

# **Microstructural Investigation of optimized Friction Stir Welded AA6082-T6 with Soft Steel (Mild Steel)**

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**ABSTRACT:** Joining the two facing workpieces without melting them by using non-consumable tool is referred as Friction Stir Welding which is a solid state joining process. This economic and technically advantages process was invented in 1991 by The Welding Institute, United Kingdom. Joining of Non-Ferrous and Ferrous materials like Aluminium to Steel finds its application in various industrial applications. Due to the large differences in melting temperature, physical and chemical properties makes it difficult to control weld and defects during welding. Formations of intermetallic compounds at the interface due to very low solubility of Fe in Al are detrimental to joint efficiency. The aim of the present work is microstructural investigation of optimized Friction Stir Welding butt joint between AA 6082-T6 and Soft Steel/Mild Steel. Radiography test is done to check weld joint is sound or not. Then microstructure evolution in friction stir weld joints was studied by optical microscopy. Fine recrystallized grains were observed in the weld nugget zone, while thermo-mechanically affected zone showed distorted and unrecrystallized grains. Further, Scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) investigations were implemented on the optimized specimen in order to study the development stages that occur during welding at the welding interface.

**KEYWORDS:** Aluminium Alloy; Mild Steel. Friction stir welding; dissimilar joining; X-Ray; Microstructure; Scanning Electronic Microscope, EDX;

## **I. INTRODUCTION**

Welding processes are classified into two groups namely: (1) fusion welding and (2) solid-state welding. In order to melt base metal fusion welding process makes use of high intensive localized heat source. In case of solid-state welding involves the combination of pressure and heat. Solid-state welding is performed below the melting temperature of base metal, where the metal turns into paste like state.

Friction stir welding is a solid state joining process which makes use of a tool to join two work-pieces into one. The contact between tool and work piece material result in heat production at the interface plasticizing the region near the tool. The stirring action of the tool blends the plasticized metal at the interface. As a result of the raised temperature the softened metal are joined by the downward force maintaining pressure and friction heat.

Welding process is achieved in three different phases that are (1) plunging and pre-heating, (2) transverse and (3) retraction of tool. The initial phase involves plunging of (rotating) tool pin into work piece slowly till the shoulder face comes in smooth contact with the work piece. Secondary stage involves the formation of weld joint by moving tool along the interface of the butted work piece with or without offsetting the tool till the desired weld length.

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Final stage involves retraction of the tool to its initial position after reaching its destined point on the work piece along the weld length. The velocity vectors of transverse motion and rotational speeds are identical in advancing side, whereas are opposite in retreating side.

Based on the base material properties the process parameters are chosen. Plates are clamped onto a fixture rigidly arresting nine degrees of freedom. A backing bar is provided to thwart the faces of the butt joint being pulled apart.

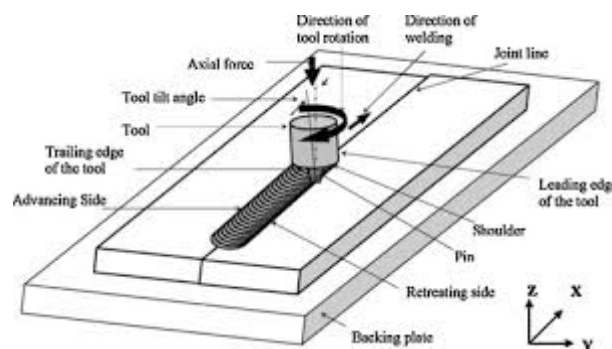


Fig. 1.1: Friction Stir Welding Process

### 1.1 Key Process Parameters:

**Tool Rotation and Traverse Speed:** Tool Rotation and Traverse speed are the two essential parameters that determine the weld quality and material flow. Rotation of tool is either in clockwise or anti-clockwise direction. Traverse speed is the rate at which the tool traverses along the weld line. Efficient welding cycle is accomplished by selecting precise input values. Rigorous stir mixing of metal is observed in the case of high rotational speeds and low traverse speeds ensuing hot weld. The material which surrounds the tool must be hot enough to assist effective plastic flow. Whilst tool rotating extrudes the plasticized material and forges at the same time traversing from front to back of the pin to form solid-state weld joint.

**Plunge Depth and Dwell Time:** Plunge depth is the depth up to which the tool pin is sunken into work piece, the surface of the shoulder is lowered below the work piece surface facilitates the necessary rise in pressure ensuring adequate forging of material. Dwell time is the time spent at the same position by the tool to initiate pre-heating of work material.

