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Experimental Evaluation of Mechanical Properties and Microstructure of Friction Stir Welded 5083 Aluminium Alloy

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Abstract—Friction stir welding (FSW) appears as a promisingly ecological weld method that enables to diminish material waste and to avoid radiation and harmful gas emissions usually associated with the fusion welding processes. Welding of non-ferrous materials like Aluminium, Magnesium, Copper etc, is difficult with the conventional welding processes as they are prone to oxidation effects. Hence we go for friction stir welding technique which makes use of a non-consumable welding tool to generate heat. Friction stir welding (FSW) process is a strong state welding strategy created by The Welding Institute (TWI) and now it is progressively utilized in Aluminum welding.

Keywords—Friction stir welding, non-consumable electrode, solid state welding.

I. INTRODUCTION

Friction stir welding (FSW) is a generally new strategy created by The Welding Institute (TWI) of UK in 1991. It is at first connected to the joining of aluminum composites, and stretched out to copper amalgams, magnesium combinations, steel compounds and titanium combinations. The essential idea of FSW is surprisingly straightforward. A non-consumable pivoting apparatus with an extraordinarily structured stick and shoulder is embedded into the adjoining edges of sheets or plates to be joined and gone along the line of joint.

The two primary functions of tool:

(a) Heating of work piece, and

(b) Movement of material to produce the joint.

The warming is proficient by contact between the instrument and the work piece and plastic distortion of work piece. The localized heating softens the material around the pin, combination of tool rotation and translation leads to the movement of material from the front of the pin to the back of the pin. Because of this procedure a joint is created in 'strong state'. The material development around the stick can be very intricate, because of different geometrical highlights of the instrument.

During FSW process, the material experiences extreme plastic twisting at lifted temperature, bringing about age of fine andequiaxed recrystallized grains. The fine microstructure in erosion blend welding produces better mechanical properties. The fine microstructure in friction stir welding produces better mechanical properties.

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II. PRINCIPLE OF OPERATION

In FSW, around and hollow carried device, with a profiled strung/unthreaded test (nib or stick) is turned at a steady speed and nourished at a consistent navigate rate into the joint line between two bits of sheet or plate material, which are smashed together. The parts must be braced unbendingly onto a support bar in a way that keeps the adjoining joint countenances from being constrained separated. The length of the nib is somewhat not as much as the weld profundity required and the instrument shoulder ought to be in close contact with the work surface. The nib is then moved against the work, or the other way around.

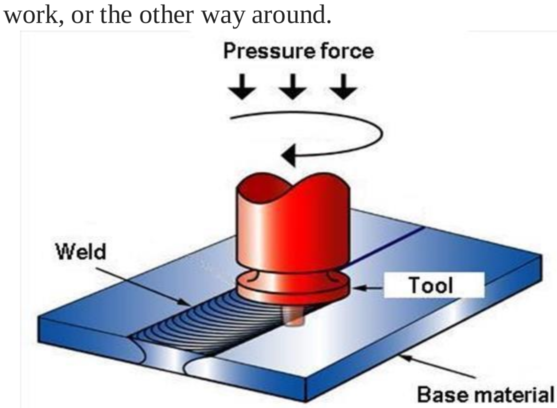


Figure 2.1 Working principle of FSW

III. FRICTION STIR WELDING PROCESS PARAMETERS

1. Tool rotation and Traverse speeds:

There are two tool speeds to be considered in friction stir welding, how fast the tool rotates and how quickly it pass over the interface. These two parameters have considered importance and must be chosen with care to ensure a successful efficient welding cycle.

The heat input increases with an increase in rotational speed and axial force and decreases with the increase in welding speed. At lower rotational speed, the heat input is insufficient, and improper stirring causes a tunnel defect in the middle of the retreating side. Higher rotational speeds could raise the strain rate and turbulence (abnormal stirring) in the material flow causing a tunnel defect at the weld nugget. As the rotational speed increases, the strained region increases, and the location of the maximum strain finally moves to the retreating side, from the advancing side of the joint. This infers the crack area of the joint is additionally influenced by the rotational speed. For FSW, two parameters are very important: tool rotation rate (rpm) and tool traverse speed (mm/min) along the line of joint. The rotation of the tool results in stirring and mixing of material around the rotating pin and the translation of tool moves the stirred material from front to the back of the pin and finishes welding process. Higher instrument pivot rates produce higher temperature due to higher grating warming and result in more serious blending and blending of material. However, it should be noted that frictional coupling of tool surface with work piece is going to control the heating. So, a monotonic increase in heating with increasing tool rotation rate is not expected as the coefficient of friction at interface will change with increasing tool rotation rates.

