ANALYSIS OF PREHEATING EFFECTS ON FRICTION STIR WELDING OF ALUMINUM ALLOY

Vivek Deswal[1], B.S. Pabla[2]

[1]M.E. Scholar, [2]Professor
Department of Mechanical Engineering
National Institute of Technical Teachers Training and Research (NITTTR), Chandigarh

Abstract: *This paper explains the principle and methodology of friction stir welding process. It covers the design of experimental set up that is needed for effective working of the FSW. The working tool for the friction stir welding process is developed followed by the adequate geometry of the tool. The various effects of preheating the aluminum alloy are studied. Various changes in microstructural properties of the aluminum alloy are characterized by using Scanning electron microscope (SEM). The temperature of aluminum alloy is changed accordingly by maintaining a proper range i.e., within two temperatures. Thus, the properties of the aluminum alloy are studied and hence compared for the respective two temperatures. The various mechanical tests are performed and hence properties like hardness, toughness and strength are observed.*

Keywords: *Friction Stir Welding, Aluminum, Muffle Furnace, Process Parameters, Hardness, Impact.*

INTRODUCTION

Friction stir welding (FSW) was invented at The Welding Institute (TWI) of United Kingdom in year 1991 as a solid-state joining technique and was initially applied to aluminum alloys only but now these days it helps to join metals such as aluminum, magnesium, and other steel alloys in the solid state **[1]**.

PRINCIPLE OF FSW

FSW's fundamental idea is incredibly straightforward. In order to attach sheets or plates, a non-consumable rotating tool with a specifically shaped pin and shoulder is inserted into their edges **[2] [3]**. The tool is then moved along the joining line as shown in figure 1. As a solid-state welding method, friction stir welding preserves as much of the native metallic characteristics of the alloys as possible. Friction A pin that is continuously rotated travels over the joint between two metal plates during stir welding. A rotating shoulder and a metal pin made of high-strength tool steel are used in the procedure **[4]**. The pin and shoulder rotate at several hundreds of revolutions per second, causing the necessary thermodynamic and mechanical changes. The steel is additionally forged as a result of the added strain from the shoulders **[5]**.