**Tool Tilt and Tool Offset:** The tool is designated by a small tilt angle. Tilting the spindle towards the dragging direction maintains proper flow following local backward extrusion. Tool offset is the length of way in of the pin perimeter into the joint line positioned on the same plane. Like this many more process parameters are their which may be considered such as Tool Material, Tool and Pin Profile, preheating, placing of work-pieces in fixture (advancing or retreating side) etc...

**1.2 Microstructure Classification of Stir Weld:** Microstructure in and around weld region is influenced by its interaction with surrounding environment, rotation and transverse of the tool affecting temperature distribution and material flow resulting an asymmetry process. It can be classified into following zones.

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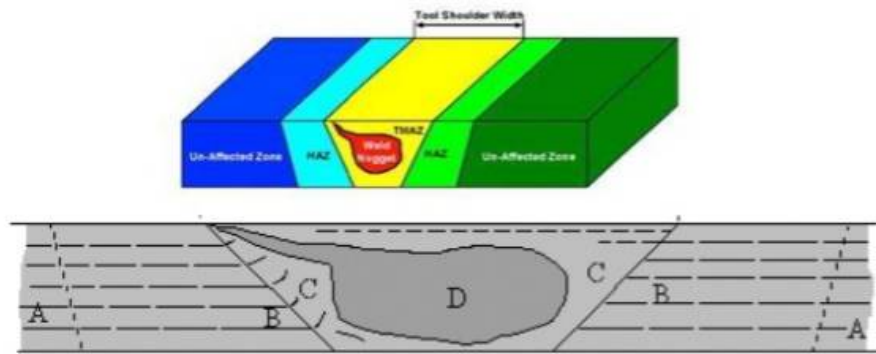


Fig. 1.2: Microstructure classification of FSW

- A: Base Metal (BM).
- B: Heat affected zone (HAZ).
- C: Thermo-mechanically affected zone (TMAZ).
- D: Nugget zone (NZ) or Dynamically Recrystallized Zone.

Base metal zone is the region which doesn't undergo any grain deformation heat produced during process doesn't affect or alter the zone structure.

Nugget zone corresponds to the actual tool pin position, includes intense plastic deformation consists mainly the recrystallized grains. Concentric onion rings are formed on the surface of this zone.

Thermo-mechanically affected zone is found on the either side of the nugget. In this zone plastic deformation and heat conduction are not as much as compared to nugget, but changes in hardness and microstructure can be observed.

Heat affected zone doesn't engage any plastic deformation, microstructure are faintly altered by heat conduction.

### II. OBJECTIVE

The objective of this project mainly consist, welding of two dissimilar material by Friction Stir Welding process which is carried out on Milling Machine (BFW make).

#### Some of the basic objectives of the research works are:

- Welding of AA6082-T6 with Soft Steel (Mild Steel) plate of 4mm thickness by Friction Stir Welding process with different parameters.
- Microstructural investigation on optimized welded specimen using Optical Microscopy and Scanning Electronic Microscope.
- Non destructing testing (NDT) is carried out for the optimized welded plates.

### III. METHODOLOGY

The process of overall project work consisting experimental details, machine details, process parameters and involving all systematic procedure to finding results is called Methodology of project study. Summarized values of test data are in order to give a response to deal with results. In methodology, it will give an overall systematic procedure of work. So methodology of FSW is to perform better welding is given below in figure 3.1.

