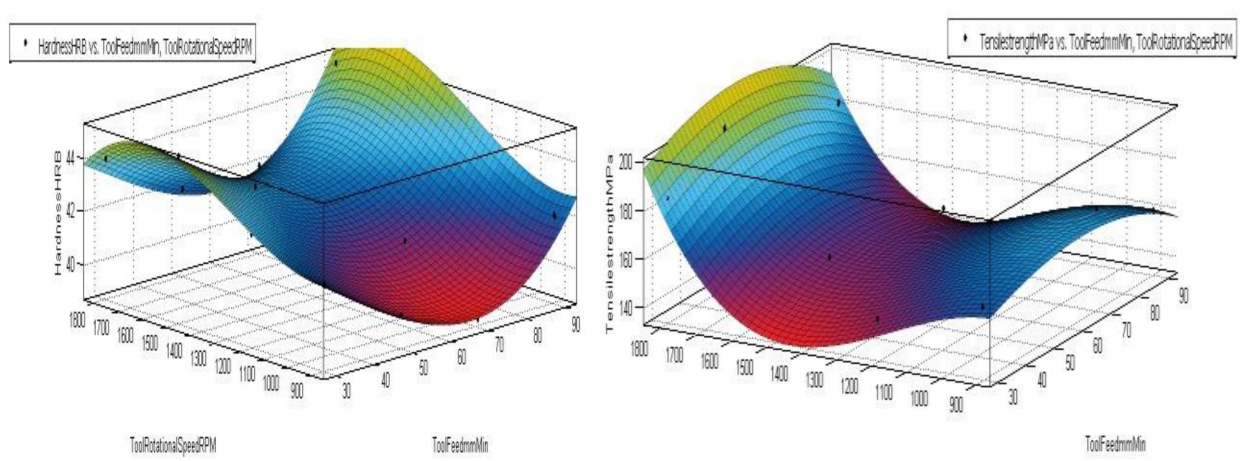
Table 7 Experimental value for the hexagonal tool

Sr. no	Tool rotational speed (rpm)	Tool feed (mm/min)	Tensile strength (MPa)	Hardness (HRB)
1	1800	30	145.19	46
2	1800	70	160.77	47
3	1500	30	183.77	45
4	1200	50	189.27	48

5	900	90	186.40	47
6	1200	30	180.35	46
7	900	70	189.44	48
8	900	30	183.02	46
9	1500	50	184.69	48
10	1800	90	151.63	45
11	1500	90	199.34	45
12	1500	70	208.00	47
13	1800	50	147.29	48
14	1200	90	194.77	46
15	1200	70	197.00	47
16	900	50	184.94	49

Figure no.13 (i) and (ii) present the response plot for the cylindrical tool. Figure no.13 (i) presents the effect of tool rotational speed and tool feed on the hardness of cylindrical tool. It noted that the hardness value is more influenced by the tool feed. If the feed is increased, hardness value decreased and then increased. Also, tool rotational speed increased hardness up to this maximum value than after decreased.

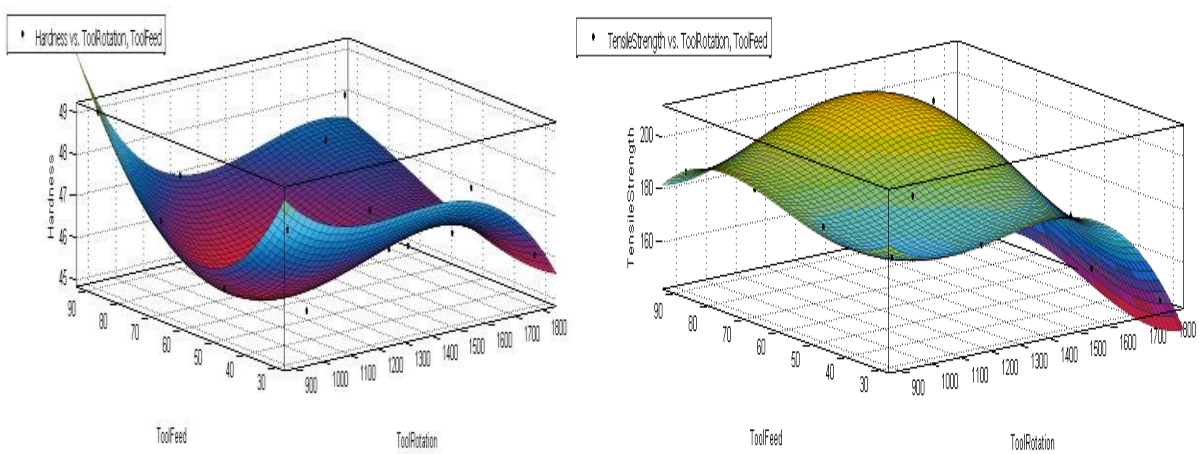
Figure no.13 (ii) Present the effect of the tool rotational speed and feed on the tensile strength for cylindrical tool. From 900 rpm to 1500 rpm tensile strength decreased and after the increased the value. If tool feed increased so tensile strength increase and after decreased. For tensile strength input parameters as a tool rotational speed is an important parameter.