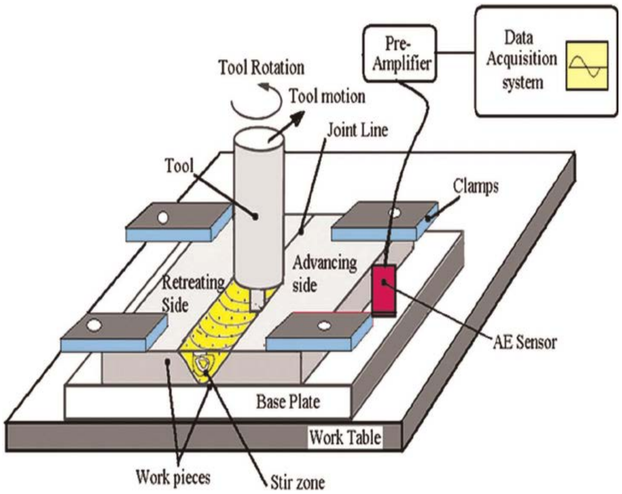

Fig. 1 Schematic Diagram of FSW Assemble

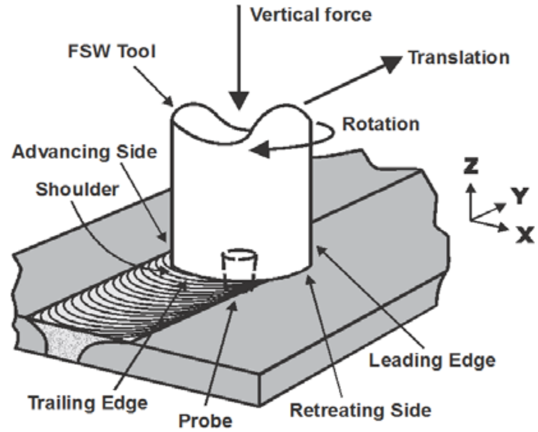

Fig. 2 Principle of Friction Stir Welding

For the designed alloy to become applicable in the automotive industry, the strength of the alloy must meet the impact and roof crushing standards. Ford has stipulated a minimum requirement of 175 MPa for yield strength and 275 MPa for tensile strength after a 2% forming strain and 30-minute paint bakes at 175°C. To improve processing efficiency, the designed alloy must be compatible with Friction Stir Welding (FSW). The designed alloy should resist deterioration of mechanical properties at the weld caused by FSW. Under the FSW, three different zones form around the weld as a result of highly irregular deformation and temperature cycles. Among the three zones in a heat treatable alloy such as 6063, the heat affected zones (HAZ) can suffer as much as 30% reduction in hardness compared to the base alloy **[6] [7] [8]**. Therefore, the designed alloy should retain at least 85% hardness compared to base alloy at the weld, especially the heat affected zones. Stress corrosion cracking resistance for the automotive design, the minimization of the susceptibility isa high priority **[9]**.

MATERIALS & METHODS

Thermo-mechanical deformation known as friction stirring occurs when the tool temperature reaches that of the work piece solidus temperature. To produce high-quality friction stir welds, the right tool material must be used for the intended purpose. Therefore, having a tool that loses its dimensional stability, loses its intended properties, or worse, fractures, is undesirable **[10]**. The FSW tool increases the weld symmetry, the volume of material swept by the pin-to-pin volume ratio, and/or the tool travel speed. Although each sort of complex motion can have an ideal tool design, many of these tool designs have concentrated on tool motion rather than precisely on the tool pin design.

Muffle furnaces are chambers that are used in laboratories and diligence to produce a terrain of high temperatures. The furnaces have walls that are hotter to high temperatures and the walls radiate the heat to the substances within the chamber [11]. This design ensures that the contents of the chamber aren't in direct contact with the heat source. The temperature within

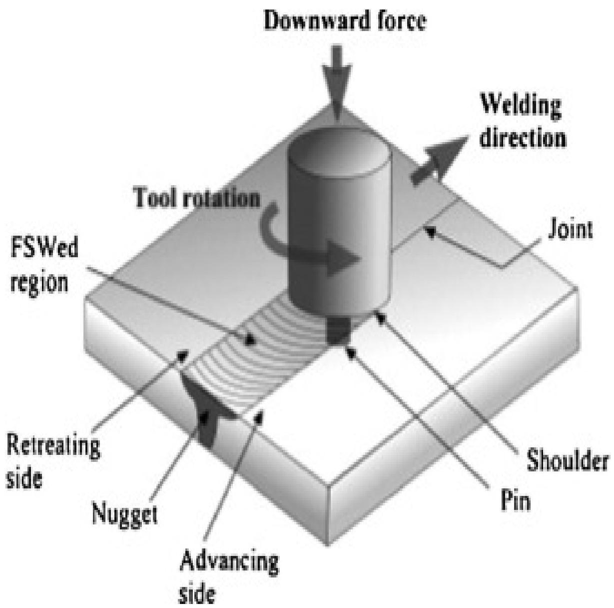

Fig 3 Motion of FSW

Fig. 4 Muffle Furnace

The furnace chamber can be controlled by the stoner and this makes the outfit available for a wide range of operations. In some laboratories, it's used as a simple heating device to dry substances. In others, it's used for more complex operations similar as chemical analysis, coal slice, gravimetric analysis, ignition tests, glass blowing, etc [12] [13].

EFFECT OF PRE-HEATING ON STIR WELDING

Pre-heating increases the heat generated during welding, reducing the variability of the cooling rate in the welded joint. Outside of the agitated zone, a 30 K higher peak temperature is attained in P-FSW (minimum distance location of thermocouple). Due to the effect of pre-heating in P-FSW, the average plunging force decreases by 22 to 28 percent in the current range of process parameters. P-FSW exhibits increases in micro-hardness and tensile strengths [14]. The strengthening effect brought by the finely distributed Al_2O_3 particles is primarily responsible for the increase in overall friction stir welded joint strength.

