EFFECT OF TiO_2 NANOPARTICLES ON FRICTION STIR WELDED JOINTS OF AA8011 ALUMINIUM ALLOY

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Abstract - *The present work investigates the Effect of TiO_2 nanoparticles on friction stir welded joints of AA8011 aluminium alloys. In this test 100x50x6mm dimensioned plates of AA8011 aluminum alloys are used test for FSW, where the tool rotates on the edges of two plates to give a complete the weld joint. Here, Titanium dioxide nanoparticles were added into the groove of size 2.5mm(W)×5mm(H) before the welding process and the welding tool is moved along the edges of similar aluminium alloys AA8011 on semi-automated milling machine to complete the welded joint. Tool geometry depends on probe length, shoulder size and pin shape which influences the heat generation and material flow in the hard condition. The shoulder produces high heat which plasticizes the material and the welded joint can form effectively in the solid state. Here the welding tool with hexagonal pin is used effectively, which improves mixing of nanoparticles in the stir zone. As it is clear from the literature the strength of the friction stir welding joint is higher than the conventional fusion welding process. The strength of the welded joint in FSW depends on the process parameters like rotational speed, welding speed, axial load and tilt angle. In order to further enhance the mechanical properties of the welded joint, the microparticles can be deposited during welding process. So, in this study we evaluate the mechanical properties and microstructure of the welded joints.*

A comparison has made between the experimental values and the recently published journal papers. The maximum peak stress obtained was 52.98 MPa at 1400RPM, welding speed of 25mm/min and tilt angle of 1.5^0. The maximum impact value obtained was 5.0 joules weld 8, maximum Microhardness of 22.79 VH average for weld8.

***Keywords**:Aluminium alloys AA8011, TIO2 nanoparticles, SEM, Friction Stir welding, Microstructure and Mechanical properties, modified Tool.*

1. INTRODUCTION

The friction stir welding (FSW) may be a new welding technique in domain of welding. it's solid condition welding process and invented by the welding institute (TWI) of Cambridge, England in 1991. This procedure is easy, environment friendly, energy efficient and becomes major attraction for an automobile, aircraft, marine and aerospace industries because of the high strength of the FSW joints as near as base metal. It allows considerable weight savings in light weight construction compared to standard joining technologies. In contrast to standard joining welding process, there's no liquid state for the weld pool during FSW, the welding takes place within the solid phase below the freezing point of the materials to be joined. Thus, all the issues associated with the solidification of a fused material are avoided. Materials which are difficult to fusion weld just like the high strength aluminium alloys may be joined with minor loss in strength. In friction stir welding a non-consumable rotating tool with a specially profiled threaded/ unthreaded pin and shoulder is rotated at a relentless speed. The tool plunges into the 2 pieces of sheet or plate material and thru frictional heat it locally plasticized the joint region. The tool then allowed to stir the joint surface along the joining direction. During tool plunge, the rotating tool undergoes only rotational motion at only 1 place till the shoulder touches the surface of the work material, this is often called the dwelling period of the tool. During this stage of tool plunge it produces lateral force orthogonal to welding or joining direction. the subsequent diagram depicts the procedures of FSW. The side of the weld consists of fabric that's dragged by the shoulder from the retreating side of the weld, and deposited on the advancing side. After the dwell period the tool traverse along the joining direction, the advance of the tool produces force parallel to the direction of travel called traverse force. After the successful weld, the tool reaches to termination phase where it's withdrawn from the work piece. this can be shown in fig. 1.1. During the welding process the parts must be clamped rigidly onto a backing bar in an exceedingly manner that forestalls the abutting joint faces from being forced apart. The length of the tool pin is slightly but the weld depth required and also the tool shoulder should be in intimate contact with the surface. Besides tight clamping of the members to be welded, the key to success is to pick out the optimum parameters which include rotational speed, welding speed, axial force, and gear pin yet as shoulder profile. Detailed description of FSW process is shown in Fig.1.2.

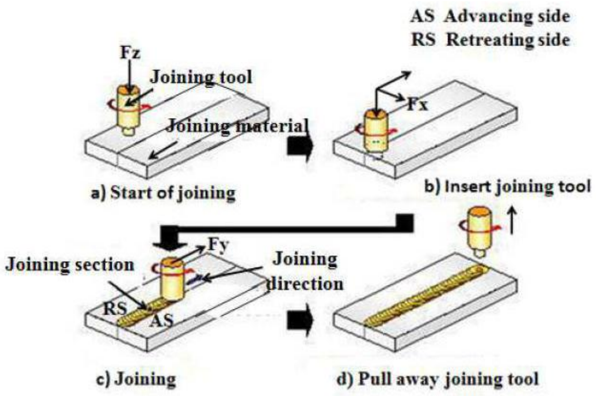


Fig. 1.1: Schematic representation of FSW

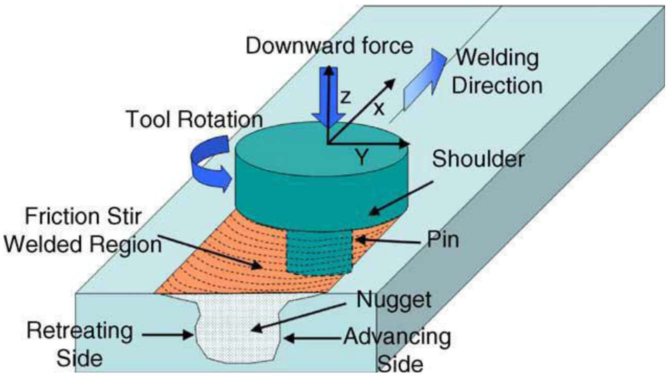


Fig. 1.2: Friction stirs welding

Hou and Baeslack 1996, Aluminium is one of the materials which are not easy to join by fusion welding methods. This is due to the low melting indicating and low hardness of the material. Conventional fusion welding process such as metal inert gas (MIG) and plasma arc welding (PAW) frequently create adverse cast microstructures in aluminium. Big distortions are cause by shrinkage in weld metal and heat affected zones. In adding together widespread soften will happen in the HAZ, lowering the mechanical properties.