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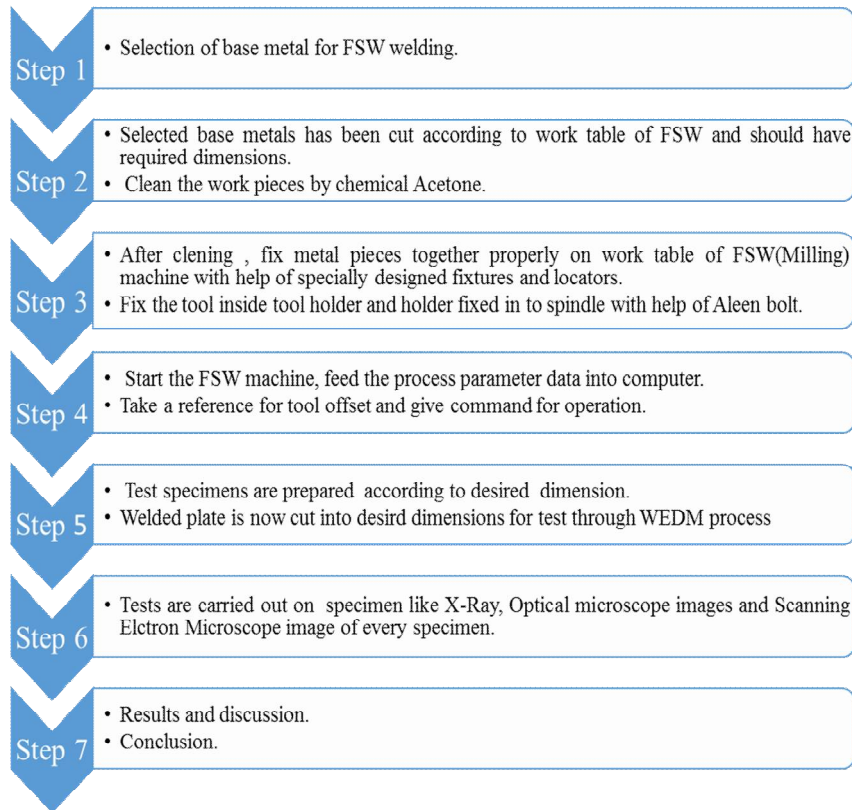


Fig. 3.1 Process flow chart of work

## IV. EXPERIMENT

To carry out the experiment Milling Machine is used, the machine specification is given below.

Table 4.1 Specification of Milling Machine

Make	BFW
Model	UF – 1
Table clamping area	1000×230 mm
No. of T- slots	3
Width of T- slots	14 mm
Centre distance	45 mm
No. of speeds	45 – 2000 RPM
Power of Main motor	3 hp
Motor speed	1500 rpm

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Fig. 4.1: Fixture to hold the Workpieces

Table 4.2. Workpiece Material

No	Material	Specifications
1	Sheet metal Al 6082-T6	100mm (length) × 50mm (width) × 4mm (thick)
2	Commercial Mild Steel	100mm (length) × 50mm (width) × 4mm (thick)

Table 4.3. Chemical Composition of Aluminium Alloy 6082-T6

Chemical Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
% Present	0.7-1.3	0.0-0.5	0.0-0.1	0.4-1.0	0.6-1.2	0.0-0.2	0.0-0.1	0.0-0.25	Balance

Table 4.4. Chemical Composition of Mild Steel

Chemical Element	C	Fe	Mn	P	S
% Present	0.14 - 0.20 %	98.81 - 99.26 %	0.60 - 0.90 %	≤ 0.040 %	≤ 0.050 %

Table 4.5. Tool Material and Specifications

Tool Material	Carbide
Pin Profile	Cylindrical Tapered
Tool Shoulder Diameter	20 mm
Tool Pin Top Diameter	5 mm
Tool Pin Bottom Diameter	3 mm
Tool Pin Length	3.4 mm
Tool Shoulder Length	30 mm

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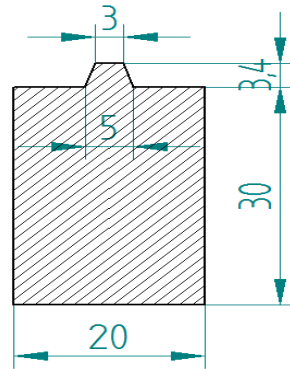


Fig. 4.2: Carbide Tool

Welding of AA 6082-T6 with Soft Steel (Mild Steel) is a complicated operation, since joining of ferrous and Non-ferrous materials is a challenging work. Proper process parameter must be known so that the joining operation gets succeeded. There are Eight trials with different combination of parameters were carried out in this work, with changing the rotational speed, offset and traverse speed an optimized welding is been studied. Some trials failed whereas some trials got an optimized welding result.

### Following are the different trials with different process parameters:

**Trial 1:** In the first trial of this project, Soft Steel / Mild Steel was placed in the advancing side and AA 6082 – T6 in the retreating side and the tool rotation direction was given as clockwise direction. In this trial the rotational speed of the tool was kept as 1400 RPM with traverse speed being 20 mm/min. offset was given as negative 1.0 mm, towards the aluminum side. The plunge depth taken as 3.8 mm. The welding was not appreciated as the quality of weld wasn't good. The welded part is shown in the fig. 4.3.