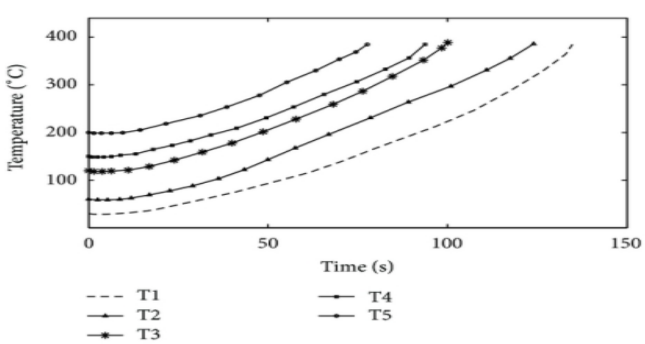

Fig.5 Effect of Pre-heating Temperature on stir welding

Fig. 6 Threaded tool made with FSW

RESULTS AND DISCUSSION

The experiment has been carried out on the vertical milling machine with necessary equipment details such as tool, process parameters and safety precautions. Process parameters involved here are the pre-heated temperature, tool rotation speed, welding speed, tilt angle and tool geometry. Figure shows the FSW tool, aluminum plates, muffle furnace, friction stir welding machine (vertical milling machine), FSW processed zone, flat aluminum plates and v-grooved aluminum plates to perform the desired experiments. A muffle furnace is often a front-loading box-type oven. They are also utilized in a variety of research settings, such as by chemists who want to know how much of a sample is non-combustible and non-volatile.

Fig. 7 Schematic of FSW Machine

Fig. 8 V-grooved plate

In order to limit the workpiece's degrees of freedom, the workpiece to be welded is clamped using fixtures. The workpiece must be manually examined to ensure that it is securely clamped. The workpiece should be kept in an abutting position (there must be a small gap between them). The tool must be kept in the correct position, that is the pin must be inserted in the gap between the workpieces and the shoulder must touch the joint. After the tool is placed in correct position, the rotation of the tool begins. Friction has created due to which heat is generated **[15] [16]**. Due to heat and force applied in a downward direction weld is created between the two workpieces. The weld is moved in forward with linear motion of the tool w.r.t to the workpiece. When the required area is welded the tool is moved upwards and the welding stops. The workpiece is then removed by loosening the fixtures.

SAMPLE PREPARATION

There are following steps for sample preparation:

- Measurement- Vernier Caliper used for this purpose,
- Cutting - Hack saw is used to cut the sample pieces. Cutting of 2 pieces of aluminumAl-6063 according to required length.
- V-grooved Cut – File is used for making of v-groove cut having dimension of 3 mm width and 1.5 mm depth.
- Aluminum alloy powder and chips are made by the use of file.
- Checking of required dimensions with the help of Vernier caliper. Sample is ready for welding and finish.

FRICTION STIR WELDING PROCESS

Before carrying out the FSW process muffle furnace is used for pre-heating of Aluminum plates. The preheating temperature used for friction stir welding process was given in the table below. A vertical milling machine was used for friction stir welding process. The aluminum plates to be welded were clamped properly on a flat texture plate in such a way that they would not be separated during welding process **[17] [18] [26]**.