D. Maneiah and Prahlada Rao performed the experimental examination on friction stir butt welded aluminum alloys AA6061-T6 alloy using taguchi L9 untried approach The aluminum 6061-T6 alloy is successfully welded by the friction stir welding process. The Taguchi optimization is performed where the optimum conditions are rotational speed 1000 to 1250RPM, tilt angle 0.5 to 1 degree and feed 30 to 60 mm/min for the response temperature 170°C. And for the response hardness at the weld bead the optimum conditions are rotational speed 750 to 1250RPM, tilt angle 0.5 to 1 degree and feed 60 to 90 mm/min, where the hardness is found to be higher i.e. 95BHN.

Dr. Ch.S.Naga Prasad et al. performed In this project cutting tool taper is designed for the FSW of two dissimilar materials Aluminium alloy 5083 and aluminium alloy6061. Modelling is done in Engineer. Structural and modal analysis is performed on the circular and taper tool to validate the deformation and stresses. By study the results, stresses produced are decreased circular tool. Two plates of the AA5083 and AA6061 are welded experimentally on a vertical CNC machine using 700rpm speed for circular cutting tool. Tensile strength, microstructure, impact and hardness are calculated after welding. By scrutinize the tensile test results; ultimate tensile strength is decreasing by increased and hardness test results, the yield stress value 51.43MPa.

Ankur S Vasava et al. in this review stated advantages of FSW that low distortion, shrinkages, fuller metal, low HAZ, free spotter, porosity etc emerging as on to fusion welding.

Arun kumar kadian et al. found that taper pin tool during low quantity of material mixing than cylindrical tool and also reduce the utmost heat obtained by the weld. Cylindrical tool pin in FSW produced fine microstructure.

Noor Zaman Khan et al. studied the effects of strain rate & heat age group on traverse force in FSW of AA2219, AA7475 aluminium alloys, This work has attempt to estimate strain rate through measured values of grain size and welding heat and found its correlation with flow stress. The following conclusions are drawn in light of the grades of the conducted experimental investigation

Ravinder Reddy Baridula et al. studied the dissimilar aluminium alloys AA2024 and AA7075 by addition of multi-walled carbon nanotubes in to the nugget zone. The mechanical properties and microstructures were calculated by varying the traverse velocity at stable rotational velocity. The results show that revolving tool pin stirring act and temperature input play an important function in calculating the grain size.

2. METHODOLOGY

This chapter includes the details of the experiment carried out to fulfill the objective of this investigation of friction stir welding by using hexagonal tool pin with titanium nano particles powder filled in similar work pieces before welding process and by moving the welding tool on edges of both plates welded joint was obtained to wire cut EDM for desire standard shape. To get the results Mechanical testing like tension test, impact izod test, micro hardness test was done to understand the influence of nanoparticles on welded joint.

Aluminium alloy: Aluminium is the world most usable metal and the third most common element comprising 8% of the earths crust. Aluminium alloy during the 97% by adding chemical composition with copper, iron, magnesium, manganese, silicon, tin and zinc.

AA8011 which is commonly used household foil is an attractive material due to the fact that it can provide a suitable combination of strength and ductility agent in aluminium alloy AA8011 are the iron and silicon constituent particles.

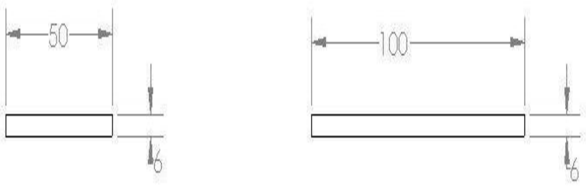
The Similar material aluminum alloy AA8011 was used in this investigation. Chemical compositions of the alloy material are given in the Table.1. Mechanical properties of aluminum alloy were given in Table.2. The Similar aluminum alloy used in this investigation was welded using Friction stir welding technique.

Table 2.1: Chemical composition of AA 8011 aluminum alloys

CHEMICAL COMPOSITION	Fe	Si	Mn	Mg	Zn	Cu	Ti	Cr	Al
AA 8011	0.74	0.52	0.46	0.28	0.08	0.1	0.01	0.02	Rem.

Table 2.2: Mechanical properties of AA 8011 aluminum alloys

MECHANICAL PROPERTIES	Tensile Strength MPa	Density Kg/m3	Thermal conductivity W/m-k	Melting point C	Hardness HRB
AA 8011	110	2689	237	660.2	60



Titanium oxide powder (TIO2): TIO2 which mean it consists of one titanium atom and two oxygen atoms (hence dioxide). Titanium found minerals in the earth's crust. It's also found with other element. Its having good tensile strengths.

Table 2.0 properties of TIO_2 powder

Properties	Values
Density	4.23 g/cm^3
Melting point	1843 ^{o}C
Boiling point	2972 ^{o}C
Solubility in water	insoluble
Band gap Magnetic susceptibility	3.05 eV 5.9x10^{-6} cm^3/mol.

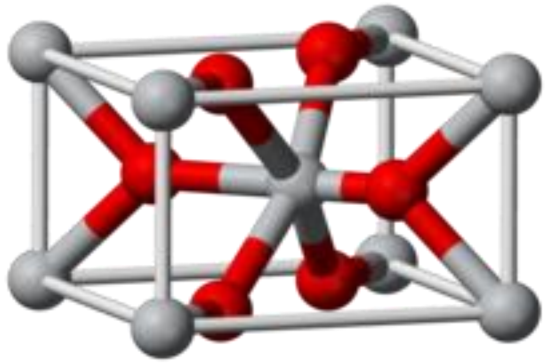


Table 2.4 chemical composition of H13 metal.