(i) (ii)

Figure 13 Response surface plots for cylindrical tool

Figure no.14 (i) and (ii) present the response plot for the hexagonal tool. Figure no.14 (i) presents the effect of tool rotational speed and, tool feed on the hardness of hexagonal tool. It noted that hardness value is more influenced by the tool feed. If tool feed is increased hardness value decreased and then increase to reach the maximum value at the lower tool rotational speed. The input parameter is tool rotational speed increased hardness value decreased up to 1500 rpm and after increased slightly than after decreased value.



(i) (ii)

Figure 14 Response surface plots for hexagonal tool

Figure no.14 (ii) present the effect of tool rotational speed and feed on the tensile strength for cylindrical tool. From 1500 rpm to 1700 rpm tensile strength value increased and after the decreased value. The lower value is at 1800 rpm because heat is generated at a higher tool rotational speed. Also, Tool feed increased so tensile strength value increase and decreased. For tensile strength input parameters as a tool rotational speed is an important parameter.

Optimization problem formulation

The present study aimed to determine the set of optimal parameters of the FSW process to ensure maximum tensile strength and hardness satisfying the condition. The multi-objective optimization obtained in terms of tool rotational speed (RPM) and hardness (HRB). This equation divided into two categories one is cylindrical tool and hexagonal tool. This multi-objective optimization generated two functionsY@1 and Y@2 for the cylindrical and hexagonal tools respectively. After generated equations, it is implement in the fitness function and directly optimize. The fitness value was penalized by using a term given below.

Maximization,

Optimization of the Cylindrical tool

Function P@1= P(x)

P(1)= $74.69 - 0.08455 \times X + 0.07654 \times Y + 7.972\text{e} - 05 \times X^2 - 0.0004717 \times X \times Y + 0.001562 \times Y^2 - 2.16\text{e} - 08 \times X^3 - 2.16\text{e} - 08 \times X^2 \times Y + 2.083\text{e} - 06 \times X \times Y^2 + -1.042\text{e} - 05 \times Y^3$;

P(2)= $-154.4 + 0.9113 \times X - 0.3802 \times Y - 0.0008883 \times X^2 + 0.001881 \times X \times Y + 0.001215 \times Y^2 + 2.654\text{e} - 07 \times X^3 - 5.824\text{e} - 07 \times X^2 \times Y - 2.869\text{e} - 06 \times X \times Y^2 - 6.182\text{e} - 05 \times Y^3$;

double P(1);

double P(2);

end

Where, x= tool rotational speed (rpm), y= tool feed (mm/min)

Regression model formulae for Hardness and Tensile strength

Hardness: $74.69 - 0.08455 \times X + 0.07654 \times Y + 7.972\text{e} - 05 \times X^2 - 0.0004717 \times X \times Y + 0.001562 \times Y^2 - 2.16\text{e} - 08 \times X^3 - 2.16\text{e} - 08 \times X^2 \times Y + 2.083\text{e} - 06 \times X \times Y^2 + -1.042\text{e} - 05 \times Y^3$ ……………………………………………………………………………(1)

Tensile strength: $-154.4 + 0.9113 \times X - 0.3802 \times Y - 0.0008883 \times X^2 + 0.001881 \times X \times Y + 0.001215 \times Y^2 + 2.654\text{e} - 07 \times X^3 - 5.824\text{e} - 07 \times X^2 \times Y - 2.869\text{e} - 06 \times X \times Y^2 - 6.182\text{e} - 05 \times Y^3$……………………………………………………………………………..……(2)

Optimization of the Hexagonal tool

Function P@2= P(x)

