Investigation of Mechanical and Microstructural Properties of Friction Stir Welded Aluminium Alloy 6063

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Abstract- **Friction stir welding (FSW) is a solid state welding process in which coalescence is achieved by frictional heat combined with pressure. In this project effect of friction stir welding on microstructure and mechanical properties of aluminium 6063 alloy is investigated .The main work is to investigate the different parameters tool rotational speed and tool transverse speed which enhance properties through FSW. In this process, the properties of the material are enhanced during visco-plastic deformation. The microstructure examination is done with optical microscope and mechanical properties tensile and hardness tests. The corrosion resistance properties are tested by the salt spray corrosion test. Microstructure and mechanical properties are correlated for the chosen alloy before and after FSW. The experimental results showed the lower the ratio of rotation speed and weld speed, the narrower the softened zone and the higher tensile strength. The corrosion resistances of the welded metal rotational speed 560rpm with traverse speed 40mm/min are high.**

I. INTRODUCTION

Welding is the process of joining metals by making the parent metal into molten stage or plastic stage with or without using a filler wire or rod to form a joint. It can be done using different energy sources. In all welding joint processes heat is applied to produce the joint and heated surfaces are brought into close contact, as result the joint surfaces to grow together into single body. We can see what happens during this growing up together process. It is we all know that the matter is made of molecules which in turn into an atom. The atoms of molecules become active when the temperature of material reaches absolute zero. At that time the molecules moves with vibratory motion.

1.1. Types of welding process

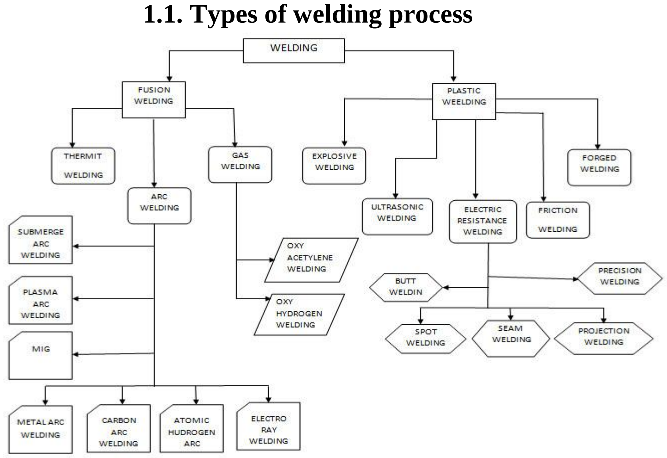


Fig. 1 Types of Welding Process

1.2. Solid state welding

Solid state welding is a welding process, in which two work pieces are joined under a pressure providing an intimate contact between them and at a temperature essentially below the melting point to the parent material. Bonding of the material is a result of diffusion of their interface atoms.

The solid state joint is formed by the massive plastic shear and mixing of the material in a zone surrounding the tool, with material being swept from the leading edge of the tool and deposited at the trailing edge, the tool shoulder and the anvil (backing plate) supporting the weld root (where the joint does not include integral root side support)

1.2.1. Friction Stir Welding (FSW)

Friction stir welding is a relatively new joining process that is presently attracting considerable interest. It was invented and experimentally proven at The Welding Institute UK in December 1991. TWI holds patents on the process, the first being the most descriptive. Friction stir welding (FSW)is a solid state welding process in which coalescence is achieved by frictional heat combined with pressure, the heat is generated the friction between the two components surfaces, usually by rotation of one part relative to the other. Then the parts are driven toward each other with sufficient force to form a metallurgical bond.

The sequence is portrayed in the typical application of this operation, welding of two cylindrical parts. It is a solid state welding process where a machine rotates, plunges, and the traverses a special shaped FSW tool along a joint to form a weld. Friction Stir Welding Process shown in fig.2. The rotation action and the specific geometry of the FSW tool generates friction and mechanical working with the material who in turn generates the heat and the mixing necessary to transport material who in turn generate the heat and the mixing necessary to transport material from one side of the joint line to the other. The process has numerous advantages over other joining technologies and can be used to weld numerous materials, including, but not limited to aluminium, bronze, copper, titanium, steel, magnesium, and plastic.

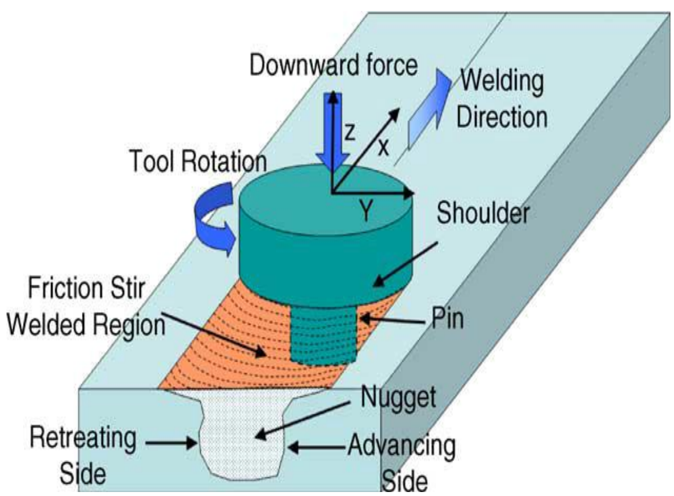


Fig.2 Illustration of Friction Stir Welding Process

Friction stir welding is a process that utilizes local friction heating to produce continuous solid state seams. It allows but and lap joints to be made in low melting point materials (such as aluminium alloys) without the use of filler material around the joint line. The process can be summarized in the following steps: first, a whole is pierced at the start with the joint with a rotating steel pin.