Element	C	Ch	Mn	P	Si	S	V
Percenta ge.(%)	0.3-0.4	4.7 - 5	0.2-0.5	0.0-0.3	0.8-1.2	0.0-0.3	0.8-1.2

Table 2.5 Physical properties of H1material

Properties of H13	**Values**
Density	7.80 g/cm^3
Melting point	1427 ^{o}C
Thermal expansion	10.4 x 10^{-6}/ºC
Thermal conductivity	28.6 W/mK
Properties of H13	**Values**
Tensile strength, (@20°C)	1200 - 1590 MPa
Modulus of elasticity	215 GPa
Reduction of area (@20°C/68°F)	50.00%
Tensile strength, yield	1000 - 1380 MPa.

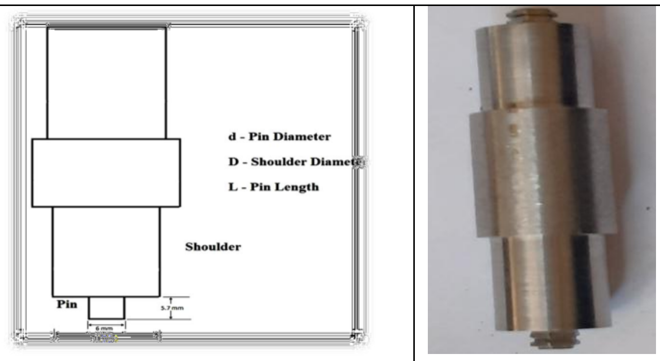


Figure 2.3: Tool Geometry

Table 2.3: Tool Geometry will given in Figure.

Details	**Dimensions**
Pin Length, L (mm)	5.7
Tool shoulder diameter, D (mm)	22
Pin diameter, d (mm)	10
D/d Ratio of tool	3.0
Tool pin geometry	Circular
Pitch (mm) and included angle (deg) of threaded pin	1 and 60
Chemical composition of the tool (wt %)	C-2.75, Si-0.60 max, Mn-0.60max Cr-13.5, Ni-.30 max, Grade- D3 (HSS)
Details	**Dimensions**
Pin Length, L (mm)	5.7
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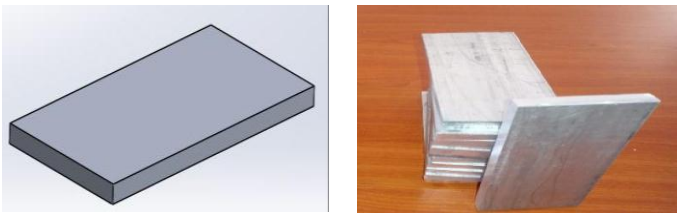
D/d Ratio of tool	3.0
Tool pin geometry	Circular
Pitch (mm) and included angle (deg) of threaded pin	1 and 60
Chemical composition of the tool (wt %)	C-2.75, Si-0.60 max, Mn-0.60max Cr-13.5, Ni-.30 max, Grade- D3 (High carbon steel High Chromium Steel)



Geometry AA8011

Figure 2.3A: AA8011 sample

Tool Details:

There are many types of tool materials available for FSW. In this experiment hexagonal shape high carbon high chromium tool was used. Dimensions and chemical composition of Tool will be given in the below table.

EXPERIMENTAL WORK

The plates of 6mm thickness AA8011 aluminum alloys were cut into required sizes (50 mm width x 100 mm length) using power hacksaw. A square but joint configuration was prepared to carry out the FSW joints. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Non consumable tool made up of High carbon High Chromium Steel was used for joining process. The aluminum alloys were joined by varying rotational speed in four levels namely 1400, 1120, 1400, 1120 and traverse speed in three levels namely 35, 25mm/min with the axial force of 15 KN. The tool used for fabricating the joints is made by High carbon High Chromium Steel of diameter 25 mm with shoulder diameter as 22mm and with a cylindrical pin of diameter 6mm. With the identified process parameters, the joints were fabricated. The fabrication process will be given in tool Figure2. As shown in Figure. 3 the direction of welding has been normal to the rolling direction. Single pass welding procedure has been followed to fabricate the joints.

Figure 2.4: Fabrication Method

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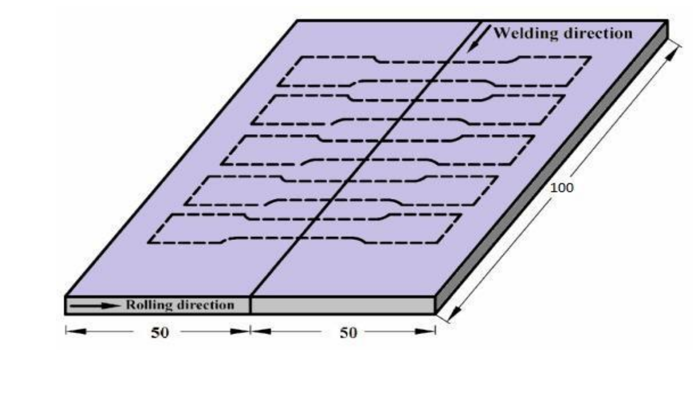


Figure 2.5: Scheme of welding with respect to rolling direction

MATERIAL CUTTING STANDARDS:

Electrical discharge machining is a metal fabrication process whereby required shape is obtained by using electrical discharges material is detached from the work piece of quickly frequent current discharges between two electrodes, divided by dielectric liquid and subject to an electric voltage. One of the electrodes is tool electrode and other one is named work piece electrode. The process depend on the tool and work piece not making physical contact, and it's controlled by CAD program, here the tool electrode is simply a wire.