P(1)= $122.7 - 0.1437 \times X - 0.8673 \times Y + 9.556\text{e} - 05 \times X^2 + 0.0007658 \times X \times Y + 0.005812 \times Y^2 - 2.315\text{e} - 08 \times X^3 - 4.167\text{e} - 08 \times X^2 \times Y - 6.042\text{e} - 06 \times X \times Y^2 + +1.563\text{e} - 05 \times Y^3$

P(2)= $815.8 \; - 1.349 \; \times X - 7.167 \times Y + 0.001069 \times X^2 + 0.003313 \times X \times Y + 0.09963 \times Y^2 - 2.811\text{e} - 07 \times X^3 - 1.022\text{e} - 06 \times X^2 \times Y - 3.598\text{e} - 06 \times X \times Y^2 - 0.0005586 \times Y^3$

double P(1);

double P(2);

end

Where, x= tool rotational speed (rpm), y= tool feed (mm/min)

Regression model formulae for Hardness and Tensile strength

Hardness: $122.7 \; - 0.1437 \times X - 0.8673 \times Y + 9.556\text{e} - 05 \; \times X^2 + 0.0007658 \times X \times Y + 0.005812 \times Y^2 - 2.315\text{e} - 08 \times X^3 - 4.167\text{e} - 08 \times X^2 \times Y - 6.042\text{e} - 06 \; \times X \times Y^2 + +1.563\text{e} - 05 \times Y^3$ ……………………………………………………………………………(3)

Tensile strength: $815.8 \; - 1.349 \; \times X - 7.167 \times Y + 0.001069 \times X^2 + 0.003313 \times X \times Y + 0.09963 \times Y^2 - 2.811\text{e} - 07 \times X^3 - 1.022\text{e} - 06 \times X^2 \times Y - 3.598\text{e} - 06 \times X \times Y^2 - 0.0005586 \times Y^3$………………………………………………………………………….…(4)

Subject to the condition that Hardness and tensile strength takes the maximum value and takes the value range between maximum and minimum value.

$X_{min} \leq X \leq X_{max}$,

$Y_{min} \leq Y \leq Y_{max}$,

i.e. 900 rpm $\leq X \leq$ 1800 rpm, 30 mm/min $\leq Y \leq$ 90 mm/min

Multi-objective GA Settings

Selection operator	= Rank order
Cross over operator probability	= 0.8
Mutation probability	=0.01
Population size	= 12
Fitness parameters	= Multi objective function

In this optimization, upper and lower limits are the friction stir welding process parameters as per the given below in table no.9.

Table 9 Limits of the input parameters

Sr no	Friction stir welding process parameters	Lower limit	Upper limit
1	Tool rotational speed (rpm) (X)	900	1800
2	Tool feed (mm/min) (Y)	30	90

Optimization results of the cylindrical tool

After the multi-objective function run in Matlab 2012a, so it is provided an optimized value. In this process, it is easily found some graphs and values. The below table no. 10 gives optimized values for cylindrical tool.

Table 10 Output value after the first interaction of the cylindrical tool.

Rank	Tool rotational speed (X)	Tool Feed (Y)	Tensile strength (F1)	Hardness (F2)
1	1045.55	50.66	166.19	40.50
2	1228.48	36.01	148.56	42.36
3	1223.89	39.52	150.97	41.94
4	1024.43	56.96	168.53	40.40
5	1137.40	46.77	159.69	40.93
6	1328.95	40.56	146.60	42.50
7	1185.48	42.90	155.05	41.42
8	1301.70	30.95	141.28	43.59
9	1061.50	43.60	162.73	40.84
10	1262.25	35.55	146.42	42.64
11	1325.00	37.12	144.65	42.87
12	1187.24	39.60	153.17	41.72

In this work, the optimized value for the different weights of the UTS and hardness has been shown in the given output table no.10. As mentioned that earlier got the solution of the algorithm stand the best amount of the input and output process parameters. Also, provide the value interaction of output parameters tensile strength and hardness. Matlab give the output value after the first interaction in the optimization table no. 10.

Optimization results of the hexagonal tool

Table 11 Output value after the first interaction of the Hexagonal tool

Rank	Tool rotational speed (X)	Tool Feed (Y)	Tensile strength (F1)	Hardness (F2)
1	1073.00	61.29	189.47	45.27
2	1074.97	57.87	187.23	45.29
3	1075.48	55.72	185.77	45.34
4	1074.55	53.50	184.25	45.40
5	1075.54	51.29	182.84	45.48
6	1789.02	71.50	163.99	45.49
7	1789.05	70.28	163.65	45.61
8	1791.60	68.07	162.17	45.80
9	1790.31	64.24	160.67	46.15
10	1789.22	32.30	146.94	46.15
11	1791.62	36.61	146.01	46.48
12	1073.00	61.29	189.47	45.27

In this work, the optimized value for the different weights of the UTS and Hardness has been shown in the given table no. 11. As mentioned that earlier we obtained solution of algorithm stand the best amount of input and output process parameters. The table no.11 provides the value interaction of the output parameters tensile strength and hardness. Also, provides the output value after the first interaction in the table no.11.