Fig. 4.3: Trial 1 of Welded Soft Steel/Mild Steel & AA6082 – T6

**Trial 2:** In this trial, the rotation tool direction is clockwise direction. Keeping steel in advancing side and aluminum in retreating side the welding is to be done. The speed of rotation was not changed as it was kept as 1000 rpm, and the traverse speed is kept as 16 mm/min. Offset along the aluminum side was changed, as in first trial it was negative 1, and plunge depth taken as 3.80mm. The weld obtained here was very good weld as the mixing of aluminum over the steel was excellent which is explained in the later part of this project. The welded specimen is shown in the fig. 4.4 below.



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Fig. 4.4: Trial 2 of Welded Soft Steel/Mild Steel & AA6082 – T6

**Trial 3:** As trial 2 gave a better result compared to first trial, the offset distance was made to increase. In this trial the offset along the side aluminum was given as negative 2mm. the tool rotation was clockwise direction and the tool speed was 1400 rpm, travel speed 16 mm/min and the plunge depth was noted to be same as previous trial that is 3.80mm. The welded specimen is showed in the fig.4.5 below. The welding quality was found to be bad compared to the second trial.



Fig. 4.5: Trial 3 of Welded Soft Steel/Mild Steel & AA6082 – T6

**Trial 4:** When the third trial saw a failed welding, the rotational speed was made to decrease. Due the high melting point of steel, it was observed that by decreasing the speed, good quality weld can be acquired and tool life can also be increased. In this trial, the rotational direction was kept the same that is clockwise direction. The rotational speed was decreased to 1400 rpm, travel speed 25 mm/min and the plunge depth was noted to be same as previous trial that is 3.80mm and the tool offset was decreased to negative 1.5mm towards the aluminum. The welded specimen is shown in the fig. 4.6. The welding quality was again found to be bad compared to the second trial.



Fig. 4.6: Trial 4 of Welded Soft Steel/Mild Steel & AA6082 – T6

**Trial 5:** In the fourth trial, the welding was not appropriate. So in this trial, there was minor change in rotational speed and the traverse speed. The rotational speed was 1000 rpm and the traverse speed was 30 mm/min compared to fourth trial. The offset was given as negative 1.5mm. In this trial the weld was much better than the fourth trial, but not up to the mark. The weld quality was average. Fig. 4.7 shows the welded specimen.

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Fig. 4.7: Trial 5 of Welded Soft Steel/Mild Steel & AA6082 – T6

**Trial 6:** In this trial the rotational speed was drastically made to decrease as there was no good quality obtained in high speed of tool rotation. The tool direction was given as clockwise direction with the tool rotation speed of 710 rpm. The travels speed of the tool was given as 20 mm/min. Plunging depth of the tool on the work piece was given as 3.80mm and tool offset along the aluminum side was placed at negative 1.5 mm. The onion rings were formed and had an average level of welding. Compared to the second trial, this trial was not up to the mark. Fig. 4.8 shows the welded specimen.



Fig. 4.8: Trial 6 of Welded Soft Steel/Mild Steel & AA6082 – T6

**Trial 7:** This trial was performed by increasing the rotational speed, more than sixth trials rotational speed. The tool rotational speed was increased to 1000 rpm, with travel speed of 25 mm/min and tool offset along the aluminum side was given as negative 1.5mm. By performing this trial, we obtained quite good welding result, as the joint strength was more and the quality of weld was good. Fig. 4.9 shows the welded specimen with above mentioned parameters.



Fig. 4.9: Trial 7 of Welded Soft Steel/Mild Steel & AA6082 – T6

**Trial 8:** The final trial was sorted as a successful trial in this particular project with different parameters. In this trial, it was proved that, for microstructural investigation purpose this was the finest trial. This trial was performed with the



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tool rotation of 1000 rpm and the traverse speed of 20 mm/min. The plunge depth was been given as 3.80mm and tool offset 0.5 mm towards steel. The welding was pretty good in the joint portion. The welded specimen was found to be very stiff. This is one of the trial which was been selected for the microstructural investigation. The welded specimen is showed in the fig. 4.10.