The rate of warming of warm cycle amid FSW is a solid capacity of the welding speed. Due to Low welding speeds, higher heat input and excess turbulence of the plasticized metal caused a tunnel defect at the top of the weld nugget. Higher welding speeds are related with low warmth inputs, which result in quicker cooling rates of the welded joint. This can essentially diminish the degree of metallurgical changes occurring amid welding. Subsequently, the nearby quality of individual areas over the weld zone.

2 .Plunge depth:

The dive profundity is characterized as the profundity of the most reduced purpose of the shoulder underneath the surface of the welded plate and has been observed to be a basic parameter for guaranteeing weld quality. Diving the shoulder underneath the plate surface builds the weight beneath the device and keeps up sufficient producing of the material at the back of the device. The dive profundity should be accurately set, both to guarantee the essential descending weight is accomplished and to guarantee that the instrument completely infiltrates the weld. welding machine may redirect because of high loads thus lessen the dive profundity contrasted with the ostensible setting, which may results blemishes in the weld. Then again an inordinate dive profundity may result in the stick rubbing on the support plate surface or a critical under match of the weld thickness contrasted with the base material. Various load welders have been developed to automatically compensate for changes in the tool displacement while TWI has demonstrated a roller system that maintains the tool position above the weld plate.

3. Tool Design:

The basic tool consists of a tool shoulder which is attached to the spindle of the machine and a tool probe or pin which is plunged into the material to be welded .The design of the tool is a critical factor and a good tool can improve both the quality of the weld and the maximum possible welding speed. Schematic drawing of the FSW tool is as shown in Fig 1.2. It is attractive that the instrument material is adequately solid, extreme and hard wearing, at the welding temperature. Further, it should have a good oxidation resistance and a low thermal conductivity to reduce the heat loss and thermal damage to the machine. Inside thickness scopes of 0.5 - 50 mm however further developed instrument materials are essential for all the more requesting applications, for example, exceedingly grating metal lattice composites or higher dissolving point materials, for example, steel or titanium.

Improvements in tool design have been proven to cause substantial improvements in productivity and quality. TWI has created devices particularly intended to build the profundity of infiltration thus increment the plate thickness that can be effectively welded. The dominant part of instruments have an inward shoulder profile which goes about as a break volume for the material uprooted by the stick and keeps material from expelling out of the sides of the shoulder and keeps up downwards weight and subsequently great fashioning of the material behind the device. The conical profile uses an alternative side. Which are intended to produce additional movement of material in the upper layers of the weld with increasing experience and some improvement in understanding of material flow, the tool geometry has evolved significantly. Complex features have been added to alter the material flow, mixing and reduce process loads.

4. Tool Geometry:

Instrument geometry is the most compelling part of process improvement. The tool geometry plays a vital role in material flow and in turn controls the traverse rate at which FSW can be conducted. An FSW tool consists of a shoulder and a pin as shown schematically in Fig1.3. As made reference to before, the instrument has two essential capacities (a) Localized heating, and
(b) Material flow.
In the underlying phase of hardware dive, the warming outcomes essentially from the erosion among stick and work piece. The instrument is dove till the shoulder contacts the work piece. The friction between the shoulder and work piece results in the highest component of heating.
From the warming angle, the relative size of stick and shoulder is vital, and the other plan highlights are not basic. The shoulder likewise gives guardianship to the warmed volume of material. The second capacity of the instrument is to mix and move the material. The consistency of microstructure and properties and additionally process loads is represented by the device plan. Friction stir Welding tools are shown in Fig 3.2