Fig. 9 Flat plate

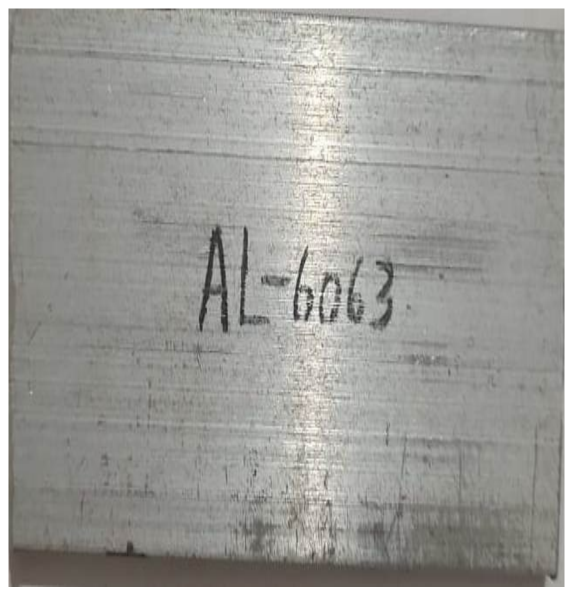

Fig. 10 Aluminum alloy-6063

The FSW tool consist of a 20 mm diameter shoulder and a 6mm diameter pin and the threaded pin has a length 4.7 mm, it is made of hot worked tool steel, high wear resistant material. The tool with threaded pin was used for welding the test Specimens. The FSW tool was plunged in the work piece. The tool starts removing the material from the specimen, and subsequently started to generate heat when the required plunging force was provided. The tool was traversed through the length of the plate. Welding was carried out at the tool rotational speed of 1200 rpm and using the welding speed (feed) of 25 mm/min. An axial load of approximately 3000N was maintained on the FSW tool during welding **[28]**. The welding parameters used for the experimental work are listed in table. The welded specimens were visually examined and defects free samples were chosen for further characterization.

Standard test pieces were made for tensile tests and for impact test by cutting with the help of hack saw. In this experimentation a total no. of 4 pieces we were carried out to relate the input and output.

EXPERIMENTAL PARAMETERS

There are two types of parameters detailed below:

VARIABLE PARAMETERS

- **Temperature: -** It is the pre-heated temperature of aluminum plates which are first pre-heated in the furnace before carrying out the friction stir welding process.

Table 1 Different Temperature Zone

Temperature	100°C	150°C

FIXED PARAMETERS

The following are the parameters that were kept constant throughout the experiment:

- **Revolutions per Minute**: It is the revolutions of the rotating chuck in a minute. Revolutions are set at 1200 rpm according to the requirement of experiment.
- **Welding speed (feed)**: It is simply the speed at which the Friction Stir welding tool is moved across the work piece. The travel speed of 25 mm/min is taken for the experiment

Fig. 11 Welded pieces

ROCKWELL HARDNESS TEST

The resistance of a metal to plastic deformation against indentation, scratching, abrasion, and cutting is known as hardness. By using the Rockwell hardness test method, a material's hardness is determined by how deeply the indenter penetrates the sample. The hardness has an inverse relationship with the penetration depth. In this test, indenters of the ball or diamond cone varieties are both employed **[29]**.

Fig. 12 Hardness Tester

Fig. 13 Universal Testing Machine

There are three scales on the machine for taking hardness readings. Scale "A" with load 60 kgf or 588.4 N and diamond indenter is used for performing tests on thin steel and shallow case-hardened steel. Scale "B" with load 100 kgf or 980.7 N and 1.588 mm dia. ball indenter is used for performing tests on soft steel, malleable iron, copper and aluminum alloys. First minor load is applied to overcome the film thickness on the metal surface. Minor load also eliminates errors in the depth of measurements due to spring of the machine frame or setting down of the specimen and table attachments.

Table 2

Sr No.	Specimen material	Type of Indenter	Rockwell Hardness Number							
			Specimen A		Specimen B		Specimen C		Specimen D	
			At HAZ	At Stir Zone	At HAZ	At Stir zone	At HAZ	At Stir zone	At HAZ	At Stir zone
01.	Aluminum Alloy Al-6063	Ball (1/16")	24	33	19	28	39	28	38	29

02.	Aluminum Alloy Al-6063	Ball (1/16")	18	29	16	24	28	24	42	15
Average Value			21	31	17.5	26	33.5	26	40	27

But at the heat affected zone (HAZ), the result shows that the specimen D (V-grooved plates preheated at 150 c) has the highest value of RHN of 40 and it is followed by specimen C with RHN value of 33.5 while the results of the specimen A and specimen B has shown lower RHN values of 21 and 17.5 respectively.