Fig. 4.10: Trial 8 of Welded Soft Steel/Mild Steel & AA6082 – T6

### V. RESULT AND DISCUSSION

#### 5.1 Radiography Test Result

Radiography test is Non-Destructive Testing which is done before cutting the welded specimen, this test gives a proper result of whether the weld joint is good or not. In this research work, trial 2, trial 7 and trial 8 are seen as the best optimized weld material. Once the specimen undergo radiography observation, the result is acquired soon. In this test, it was noted as there is no significant defect found in trial 7 and 8. Whereas in trial 2 it was an average result. The images captured by radiography inspection of welded material is shown in the figure below.



Fig. 5.1.1: Radiography Film Image of Trial 2 Welded Material



Fig. 5.1.2: Radiography Film Image of Trial 7 Welded Specimen

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Fig. 5.1.3: Radiography Film Image of Trial 8 Welded Specimen

### 5.2 Optical Microstructure Results

The surface image of the welded material microstructure is shown in the figure below. In the present work, the optimized trial was noted to be trial 2, 7 and 8 which were studied under optical microstructure. Out of this trial 8 had the best welded zone compared to other two trial. The grain structure was visible in this particular specimen. Trial 2 was found to be second best optimized specimen with grain structure visible lower than that of trial 8's specimen. Grain structure was noted also in the trial 7, which was least of these three optimized specimen. The grain size and grain structure is been studied in all this specimen. As shown in the above figure, the weld zone is magnified into various magnification and studied thoroughly. It is been seen that high composition of aluminum particle is deposited over the steel metal as shown in the figure above. Since the offset of the tool during weld is much along the aluminum side, the transfer of aluminum over the steel is more. In trial 8 the grain structure is visible clearly. The etching operation for this trial was optimum. Once the etching process is been done, the specimen is taken to the microscope for the investigation in order to prevent age hardening of the welded material.

The highly cleansed and etched specimen with the mirror finishing can be easily studied under the optical microscopy. The best of the 8 trials were selected, as the result, trial number 2, trial number 7 and trial number 8 were been optimized. Out of these three trial, the best etched and cleansed specimen was found out to be trial 8. All the three trial specimen had a mirror finishing, but chemically etched best specimen was noted as trial 8.

So for optical microscopy, the first specimen which was studied was trial 8 specimen. The images of optical microscopy of trial 8, trial 7 and trial 2 are shown in the fig. 5.2.1, 5.2.2 and 5.2.3 respectively with different magnification of view from the microscope.

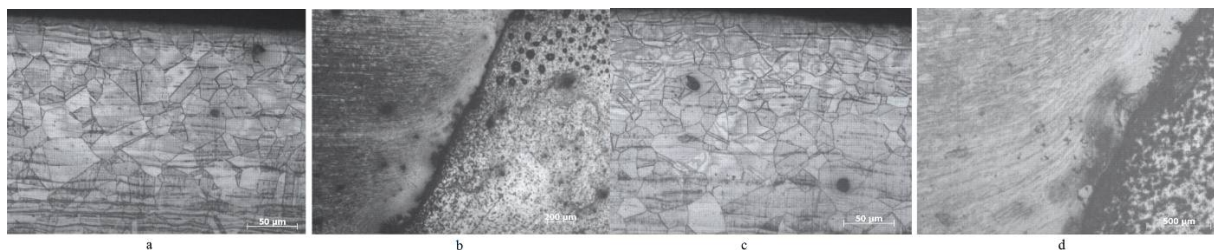


Fig. 5.2.1: Microstructural View of Specimen of Trial 8 (a) Grain Structure Visible at 50µm of AA (b) Fusion Zone Image at 200µm (c) SS Composition as Dot Shaped on AA (d) Intermixing of SS and AA in Interface

In this trial, there is some vision of grain structure in fine way. Dotted black circles are the foreign material composition. The black dots here refer to the steel. Etching in this trial of AA side has been done nicely. In the interface we can see the deformation of grain into sub division grain, and there are mixing of component taking place in the

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interface. With different magnification, the images are been captured. Magnification at 50 $\mu$ m, 200 $\mu$ m and 500 $\mu$ m are shown in the image.