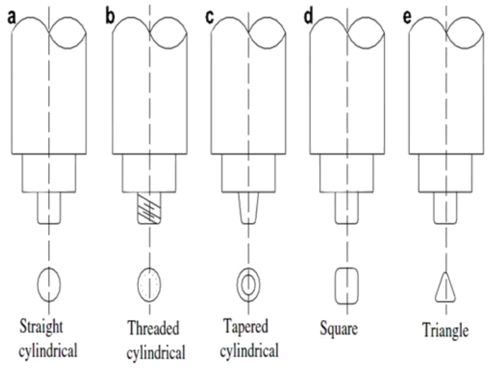


Figure 3.1 Friction stir welding tool profiles
SC: Straight cylindrical pin profiled tool
TH: Threaded cylindrical pin profiled tool
SQ: Square pin profile tool
TR: Triangular pin profiled tool
TC: Tapered cylindrical pin profiled tool.

5. Tool Shoulders

Tool shoulders are designed to produce heat to the surface and subsurface regions of the work piece through friction and material deformation. The instrument bear delivers a dominant part of the deformational and frictional warming in thin sheet; while the pin produces a majority of the heating in thick work pieces. Also the shoulder generates the downward forging action necessary for weld consolidation. The two types of tool shoulders are

1. Convex shoulders
2. Concave shoulders

Welding Parameters

For FSW, two parameters are essential: apparatus pivot rate (v, rpm) in clockwise or Counterclockwise course and device navigate speed (n, mm/min) along the line of joint. Higher apparatus pivot rates produce higher temperature on account of higher grinding warming and result in more extreme mixing and blending of material. Be that as it may, it ought to be noticed that frictional coupling of hardware surface with work piece will control the warming. Further, the addition profundity of stick into the work pieces (additionally called target profundity) is essential for creating sound welds with smooth apparatus shoulders. The putting profundity of stick is related with the stick stature. At the point when the inclusion profundity is too little, the shoulder of hardware does not contact the first work piece surface. In this way, pivoting shoulder can't move the mixed material from the front to the back of the stick, bringing about age of welds with internal ch productively annel or surface depression. Table 3.1 Main process parameters in Friction stir welding

Parameter	Effects
Rotation speed	Friction heat, "stirring", oxide layer breaking and mixing
Tilting angle	The appearance of the weld, thinning.
Welding speed	Appearance, heat control
Down force	Friction heat

FSW Terminology

a) Tool: The tool is defined as the rotating piece designed to generate heat, plastically deforming the weld material in order to form the bond.

b) Probe: The probe is the part of the tool which is plunged below the surface of the work piece being welded. It could conceivably be "stick formed" and might possibly exist contingent upon the application.

c) Shoulder: The shoulder of the tool rests on the surface of the material being welded and may be plunged slightly into it.

The probe is always of a greater diameter than the shoulder.

d)Leading & trailing edge :The leading and trailing edge terminology used as an analogy to airfoils, Thread gill points out, is misleading due to the fact that most tools are cylindrical and therefore do not have edges. The terms leading face and trailing face will be used to differentiate between the front and rear limb of the tool, as the front is described as the direction of Travel.

e) Heel: In the event that the tool is tilted away from the direction of travel and the Shoulder is plunged into the material, the portion of the shoulder under the material is called the heel.

f) Tool title angle: The angle of the tool with respect to the vertical axis is known as the title angle or travel angle.

g) Heel plunge depth: The amount the tool shoulder is plunged into the work piece is known as the heel plunge depth.

The terminology was used in the FSW to know the actual understanding of the different operations worked in FSW.

Materials Thickness of FSW

Friction stir welding can be used for joining various types of materials and material combinations, if tool materials and designs can be found, which operate at the forging temperature of the work pieces. For aluminum alloys, the following alloys are easily welded. Maximum thickness in a single pass is dependent on machine power, but values 50mm are achievable. TWI has welded 75mm material in a single pass, and larger thicknesses are possible.

Other materials successfully welded include:

- Copper and its alloys (up to 50mm in one pass)

- Lead
- Titanium and its alloys
- Magnesium alloys
- Zinc
- Plastics
- Stainless steel (austenitic, martensitic and duplex).

IV. DIFFERENT ZONES IN FSW.

The main endeavor at grouping microstructures was made by P L Thread gill (Bulletin, March 1997). This work depended exclusively on data accessible from aluminum amalgams. However, it has become noticeable from work on other materials, that the behavior of aluminum alloys is not typical of most metallic materials and therefore the plan cannot be broadened to encompass all materials. It is along these lines recommended that the accompanying amended plan is utilized. This has been developed at The Welding Institute(TWI), but has been discussed with a many number of appropriate people in industry and academia and has also been provisionally accepted by the Friction Stir Welding Licensees Association.