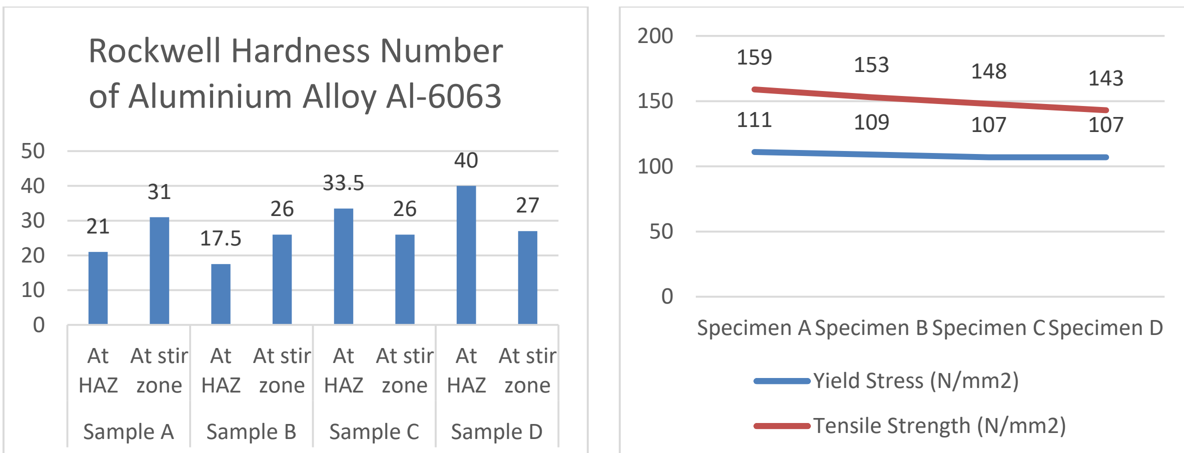

Fig. 14 Relation between the yield strength and ultimate tensile strength for the specimen

TENSILE TEST

To determine material properties including ultimate strength, yield strength, percent elongation, percent area of reduction, and Young's modulus, the tensile test is known as a fundamental and universal engineering test. When choosing engineering materials for any application, these crucial criteria from the common tensile tests are helpful **[30]**.

Table 3 Reading of tensile stress and elongation(%) of FSW welded specimen

Sr.no	Parameters	Specimen A	Specimen B	Specimen C	Specimen D
01.	Thickness (mm)	5	5	5	5
02.	Width of test Specimen (mm)	12.5	12.5	12.5	12.5
03.	Cross sectional area (mm^2)	62.5	62.5	62.5	62.5
04.	Gauge Length (mm)	50	50	50	50
05.	Breaking Load (N)	9940	9560	9190	8940

06.	Final Gauge Length (mm)	54.15	54.05	53.95	53.90
07.	Tensile Strength (N/mm^2)	159	153	148	143
08.	Yield Stress (N/mm^2)	111	109	107	107
09.	Elongation (%)	8.3	8.1	7.9	7.8