Figure 2.6: EDM wire cut process

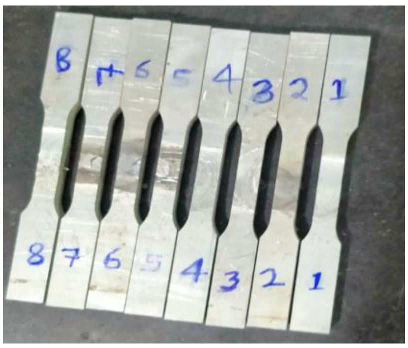


Figure 2.7: samples for tensile test after EDM wire cut machine

Tensile test

A tensile test is the most essential and usual types for mechanical testing of material. In tensile test a pulling force is applied to a material and finds out the specimens response to the stress created in it. By conducting tensile tests one can know how strong a material is to load applied to it and how much it can elongate with the load applied. A tensile test is mainly conducted on UTM-Universal Testing Machine and the tensile specimen is of standard ASTM E8 (American society for testing of material) i.e. standard dog bone shape sample as shown in the figure 3.20. The test results are plotted on a graph where this data results in a stress/strain curve which tells how the Specimen respond to the forces applied to it. In tensile test the point of break or failures is very crucial point to be noted, other important properties along with break or failure point is the elasticity, peak stress, peak load, yield strain, yield load, etc.

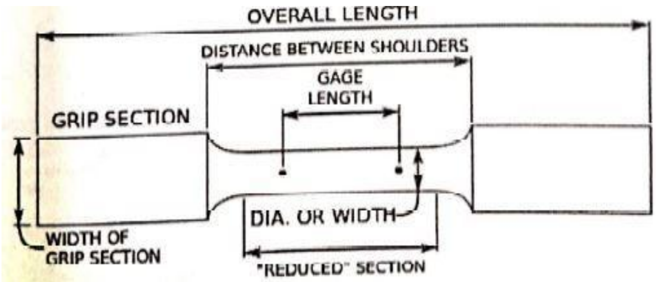


Figure 2.8: Tensile sample

ASTM E8: ASTM E8 Tension specimen (Dog Bone Shape) is made out the FS welded specimen in rectangular shoulder with 40mm gauge length with the help of EDM wire cut machine where a wire is passed through the welded specimen based on the path information given to it. A Dog Bone Shape input data is given to it and works according to the input command.

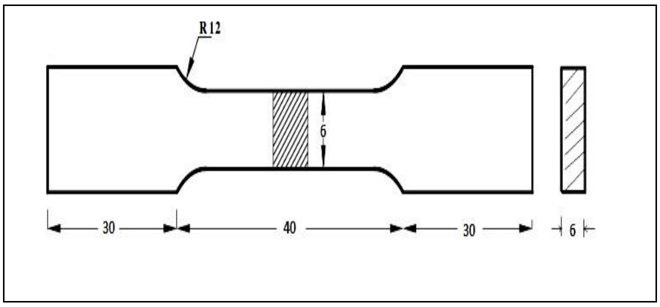


Figure 2.9: Tensile test sample

CHARPY IMPACT TEST:

The Impact Test entails protest a notched impact specimen with a wavering weight or a "tup" attached to a swinging pendulum. The specimen breaks at its notched cross-section upon impact, and the upward swing of the pendulum is used to regulate the amount of energy absorbed (notch toughness) in the process. Energy absorption is directly related to the brittleness of the material. Since temperature can affect the toughness of a material, the charpy test is executed at a series of temperatures to show the relationship of ductile to brittle transition in rivetted energy. ASTM E23 standard to EDM wire cut for charpy impact test shown the below figure.

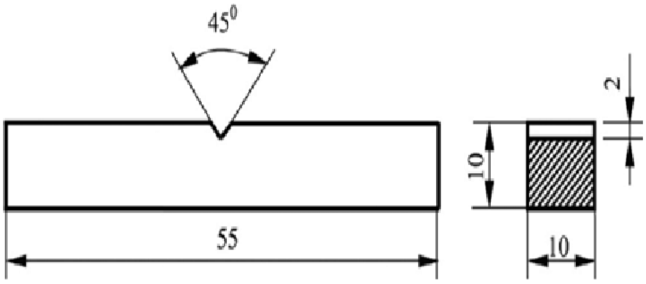


Figure 2.10: ASTM E23 for Charpy impact test

Figure 2.11: Impact test sample by EDM

MICROHARDNESS TEST:

Micro hardness Testing is a technique of defining a material's hardness or resistance to penetration when test samples or specimen are very small, thin and when small regions in a composite sample or plating are to be investigated or measured. Micro hardness test can provide precise and detailed data about surface features of materials that have a fine microstructure, multi-phase, non-homogeneous and also prone to cracking. By micro hardness test one can measure precisely surface to core hardness on carburized and case-hardened parts, as well as surface conditions such as grinding burns, carburization or decarburization. Micro hardness test specimen testing is carried on the specimen on which the Microstructure study is carried out.