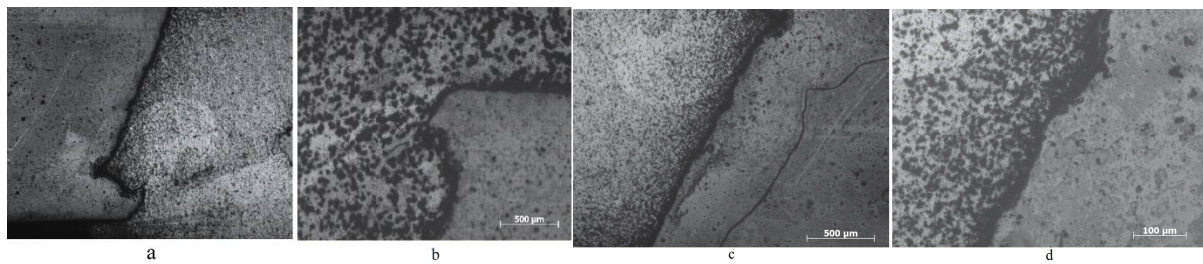


Fig. 5.2.2: Trial 2 specimen for microstructure (a) Image on interface at 50 $\mu$ m (b) Image on the Steel at 500 $\mu$ m (c) Image at interface with 500 $\mu$ m (d) Image at 100 $\mu$ m

Trial 2 was inspected, and as in the image it's shown that both composition are distributed equally. If seen with more magnification, AA is much transferred over SS at the HAZ. In this images the magnification of 50 $\mu$ m at interface to 500 $\mu$ m at interface is clearly shown. The etching on this specimen is second best behind trial 8 etching.

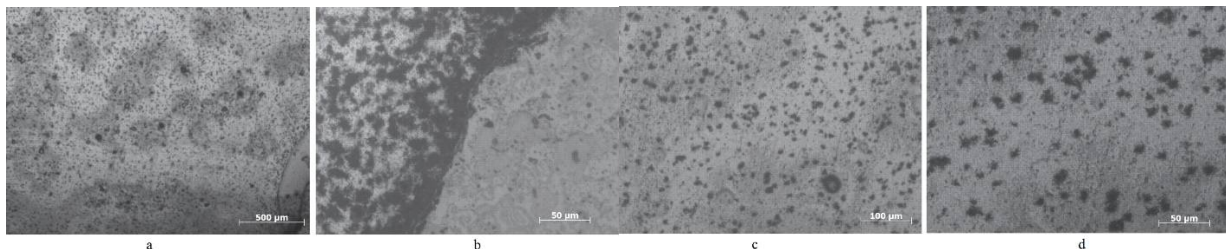


Fig. 5.2.3: Microstructural View of Specimen of Trial 7 (a) Zone near to HAZ at 500 $\mu$ m magnification (b) Interface Zone at 50 $\mu$ m magnification (c) SS Composition on AA at 100 $\mu$ m (d) Image at 50 $\mu$ m magnification over AA

As shown in the above images, trial 7 had least optimized etching process where the grain deformation can be visible but the grain size is not much visible with the help of OM. The grain structure are not visible clearly but has a satisfactory vision.

The interface zone has grain flow as a columnar flow and in some condition an axial flow of grain. The grain size of the optimized specimen of trial 8 is shown below. The material flow can be still more explained by SEM computerized technique.

### 5.3 SEM and EDX Analysis Results

Scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) investigations were implemented on the optimized specimen in order to study the development stages that occur during welding at the welding interface. The operation was carried on the SEM equipment which was associated with the EDS. On the top plane surface of the specimen the equipment was made used for the proper study of the interface. The images obtained by the trail 2, 7 and 8 by the SEM equipment is given in the fig. 5.3.1, 5.3.2 and 5.3.3 of the trial 2, 7 and 8 respectively.

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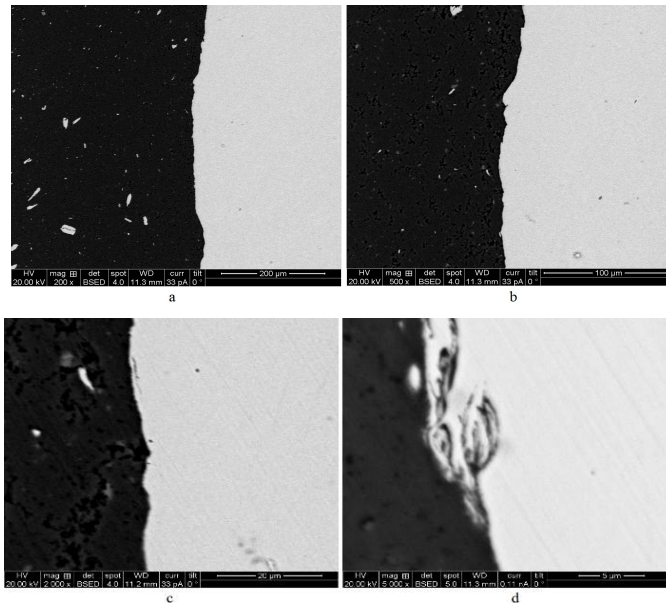