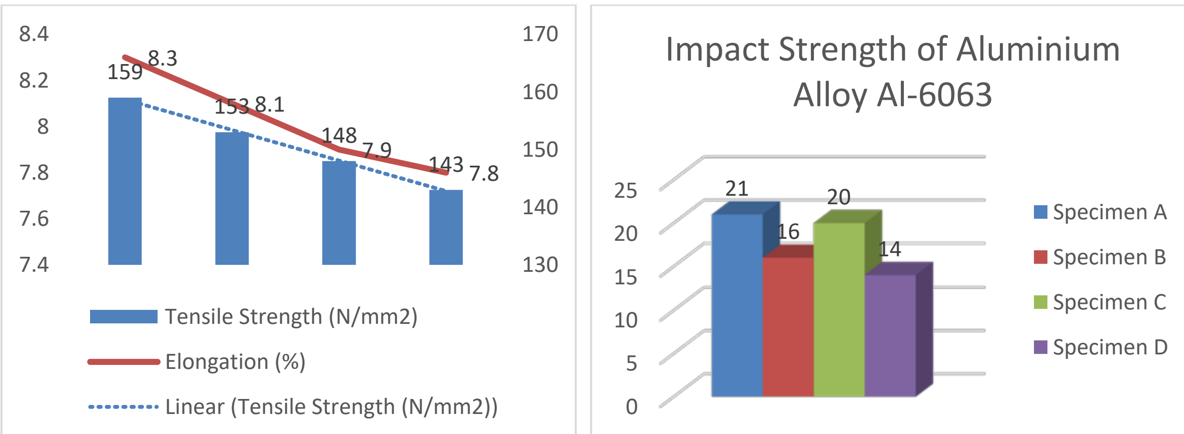

Fig. 15 Relation between tensile strength and elongation (%) for the various specimen

The applied tensile load and extension are recorded during the test for the calculation of stress and strain. To evaluate tensile strength of test samples were tested on the Universal Testing Machine (Capacity 100 KN). The dimensions of the samples used for this test followed the ASTM (American society for testing and material) standard. The flat specimens of average width and thickness measured along the central portion of the sample using vernier calipers and a gauge length equal to four times the average thickness. The specimens were loaded. The loads at which specimens has reached the yield point and broken were noted down.

CHARPY IMPACT TEST

The Charpy impact test is used to evaluate the specimen's impact toughness or strength. The tools utilized are a V-Notch Charpy type specimen and an impact testing equipment. The Charpy impact test machine's pendulum strikes the specimen positioned between the anvils, and the energy absorbed in the specimen's fracture is measured to determine the metal's impact

Table 4

Sr.no.	**Specimen Material**	**Impact Strength (In joule)**			
		Specimen A	Specimen B	Specimen C	Specimen D

1.	Aluminum Alloy Al-6063	21	16	20	14

toughness. The temperature has an impact on a metal's toughness. The area under the stress-strain graph is the simplest way to measure a material's toughness. Repeatedly performing the Charpy test on a given metal results in a graph indicating the material's impact toughness. The material is more brittle and has lower impact resistance at low temperatures. At low temperatures, the material has low impact toughness and it is more brittle while at high temperatures the material has high impact toughness and it is more ductile **[31]**.

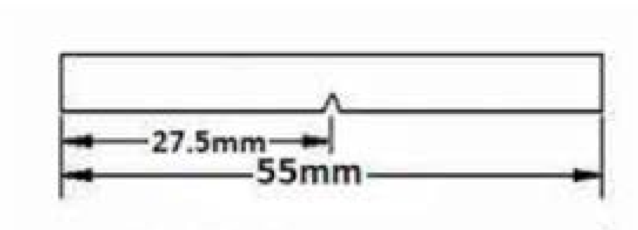

Fig. 16 Test Sample

The sample must be a V-Notch Charpy type specimen. According to the ASTM E23, the sample must be 55mm wide and have a 10mm x 05mm square area on both ends, the V-Notch must be 1mm deep with a 45° angle (Harbor, 2007). Make sure the specimen has been placed in an environment of the correct temperature. Measurement is done by the vernier caliper.