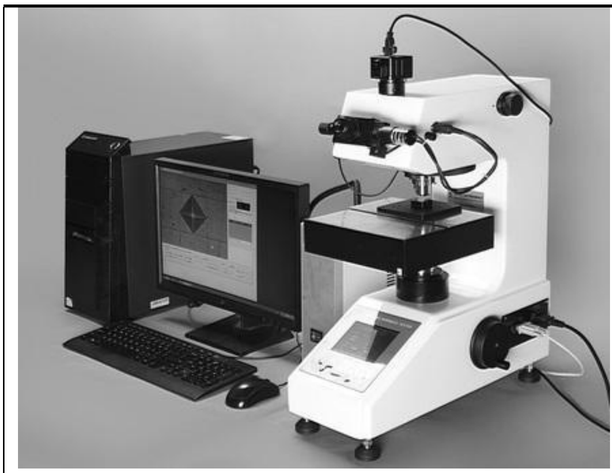


Figure 2.12: Digital Vickers hardness tester

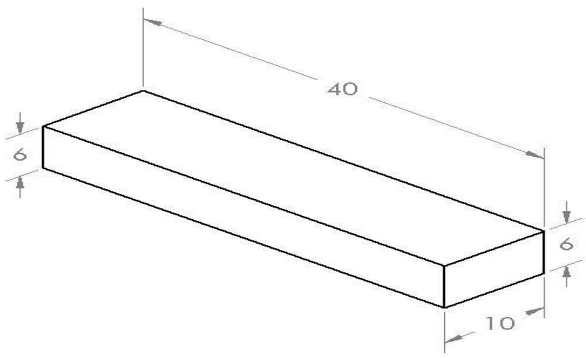


Figure 2.13: micro hardness test samples from EDM wire cut

MICROSTRUCTURE TEST

Metallographic Microscope examination was done in Crystal metallurgical laboratory in Hyderabad. Eight flat sample of thickness 6mm and overall length of 40mm and width is

10mm from welded specimen are used for metallographic examination to study the Microstructure of the specimen. The welded sample is trimmed or machined based on the required dimension for conducting the Metallographic test to study microstructure on a EDM wire cut machine in such a way that better microstructure can be revealed. The polished samples were etched with Keller's Etching agent used for Aluminium for 15 minutes to reveal microstructure. The microstructure of samples was examined by using optical Microscope. These different zone in specimen study were primarily characterized into (a)Weld zone or Nugget Zone and b) TMAZ c) HAZ zone and finally the parent material Zone.

Figure 2.14: Metallurgical microscopes

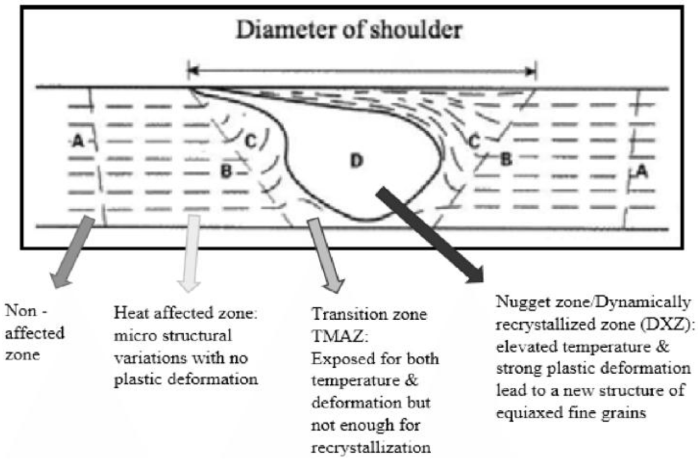


Figure 2.15: different zones in microstructure test

Note: here metallography test sample prepared same as well as hardness test sample.

3. RESULTS AND DISCUSSION

In experimental investigation of project is done the results and comparing by the result with standard papers mentioned in the Literature Review of this project, journal, with standard parameters like how and what is the percent of variation with respect to standard one of examination the results of friction stir welded of aluminum alloys by the addition of reinforcements are given below, it has been observed that the process parameters play an important role during of metals by FSW process.

Tensile test

Tensile test was conducted by using UTM and the results are given in following table 4.1. The parameter range of tool rotational speed 1400 rpm and welding speed of 25 mm/min and tilt angle 1.5^0 can gives the high range of Tensile Strength than other parameters. The tensile samples after the test are shown in the figure 4.1 below. The reading obtained while performing the tensile test are shown below in table4.1:

Table 3.1: Showing Reading Recorded while tensile test

Identification of the Sample	Tool rotation speed RPM	Weld speed mm/min	Tilt angle °	TENSILE TEST RESULTS					
				C/S Area (mm²)	Ultimate Load (KN)	UTS (MPa)	Yield Strength (MPa)	% Elongation	Results/ Remarks
Weld '1'	1120	25	1	37.50	1.48	39.48	30.13	09.24	Broken in Weld Zone
Weld '2'	1400	35	1	35.82	1.20	33.50	31.27	09.96	
Weld '3'	1120	35	1	36.36	0.80	22.00	09.90	05.72	
Weld '4'	1400	25	1	33.33	1.24	37.09	32.30	06.40	
Weld '5'	1120	25	1.5	37.50	1.20	32.00	26.67	05.92	
Weld '6'	1400	35	1.5	37.27	1.16	31.12	2.68	07.20	
Weld '7'	1120	35	1.5	36.36	0.82	22.01	09.94	05.71	
Weld '8'	1400	25	1.5	34.75	1.84	52.95	34.53	08.12	

Calculating Strain using %Elongation:

Gauge Length = 40mm (initial length L1)

L2 = final length

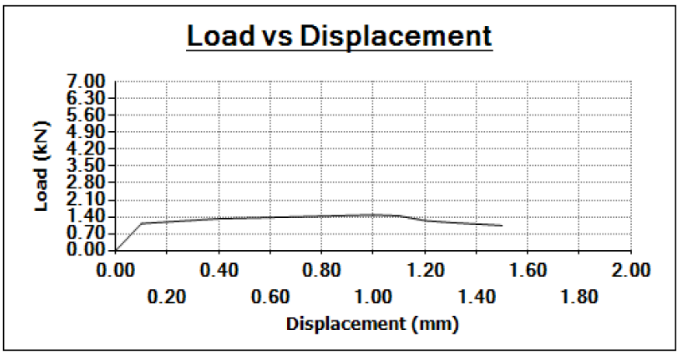
Therefore:

L1 – L2/L1= 16

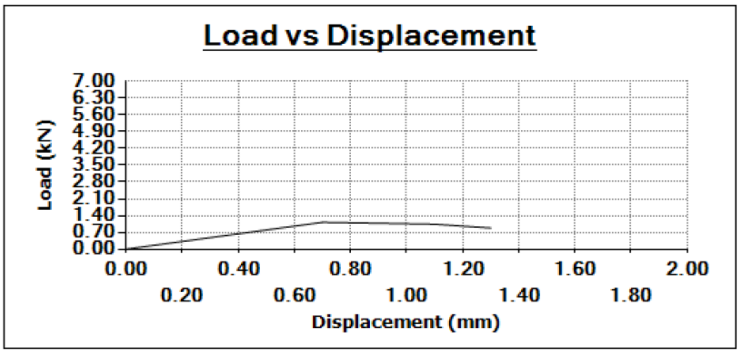
After calculation L2= 43.2mm

From above calculation we can know that after break the final gauge length is 43.2mm.