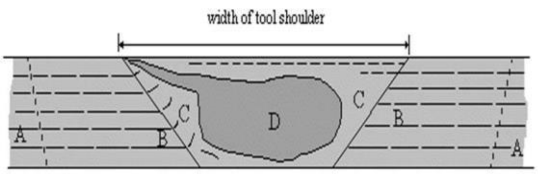


Fig 4.1 Schematic view of friction stir weld zone microstructure

There are mainly four zones in FSW
A. Unaffected material
B. Heat affected zone (HAZ)
C. Thermo-mechanically affected zone (TMAZ)
D. Weld nugget (Part of thermo-mechanically affected zone)

UNAFFECTED MATERIAL

This is the material remove from the weld, which is deformed, and which although, it may have experienced a thermal cycle from the weld is not affected by the heat in terms of microstructure or mechanical properties.

HEAT AFFECTED ZONE

In this region, which clearly will lie closer to the weld center, the material has experienced a thermal cycle, which has modified the microstructure or the mechanical properties. However, there is no occurrence of plastic deformation in this area. In the past framework, this was alluded to as the "thermally influenced zone". The term warm influenced zone is presently favored, as this is an immediate parallel with the warmth influenced zone in other warm procedures, and there is little legitimization for a different name.

THERMO MECHANICALLY AFFECTED ZONE

In this region, the material has been plastically deformed by the friction stir welding tool and the heat from the process will also exert some influence on the material. In the case of aluminum, it is possible to get significant plastic strain without Recrystallization in this region, and there is generally a deformed zones of the TMAZ. In the earlier classification, these two sub-zones were treated as different micro structural regions. However, subsequent work on other materials has shown that aluminum behaves in a different manner compared to other materials, in that it can be extensively deformed at high temperature without recrystallization. In different materials, the unmistakable Recrystallized area (the piece) is missing, and the entire TMAZ seems, by all accounts, to be recrystallized.

WELD NUGGET

The recrystallized territory of aluminum compounds TMAZ has customarily been known as the chunk. In spite of the fact that this term is illustrative, it isn't extremely logical. Be that as it may, its utilization has turned out to be boundless, and as there is no word which is similarly basic with more prominent logical legitimacy, this term has been embraced. A schematic outline is appeared in the above Figure (3.5.1) which plainly distinguishes the different locales. It has been proposed that the zone quickly underneath the apparatus bear (or, in other words of the TMAZ) ought to be given a different classification, as the grain structure is regularly extraordinary here. The microstructure is dictated by rubbing the back substance of the shoulder and the material may have cooled beneath to its greatest. It is proposed that this zone is treated as a different sub-zone of the TMAZ.

V. EXPERIMENTAL PROCEDURE

The main material used in the experiments was 5083 (Si 0.122%, Fe 0.250%, Cu 0.024%, Mg 4.528%, Cr0.076%, Zn 0.023%, Ti 0.011%, Al Bal. mass fraction) Al alloy, the most commonly used material for vessel construction among the 5000-series of Al alloys. The experimental study includes the butt joining of 4 mm AA 5083 plates. The welding process is carried out on a vertical milling machine (Make HMT FM-2, 10hp, 3000rpm) as shown in fig 4.1. Tool will be held in tool arbor as shown in fig 4.7. Special welding jigs and fixtures are designed to hold two plates of 150 mm X 75 mm X 4 mm thickness as shown in fig. demonstrates the blends of the apparatus rotational speed (rpm), welding speed (mm/min) and device geometry and width of the device shoulder to the breadth of the instrument stick (Ds/Dp). These combinations are chosen based on the literature survey and the capability of the milling machine used for the experimental study.