Fig. 5.3.1: SEM Images of Trial 2 at (a) Image of 200X Magnification (b) Image of 500X Magnification (c) Image of 2000X Magnification (d) Image of 5000 Magnification

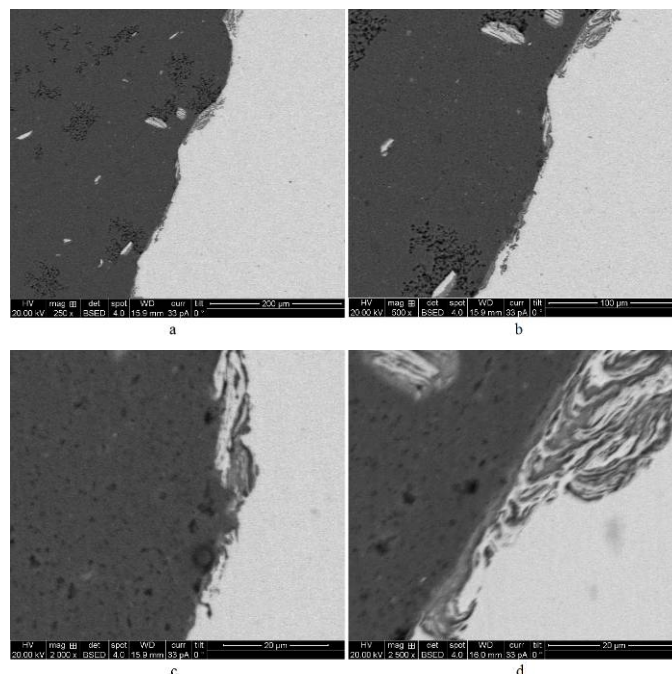


Fig. 5.3.2: SEM Images of Trial 7 at (a) Image at 250X Magnification (b) Image at 500X magnification (c) Image at 2000X magnification (d) Image at 2500X Magnification



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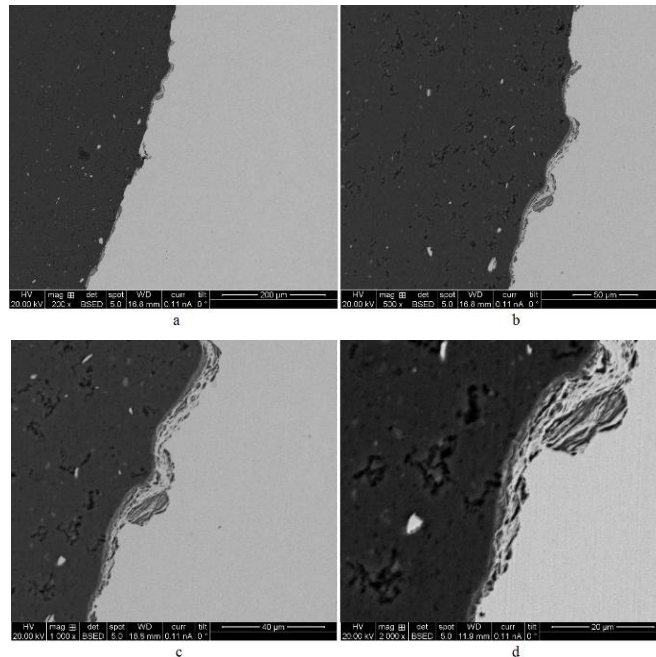


Fig. 5.3.3: SEM Images of Trial 8 at (a) 200X Magnification (b) 500X Magnification (c) 1000X magnification (d) 2000X Magnification