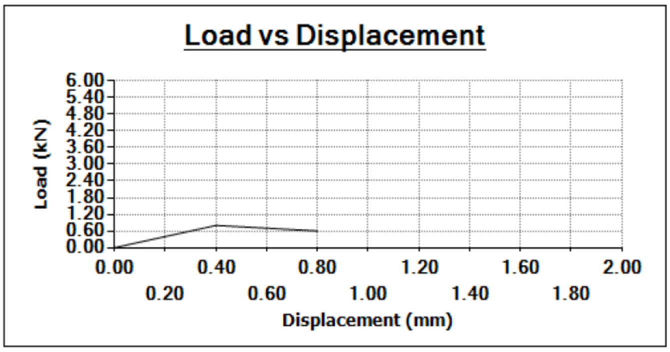
Note: The displacement vs load curve for ten samples as shown below graphs:



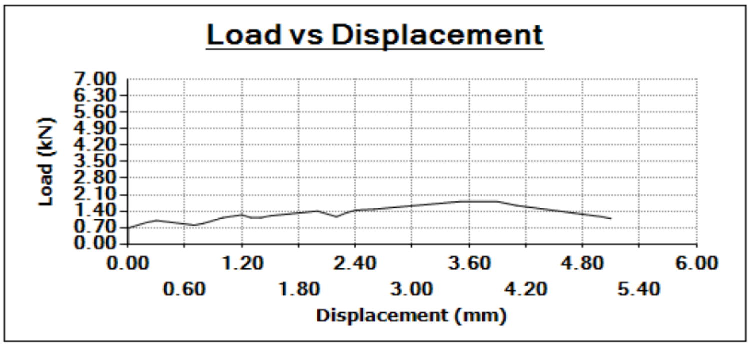
Graph 1: Sample 1



Graph 2: Sample 2



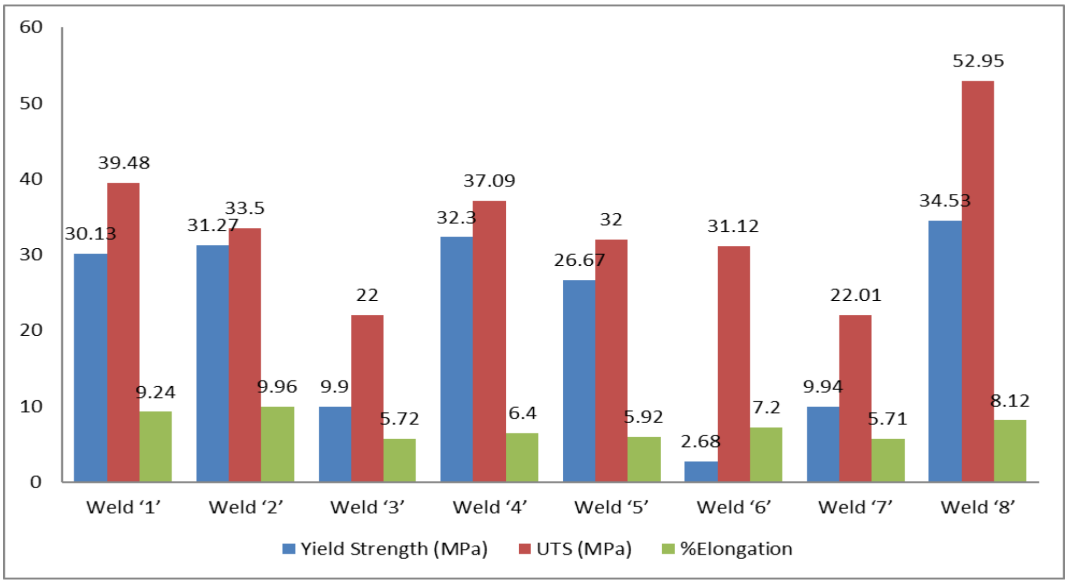
Graph 3: Sample 7



Graph 4: Sample 8

Figure 3.1: load vs dispacement graphs of eight samples

Figure 3.2: Tensile Test specimen after Break.



Graph 3.1: UTS and yield strength and %elongation graphs

- From the above data we can clearly notice that Highest peak stress is 52.95 MPa for Hexagonal Tool pin profile at 1400 rpm, 25mm/min weld speed, 1.5^0 tilt angle on UTM.