Figure 5.1 Schematic Diagram of Vertical Milling Machine

CHEMICAL COMPOSITION OF ALUMINIUM 5083 ALLOY

Table 5.1 Chemical Composition of 5083

Chemical Element	% Present
Al	92 - 94
Fe	0.4
Cu	0.1
Mg	4.0 - 4.9
Mn	0.4 - 1.0
Si	0.4
Zn	0.25
Ti	0.15
Cr	0.05 - 0.25

PHYSICAL PROPERTIES

Property	Value
Density	2.65 g/cm³
Melting Point	570 °C
Thermal Expansion	25 x10-6 /K
Modulus of Elasticity	72 GPA
Thermal Conductivity	121 W/m.K
Electrical Resistivity	0.058 x10-6 Ω .m

SPECIMEN MAKING PROCEDURE

The amalgam chose was AA5083. Two 9.5-mm-(0.374-in.-) thick plates for each sort of the material were joined utilizing rubbing mix welding on the Supermill-5VR plant at the University of South Carolina. The FSW instrument is made of hardware steel with a strong stick. The outside distance across of the device is 28 mm (1.1 in.) and the stick width and length are 10 mm and 7.5 mm (0.394 and 0.295 in.), separately. The movement speed for welding is 113 mm/min (4.4 in. /min) with an axle speed of 215 rpm .A schematic of the friction stir welding process is shown in Fig.5.1 After welding, cylindrical specimens are cut from the base metal and the weld zones of the aluminum plate. The orientation of the cylindrical axis of the specimen was perpendicular to the aluminum plate, as shown schematically in Fig 4.10.The specimen has a diameter of 20 mm (0.787 in.) and thickness of 9 mm (0.354 in).

WELDING PROCESS

FSW is a solid state joining process carried out on a vertical milling machine. The plates to be welded are initially machined to the required dimensions and the process operations. A clamping system must keep the work-pieces rigidly fixed using fixtures onto a backing bar to prevent the abutting joint faces as shown in the figure. Prior to welding initially a hole is made using a drill bit that is fixed in the tool holder then the drill bit in the tool holder is replaced with the weld tool. Then the shouldered pin is rotated at constant speed and plunged into the joint line between the two metal sheets butted together.

Fig 5.2&5.3 clamping the plates with fixtures

Once the tool probe has been completely inserted the shoulder base will be in contact with the base metal surface so that it can take part in heating the metal surface for proper weld to occur. While rotating, it is moved at constant advancing velocity along the welding line.

There are two instrument velocities to be considered in rubbing mix welding how quick the apparatus turns and how rapidly it crosses the interface. These two parameters have great significance and must be picked with consideration to guarantee a fruitful and effective welding cycle.

Due to the rotation and the advancing motion of the pin, the material close to the tool, in the so called stir-zone, is softened by the heat generated by the stirring effect (plastic dissipation) what's more, the warmth instigated by the contact grating between the test, shoulders and the sheet. As a consequence, the material is stretched and forged around the rotating probe flowing from the advancing side to the retreating side of the weld, where it can rapidly chill off and unite, to make a brilliant strong state weld. Each weld combination has been given its own nomenclature in order to avoid confusion of the weld speeds on the welds conducted.

Figure 5.4 Welded plate at condition 1

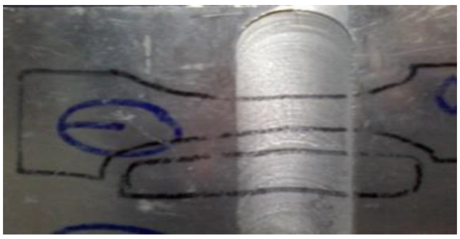
Figure 5.5 Welded plate at condition 2

VI. RESULTS AND DISCUSSION

Amid FSW, the material stream around the instrument stick is because of the warmth produced by the grating and blending activity. In combination welding of copper deserts like porosity, slag considerations cementing breaking and so forth.decays the weld quality and joint properties. As a rule, grating blend welded joints are free from these imperfections, since there is no liquefying happens amid welding and the metals are participated in the strong state itself because of warmth produced by contact and stream of the metal by the mixing activity.

VISUAL ASSESMENT OF FSW WELDS

Figure 6.1 shows a top view of the FSW welds.



Sample1:
TR= 710 rpm
Welding speed=80mm/min

Sample2:
TR= 710 rpm
Welding speed=160mm/min

TENSILE PROPERTIES

The transverse tensile properties such as yield strength, tensile strength and percentage of elongation of the joints were evaluated. Tensile strength & yield stress was observed at the fusion zone of aluminum welds at different tool rotation speeds i.e. 710rpm, 900rpm and welding speeds of 40mm/min , 80mm/min , 125mm/min , 160mm/min.