As shown in the figure, trial 2 specimen's microstructure is visible with the help of SEM. In trial 2, as mentioned before the brighter portion is the steel portion and darker portion is aluminium. As shown in the figure, the steel composition is found in the aluminium side near the welded zone or the stir zone. The images taken in this trial are of magnification of 200X, 500X, 2000X and 5000X magnification. When the magnification is about 200X on the interface zone, it is been observed that most of the steel composition as white dots found in the black aluminium side. Same at 500X magnification the transferred composition of steel over aluminium is observed. In 2000X and 5000X it is clearly seen that there is much traces of aluminium particles over the steel, very near to the interface. It is visible in the image that little amount of aluminium is present on the steel side, but compared to steel on aluminium, its transferred composition is low. This can be verified or proved by EDX table where the distribution of the composition is easily found out. Much of the steel composition is found in the aluminium side. Welding interference is found to be good in this trial 2. When we study for the next trial, which is trial number 7, as shown in the images above it can be said that, here too at the interface, most of the steel composition is found over the aluminium metal. Images obtained from SEM are with the magnification of 250X, 500X, 2000X and 2500X. When the magnification of lens is kept at 250X, it is seen that, in interference, steel composition is found upon the aluminium portion. Dots which are white in color is seen on aluminium side in the stir zone. When the magnification is increased to 500X, traces of aluminium is found in the steel side, and even steel portion in the aluminium side. Further when magnification is increased to 2000X on the interface, it is been seen that aluminium traces are found much over the steel on the interface. The magnification is then increased to 2500X, its visible in the microscope that much amount of aluminium composition are transferred to steel at the heat affected zone. After two trials are noted, next trial of number 8 trial specimen is studied under SEM. In low magnification of 200X, it is noted that steel composition is transferred to aluminium near to interface zone. In 500X magnification, we can see traces of aluminium on steel in the interface, and steel on aluminium next to the stir zone. In 2000X magnification, aluminium is clearly seen transferred to the steel side in the interface. The distribution of composition is clearly found using EDX graph. EDX is been connected with the same system.

In the graph below, it represent the amount of composition transferred from parent metal to other metal is shown in graph.

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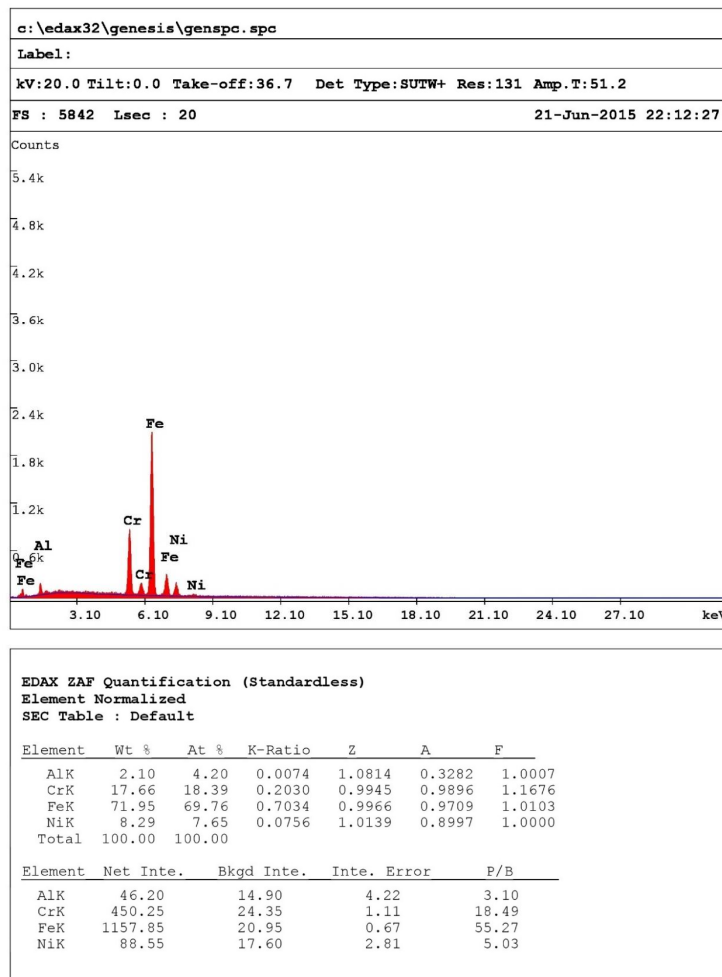


Fig. 5.3.4: SEM-EDX Graph

## VI. CONCLUSION

As of this research work of welded AA6082 – T6 with Soft Steel (Mild Steel), the final result was found out to be good.

Friction Stir Welding transformed the microstructure of base material and creates weld nugget zone, thermo-mechanically affected zone and heat affected zone in the base material.

Fine grained recrystallized microstructure in weld nugget zone is mainly responsible for higher hardness of weld nugget zone than base material.

In the next level of work, preheating – FSW is planned, in assumption of preheating gives better mixing of materials and better joint strength.

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