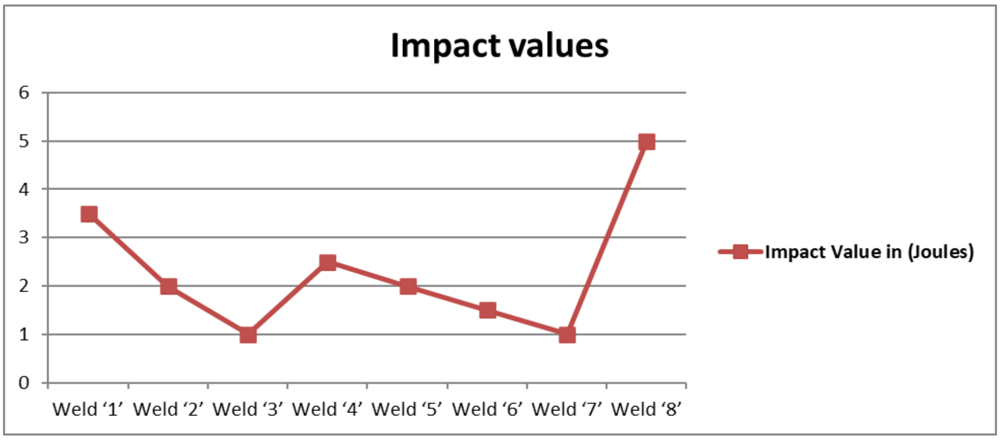
CHARPY Impact Test

Charpy impact test was conducted by using impact tester machine and the results are given in following table 4.3. The parameter range of tool rotational speed 1400 rpm and welding speed of 25 mm/min and tilt angle 1.5^0 etc. can gives the high range of impact value than other parameters. The impact samples after the test are shown in the figure. The reading obtained while performing the charpy impact test are shown below in table 4.2:

Table 3.2: Showing Reading Recorded while the charpy impact test

Observed Values in Joules	
Sample ID	**Impact Value in (Joules)**
Weld '1'	3.5
Weld '2'	2.0
Weld '3'	1.0
Weld '4'	2.5
Weld '5'	2.0
Weld '6'	1.5
Weld '7'	1.0
Weld '8'	**5.0**

Figure 3.3: Impact test specimen after break



Graph 3.2: Graph of charphy Impact Value

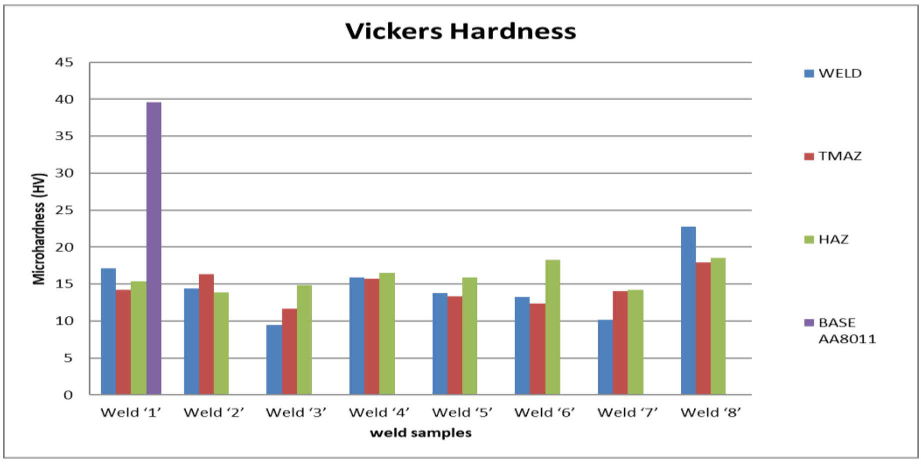
MICROHARDNESS TEST

The micro hardness test conducted on Vickers hardness tester to the welded specimen was measured using diamond intender for various welded specimens with varying rotational speed and transfer speed were prepared and tested. Hardness values consider under micro scale. Form the vickers hardness test the welding speed of 25 mm/min and the tool rotational speed of 1400 RPM & tilt angle 1.5^o is given good range of hardness value 22.79 HV.

Micro hardness test is carried in four different zones: a.) Weld zone or Nugget Zone b) TMAZ c) HAZ zone and finally the d) parent material Zone.

Table 3.3: Reading is recorded while the micro hardness tester

SAMPLES / *LOCATION*	SNO:1 (HV 0.1)	SNO:2 (HV 0.1)	SNO:3 (HV 0.1)	SNO:4 (HV 0.1)	SNO:5 (HV 0.1)	SNO:6 (HV 0.1)	SNO:7 (HV 0.1)	SNO:8 (HV 0.1)
BASE METAL AA8011	39.6	-	-	-	-	-	-	-
HAZ ZONE	15.33	13.91	14.83	16.52	15.87	18.27	14.22	18.53
TMAZ ZONE	14.25	16.31	11.68	15.75	13.31	12.35	14.08	17.89
WELD ZONE	17.10	14.40	09.46	15.94	13.76	13.26	10.13	**22.79**



Graph 3.3: Graph micro hadrness test report.3

MICROSTRUCTURE

Microstructure test performed from the micrographs, it can be inferred that the weld section of all the joints invariably contain uniformly circulated. However, the size of the particles is different, and it is found to be influenced by the tool rotation speed. Total 8 welded specimen Micro structural study was carried out in different zones like: 1)Nugget zone NZ 2) TMAZ 3) HAZ 4) Interface Zone 5) Base metal

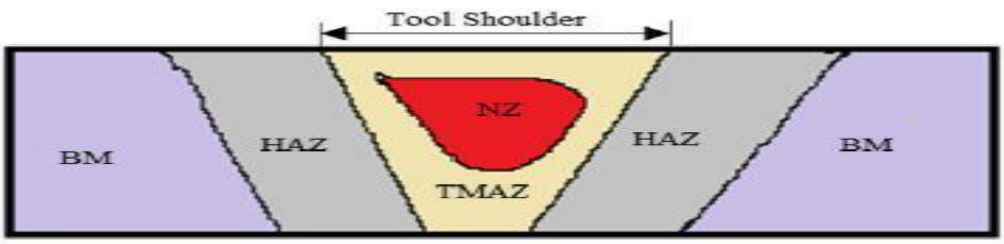
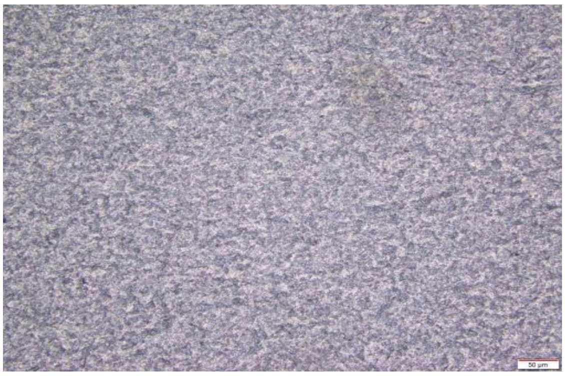


Figure 3.4: Figure showing the different zones of FSW.