MICROSTRUCTURE TEST

In this test micrographs were generated with the help of optical microscope **[32]**. As seen from these images the size of Al particles has much importance in terms of comparison between various FSW samples. Figure shows the optical images at:

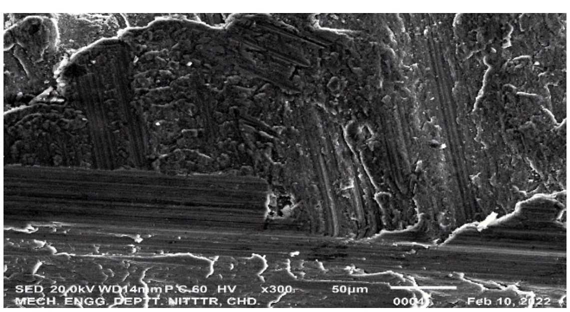

Fig. 17
Flat FSW plates preheated at 100°C

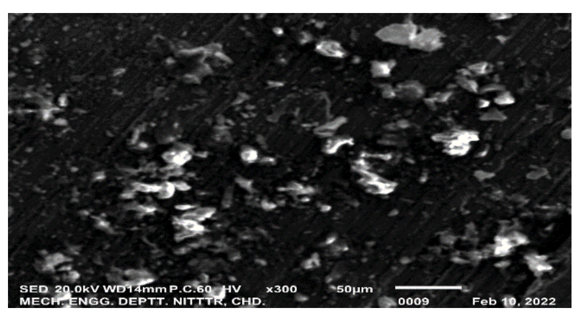

Fig. 18
Flat FSW plates preheated at 150°C

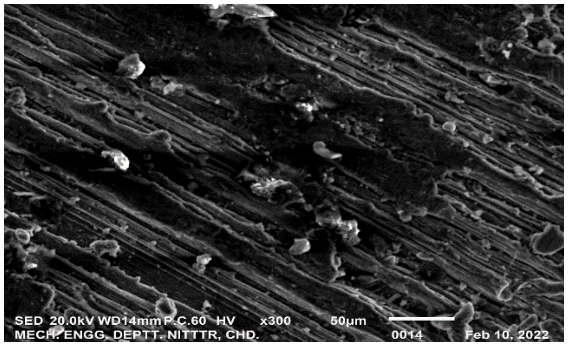

Fig. 19
V-Grooved FSW plates preheated at 100°**C**

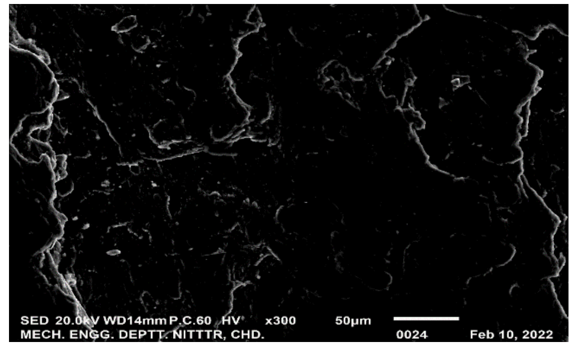

Fig. 20
V-Grooved FSW plates preheated at 150°**C**

The weld zones are clearly visible in the images; because of the different contrast develop after etching the weld zone porous. As figure illustrates, the microstructure at the retreating side in the TMAZ and heat affected zone (HAZ) shows larger that of the base metal AL-6063.

CONCLUSION

In the preheated-FSW joints, the grains of preheated flat FSW plates at the retreating side were found finer than those of V-grooved shaped FSW joints in the HAZ. The weld nugget had finer grains at the composite structure of preheated FSW joints (flat plates) due to sufficient and smooth plastic flow phenomena under the effect of preheating. During FSW process, the yield strength of welds for all the specimen is almost same. Flat aluminum plates preheated at 100°**C** has higher ultimate tensile strength in comparison with the other FSW welded specimen. During impact test, it has found from the results that the specimen D has more brittle in the comparison between all the test specimens It has found that the specimen D (V-grooved plates preheated at 150 c) has the highest value of RHN of 40 and it is followed by specimen C with RHN value of 33.5 while the results of the specimen A and specimen B has shown lower RHN values of 21 and 17.5 respectively. The specimen A (preheated at 100°**C** flat aluminum plates) has higher RHN value at FSW processed zone while the specimens B, C and D has almost same RHN value at the FSW processed zone.

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