The tensile strength was observed i.e., 185 MPa and the yield was 136.258 MPa at the fusion zone of aluminum welds at tool rotation speed of 710rpm and a welding speed of 80mm/min with (D/d ratio 4) tool pin profile. This is due to the fact that with increase in tool rotation speed coarse grain structure produced which results in low ultimate tensile strength.

Graph 1: Mechanical properties by varying the welding speeds with 710 rpm:

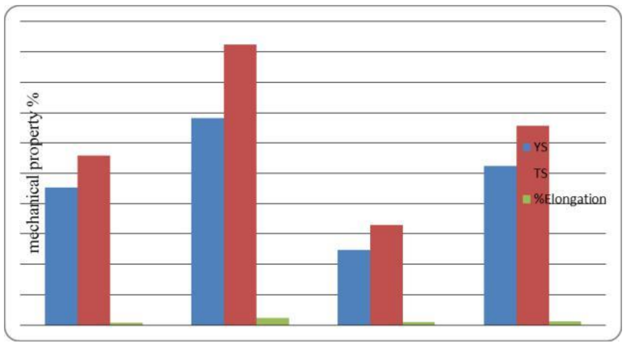


Fig6.2 Mechanical properties for base metal at various travel speeds and 710 rev/min rotational speeds

Graph 2: Mechanical property by varying the welding speeds with 900 rpm:

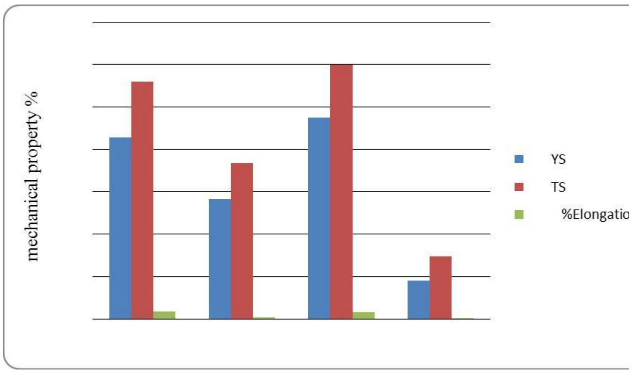
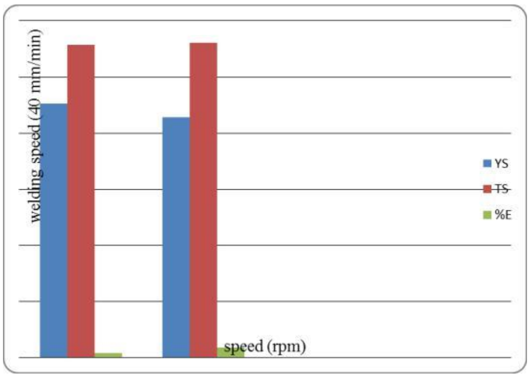
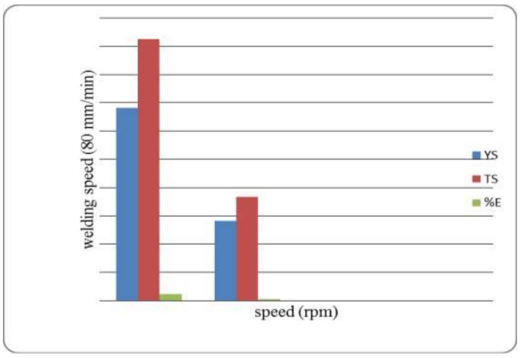


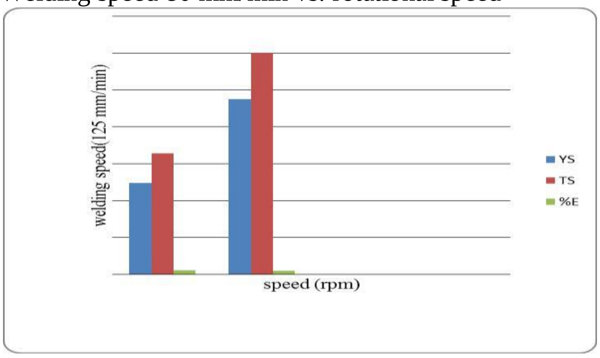
Fig6.3 Mechanical property for base metal at various travel speeds and 900 rev/min rotational speeds