MICROSTRUCTURE OF BASE METAL AA8011:

Base metal AA8011 at 100X

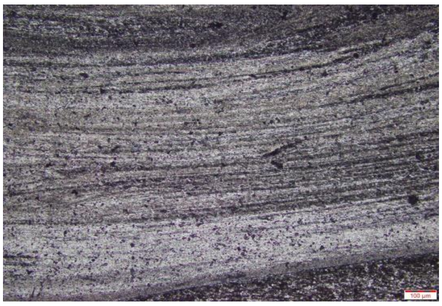


Base metal AA8011 at 200X

WELD Sample No.3

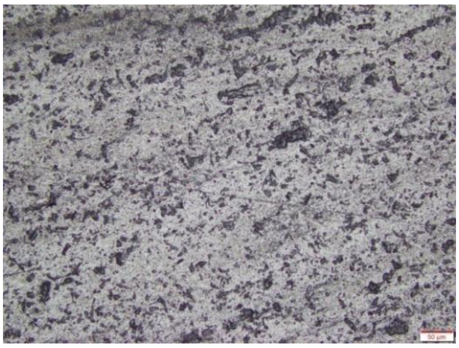
Weld zone at 200X

TMAZ at 200X

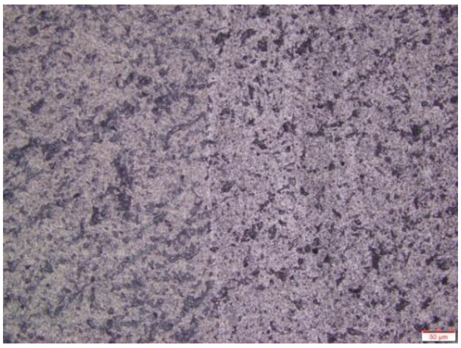


HAZ Weld at 200X

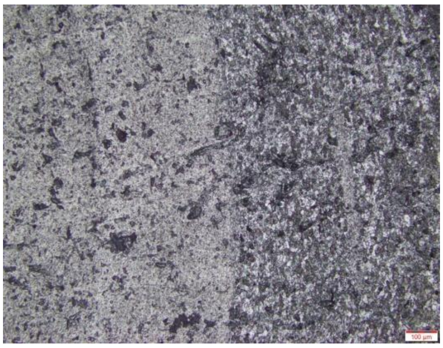
WELD Sample No.8



Weld zone at 200X



TMAZ at 200X



HAZ Weld at 200X

Figure 3.5: Microstructure of AA8011 Base metal, welded specimens weld3 & weld8.

- The microstructure of the optimum weld which has the highest UTS within the process condition and the joint are talk about in this part. The weld efficiency of the optimum joint and the weakest joint is 52.98 MPa and 22.00 MPa, respectively. The optimum joint was obtained by using the parameters of welded sample No.08. The weakest joint was obtained by using the welded sample No.03 by the addition of TiO_2 powder during welding between the plates. The amount of the temperature generated in FSW usually depends on three parameters: diameter of the shoulder and the combination of the welding speeds and tilt angle.

3. CONCLUSIONS

The present work investigates the friction stir welding of aluminium alloys AA8011. In this test initially 100×50×6mm dimensioned plates of AA8011 are Friction Stir Welded with hexagonal welding tool rotated on the edge of two plates attached together on a milling machine. From the FSW data investigated above many important parameters have been gathered regarding the Friction Stir Welding by the addition of nanoparticles. From the Investigation data and from the Methodology the values obtained practically. The following data were concluded from the Investigation:

- From the Tensile Test report the Maximum Peak stress obtained was 52.98MPa on a digitally Automated UTM machine at 1400 rpm and 25mm/min, tilt angle 1.5º weld speed by using hexagonal tool pin.
- From the Tensile Test report the Minimum Peak stress obtained was 22.00MPa on a digitally Automated UTM machine at 1120rpm and 35mm/min, tilt angle 1º weld using Hexagonal tool pin.
- From Impact Test report the maximum impact value obtained was 5.0 joules on a digitally Automated impact tester machine at weld specimen.08 and 1400rpm and 25 mm/min, tilt angle 1.5º speed using Hexagonal tool pin.
- And minimum impact values obtained were 1.0 joules on a digitally automated impact test machine at weld3, weld7 due to same values.
- From Microhardness Test is conducted at two point in each location and it is observed that Maximum Hardness is obtained to specimen no: 08 that is FS welded at 1400rpm; 25 mm/min weld speed and 1.5º tilt angle. The obtained hardness is at HAZ@18.53HV, at TMAZ@17.89HV, at NZ@22.79HV. Lowest Hardness is obtained at Weld specimen no:03 which is welded at 1120rpm ,35mm/min weld speed and 1º tilt angle. The obtained Hardness is at NZ@09.6HV.
- Microstructure results show that better mixing of material in the stir zone by using hexagonal pin. The grain size was found to be fine due to the addition of nanoparticles in the stir zone. Microstructure result also showed best mixing of material in fourth chapter 4.4 microstructure.
- The results also show that process parameters and addition of nanoparticles influence the strength of the welded joints.

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