Validation

Values of input parameters as per the multi-objective optimization of the input parameters and output parameters are as below in table no.12.

Table 12 Range found in input and output parameters

Factors	Notation	Range observed during the experiment	Predicted values of output parameters	
			Cylindrical tool	Hexagonal tool
Tool rotational speed (rpm)	TS (X)	900-1800	1024.43-1328.95	1073.005-1791.621
Tool Feed (mm/min)	TF (Y)	30-90	30.95-56.96	53.50-71.50
Tensile strength (Mpa)	UTS (F1)	146-208	141.28-168.18	146.00-189.47
Hardness (HRB)	HRB (F2)	40-48	40.49-43.58	45.27-46.47

After the validation table no.12 is generated in the software then validate this work with practical output. In our some of the machine limitations it was not take speed and feed in two decimal so that some of the error generated in research work. The results obtained through optimization validate. This was done through the practical performance of the experiment in the same manner as the practical performed earlier as per DOE. The results are tabulated as under table no. 13 and 14.

Validation of the cylindrical tool

Table 13 Validation table of the cylindrical tool

Types of values	**Input and output parameters for the cylindrical tool**			
	Tool rotational speed (rpm)	**Tool feed (mm/ min)**	**Tensile strength (Mpa)**	**Hardness (HRB)**
Predicted values of parameters	**1045.551**	**50.66**	**166.1867**	**40.49**
Actual obtained values of parameters	**1046**	**51**	**162.47**	**42**
Error %	**_**	**_**	**2.2%**	**3.7%**

Validation of the hexagonal tool

Table 14 Validation table of the Hexagonal tool

Types of values	**Input and output parameters for the hexagonal tool**			
	Tool rotational speed (rpm)	**Tool feed (mm/ min)**	**Tensile strength (Mpa)**	**Hardness (HRB)**
Predicted values	**1073.005**	**61.29**	**189.47**	**45.27**
Actual obtained values	**1073**	**61**	**186.03**	**47**
Error %	**_**	**_**	**1.8%**	**3.8%**

From the above validation of this work, some of the errors were generated but this error depends on the tool rotational speed and, the tool feed is not in the two decimal. In addition, one is that the hardness tester is not indicating the value in two decimal so an error is higher in the hardness.

Conclusions

The friction stir welding process is a high potential in the field of metal joining with various aluminium alloys especially the high strength alloys which are difficult to join with conventional techniques. This synopsis presents an experimental investigation of friction stir welding on AA7108 T79 using a counter-rotating twin tool. In this work design and development of twin tool analyses of the best material for the tool and then after experiments were conducted for various combinations of tool rotational speed, tool feed, tool profile, and this rotational speed and feed are taken as four levels and two pin profile. The parameters were optimization using a full factorial and multi-objective genetic algorithm. The strength of the joint was analyzed by the tensile test (UTS) and hardness was tested. In addition microstructure investigations across the weld zone. Multi-objective optimization of the process parameters and validate this work to the experiments of optimized value. From these tests and analyses, the following conclusions are derived.

- In this work, Twin tool gear calculations were calculated. The twin tool was designed on CREO (CREO PARAMETRIC 3.0®), grid generation, analysis on the ANSYS (ANSYS WORKBENCH 16.0®) which are suitable for friction stir welding.
- From ANSYS analyses select the best gear material for twin tool. Select the best gear material as EN 8 compared to the other material and develop a twin tool.
- Friction stir welding tool pins designed and manufactured carefully, which are suitable for the AA 7108 T79 material.
- The working range of the process parameters was found with the help of the pilot tests for the AA 7108 T79 material. Also, select the best tool pins and fixture geometries.
- The friction stir welding was applied on the 6 mm thick plate with a butt joint on the base material.

- Design of experiment with full factorial was successfully used to find the four levels with process parameters and two tool pin geometries.

- Empirical relationships were developed with the four levels of process parameters and two tool pin geometries using the design of experiment. Radiography and ultrasonic testing performed to found the defect-free joint.