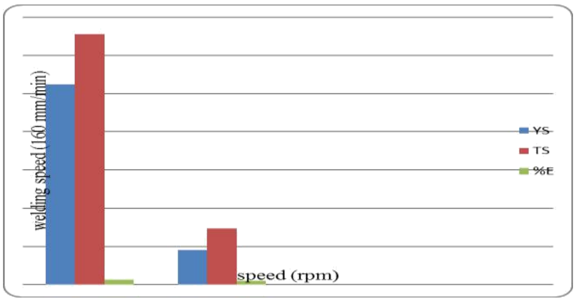
Welding speed 40mm/min vs. rotational speed



Welding speed 80 mm/min vs. rotational speed



Welding speed 125 mm/min vs. rotational speed



Welding speed 160 mm/min vs. rotational speed

IMPACT STRENGTH

Impact toughness was observed at the fusion zone of aluminum welds with pin profile at 710 rpm and constant welding speed 80mm/min was 19J, whereas the Toughness is higher due to the presence of fine grain size. The result of impact test showed that samples welded at lowest rotational speeds and has maximum impact energy as compared with those welded at higher tool rotational speed.

Table 5.1 optimum mechanical properties of FSW

in pro file	**T ool rotatio n speed(r pm)**	**T ravers e speed (mm/ min)**	**S MP a)**	**TS MP a)**	**l (%)**	**ardn ess (HRB)**	**mpa ct stre ngth (J)**
ape red con ical	7 10rpm	8 0mm/ min	36. 258	85. 090	.5 6	74	19

MICROSTUDY

1) Weld: The microstructure consists of equiaxed dendrites of Al with a fine precipitates of Mg, AL dendrites at dendrite boundaries with G.S No: 6-7 HAZ: The microstructure of HAZ shows equiaxed dendrites of Al with much Mg, AL precipitates near dendrite boundaries with G.S No: 6-7 Parent metal: The microstructure consists of fine grains of Mg,Si,Fe, in the matrix of Al with grain size num 4-5

2) Weld: The microstructure consists of equiaxed dendrites of Al with a fine precipitates of Mg, AL dendrites at dendrite boundaries with G.S No: 5-6 HAZ: The microstructure of HAZ shows equiaxed dendrites of Al with much Mg, AL precipitates near dendrite boundaries with G.S No: 6-7 Parent metal: The microstructure consists of fine grains of Mg,Si,Fe,in the matrix of Al with grain size Num 4-5

3) Weld: The microstructure consists of equiaxed dendrites of Al with a fine precipitates of Mg,Al dendrites at dendrite boundaries with G.S No: 6-7 HAZ: The microstructure of HAZ shows equiaxed dendrites of Al with much Mg,Al precipitates near dendrite boundaries with G.S No: 6-7 Parent metal: The microstructure consists of fine grains of Mg,Si,Fe,in the matrix of Al with grain size num 5-6

4) Weld: The microstructure consists of equiaxed dendrites of Al with a fine precipitates of Mg,Al dendrites at dendrite boundaries with G.S No: 5-6 HAZ: The microstructure of HAZ shows equiaxed dendrites of Al with much Mg,Al precipitates near dendrite boundaries with G.S No:5- 6 Parent metal: The microstructure consists of fine grains of Mg,Si,Fe,in the matrix of Al with grain size num 4-5

5) Weld: The microstructure consists of equiaxed dendrites of Al with a fine precipitates of Mg,Al dendrites at dendrite boundaries with G.S No: 5-6 HAZ: The microstructure of HAZ shows equiaxed dendrites of Al with much Mg,Al precipitates near dendrite boundaries with G.S No: 6-7 Parent metal: The microstructure consists of fine grains of Mg,Si,Fe,in the matrix of Al with grain size num 4-5

6) Weld: The microstructure consists of equiaxed dendrites of Al with a fine precipitates of Mg,Al dendrites at dendrite boundaries with G.S No: 7 HAZ: The microstructure of HAZ shows equiaxed dendrites of Al with much Mg,Al precipitates near dendrite boundaries with G.S No: 7 Parent metal: The microstructure consists of fine grains of Mg,Si,Fe, in the matrix of Al with grain size num 6-7

7)Weld: The microstructure consists of equiaxed dendrites of Al with a fine precipitates of Mg,Al dendrites at dendrite boundaries with G.S No: 5-6 HAZ: The microstructure of HAZ shows equiaxed dendrites of Al with much Mg,Al precipitates near dendrite boundaries with G.S No: 6-7 Parent metal: The microstructure consists of fine grains of Mg,Si,Fe, in the matrix of Al with grain size num 4-5

8) Weld: The microstructure consists of equiaxed dendrites of Al with a fine precipitates of Mg,Al dendrites at dendrite boundaries with G.S No: 5-6 HAZ: The microstructure of HAZ shows equiaxed dendrites of Al with much Mg,Al precipitates near dendrite boundaries with G.S No: 6-7 Parent metal: The microstructure consists of fine grains of Mg,Si,Fe,in the matrix of Al with grain size num 4-5

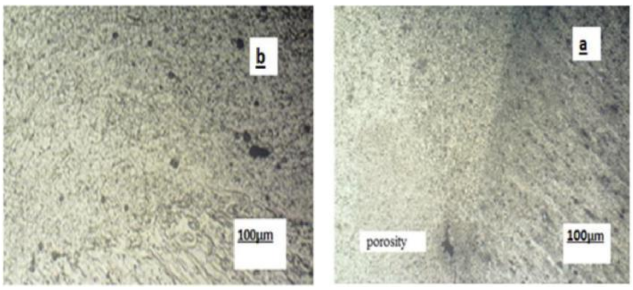


Fig6.4 Optical microstructure at different location corresponding to locations for 710rpm rotation speed. (a) 40mm/min (b) 80mm/min

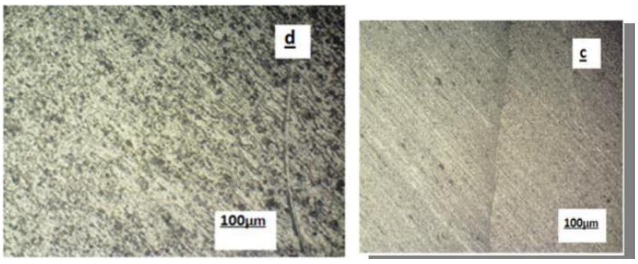


Fig6.5. Optical microstructure at different location corresponding to locations for 710rpm rotation speed. 125mm/min &160mm/min

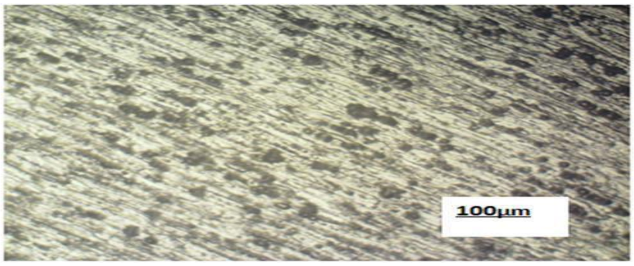


Fig6.6 Base metal of aluminum 5083

VII. CONCLUSIONS

Friction stir Welding of AA5083 was successfully obtained for different welding speeds, rotation speeds and the tool profile.

Based on the analyzed results the following can be concluded.

1. Among two welds of 710 rpm, weld with same rotational speed & 80 mm/min traverse speed with conical profile resulted in good mechanical properties.
2. Among two welds of 900 rpm, weld with same rotational speed & 125 mm/min traverse speed with conical profile resulted in good mechanical properties.
3. It is observed that, at 710 rpm, the mechanical properties are better than at 900 rpm, this is due to sufficient heat is obtained.
4. The weld with conditions of 710 rpm & 80 mm/min gives the best results as compared to the other welding conditions.
5. At 710rpm and travel speed of 80mm/min the equiaxed fine grain size obtained and the grain sizes are half of the base metal grains.
6. The tensile strength decreases as the tool rotation increases. At 710rpm the strength was 185 M Pa. because at this condition the heat input is sufficient due to cold deformation.

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