- In hexagonal tool, pin profile tool rotational speed 1500 rpm and 70 mm/min feed is best compared to the 30, 50, 90 mm/min, and second-highest tensile 1500 rpm and 90 mm/min feed. In a hexagonal tool due to the edge of the tool pin stirring of the grain is higher compared to the cylindrical tool. Also, higher heat is generated at the lower feed so the proper heat is generated at the higher feed. If the tool feed and speed is increased so higher heat generates and, its effect on the output parameters.

- In cylindrical tool pin profile, rotational speed 1800 rpm and 50 mm/min is best compared to another and 1800 rpm tool rotational speed, 70 mm/min feed is second highest. In the cylindrical tool, the pin is properly straight so that the stirring of the grains is lower so requires lower feed and higher speed of the tool rotational speed.

- The hexagonal tool is best compared to cylindrical tool because hexagonal tool shape plays an important role to found a pulsating stirring action that is higher compared to the cylindrical tool so that the lower rotational speed and tool feed gives the best result of the output value.

- An increase in the tool rotational speed and feed causes more heat to be generated it turns in to enlarge the TMAZ and HAZ which results reduce the tensile strength. If lower feed and speed so smaller TMAZ and HAZ which leads to the greater tensile strength. It is also found that heat is an important role in the output parameters.

- The samples were characterized by means of the increase in tool rotational speed and feed are increase tensile strength which reaches the maximum value and then decrease.

- Increased tool rotational speed and feed are increasing tensile strength which reaches the maximum value and then decreases.

- In the hexagonal tool, hardness reaches up to 45 to 49 HRB. In the cylindrical tool, hardness is 39 to 45 HRB and its most important input parameter is tool feed.

- The analysis of the microstructure found that the average grain size for cylindrical tool was 5.72 μm and hexagonal tool was 5.45 μm. If the grain size is decreased so that tensile strength increases. In this microstructure, $MgZn_2$ and MgZn give white particles in the aluminium.

- From the ANOVA, it concluded that the tensile strength depends on the tool rotational speed. For the hardness, the most significant parameter is tool feed and it varied with different tool geometry. Also, P-value is lower than the 5% and the model is satisfied.

- A genetic algorithm was able to reach the optimal solution after satisfying the constraints. This work was validated practically experiments as the parameters optimized by the multi-objective GA. After founding the maximum error in the hardness and tensile strength is below 4% from the predicted weld geometry and measured weld geometry.

Future scope

- Further research by an increase or decrease the distance between two tools in the twin tool.

- The research on the friction stir weld tool design will modify and the tool profile change with different tool rotational speed, feed, and other input parameters effect on the output parameters.

- A double-sided weld joint will perform with different thicknesses of the material.

- Dissimilar joints will studies for their performance on the different output parameters.

- The researcher will take further welding joint with other aluminium alloys series such as 2XXX, 6XXX, and 8XXX. These are found to be the other most preferred series in commercial structural applications.

Limitations of the research

- Tool tilt angle is not possible by this indigenously designed twin technology.

- In this work tool, the rotational speed was same for the two tools.

List of publications:

1. Genetic algorithm-based optimization of friction stir welding process parameters on AA7108T79: International journal of innovative technology and exploring engineering, volume 10 issue 8 June 2021.

2. Studies the twin stir technology and welded parameters of friction stir welding on AA7108T79: Journal of Xi'an University of architecture & technology, volume VIII issue VI June 2021.

3. A review on tool rotational speed and tool transverse speed affect the mechanical properties on the friction stir welding: Zeinchen journal, An UGC Care approve journal, Volume 6 issue 9 September 2020.

4. Design and development and finite element analysis on the twin tool for friction stir welding: 32nd World Conference on the Applied science, Engineering and technology Goa. This is a peer-review conference. 30th - 31st December 2020.

5. A review on the friction stir welding of various tool geometry: International journal of production engineering: Volume 6 issue 02, February 2021.

6. Experimental investigation of FSW with twin stir technology and its optimization: Transaction of Indian Institute of metals: Springer Under review.

7. An experimental investigation of friction stir welding on aa7108 t79 using counter-rotating twin tool: Welding international Taylor and Francis Under review.

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- Ajay Kumar: Optimization of process parameter for AA6061 alloy during friction stir processing: Assistant professor department of mechanical Engineering, Deen Bandhu chhotu ram university of science and technology, Murthal, India: Materials today proceedings.