The pin continues rotating and moves forward in the direction of welding. As the pin proceeds, the friction heats the surrounding material and rapidly produces plasticized zone around the pin. Pressure provided by the pin forces plasticized material at the rear of the pin where it consolidates and cools to form a bond. No melting occurs during this process, and the weld is left in a fine grained, hot worked condition with no entrapped oxides or gas porosity.

1.2.2. Characteristics of friction stir welding

- Weld (bonding) is free from microstructure defects (pores, non metallic inclusions, segregation of alloying elements)
- Mechanical properties of the weld are similar to those of the parent metals.
- No consumable materials (filler material, fluxes, shielding gases) are required.
- Dissimilar metals may be joined (steel-aluminium alloy, steel-copper alloy)
- Good mechanical properties the as welded condition.

1.2.3. Applications of friction stir welding

- In ship building it is applied in deep freezing of fish on fishing boatsand panels for deck and wall construction.
- In Rail craft it is applied in making railway carriages panels and joining the tracks.
- In aeronautical industry it is applied in making large-thin wall aircraft floor structure.
- In aerospace industry it is applied in making large tanks for launch vehicles and spacecrafts.
- In automotive industry it is applied in making chassis, centre tunnel, suspension links, rear doors and bonnet.

II. RELATED WORK

AkosMeilinger and ImreTörök [1] investigated on The Importance of Friction Stir Welding Tool with Shoulder: The 1 - 2° tilting angle of the tool is usually quite normal, but it results too wide weld, thickness reduction and greater downward force which increase the tool wear. Therefore the concave shoulder design is unnecessary. However the heat input is very important which is not always ensured by the convex shape. Accordingly we used a simple shoulder, which is neither concave nor convex, but a simple flat surface. Pin: The usage of thread is not advantageous because it can cause aluminium oxide stirring from the surface to the weld, stronger wear of the shapes which affects to the reproduction. The simple pin shape is also not favourable because it cannot produce enough heat input on the whole thickness of aluminium alloys. The solution was a little used pin geometry, the staged shape. Adequate heat came inside the weld with this pin geometry so the root was sufficient.

Bilici .M.K [2] has investigated on Effect Of Tool Geometry on Friction Stir Spot Welding of Polypropylene Sheets with the biggest tensile strength were obtained with threaded tool (Pitch length 0.8 mm, 7.5 mm pin diameter, 5.5 mm pin length, 30 mm shoulder diameter and 6° shoulder angle.In polypropylene FSSW, the weld tool geometry affects stir zone formation and weld lap-shear fracture load.

The optimum straight tool geometry for 4 mm thick sheets was determined as 7.5 mm pin diameter, 15° pin angle, 5.5 mm pin length, 30 mm shoulder diameter and 6° shoulder angle. The weld strength obtained with a threaded pin decreases with the pitch. Pitch length of threaded pins are very important for the weld quality and the weld strength. Giuseppe Casalino yet to all [3] deals with Influence of Shoulder Geometry and Coating of the Tool on the Friction Stir Welding of Aluminium Alloy Plates The large shoulder coated carbide with coating tool gave almost defect-free weld. The shoulder size influenced the size of the microstructural zones and the hardness profile.The grain size in the TMAZ was sensitive to the tool shoulder. The conic tool produced a regular joint with a smooth surface and little flash.

Guo J.F. yet to all [4] investigated on Friction Stir Welding of Dissimilar Materials Between AA6061 and AA7075 Al Alloys Effects Of Process Parameters the Both AA6061 and AA7075 alloys have experienced dynamic recrystallization and the grain size in both alloys decreases significantly with the increase of welding speed. The grain size of AA7075 alloy sub-layer is much smaller than that ofAA6061 sub-layer in the same weld.

Khaled J. yet to all [5] deals with micro structure And Mechanical Properties Of Multi-Pass Friction Stir Processed Aluminum Alloy 6063. A reduction in the strength and microhardness of multiple-pass FSP samples occurred due to the precipitate dissolution and the limited reprecipitation by the thermal cycle of FSP.

On the other hand, SHTA led to the formation of strengthening precipitates, thus increasing the values of strength and microhardness close to that of the base metal.
FSP resulted in fine and equiaxed grains with predominant HABs in the SZ and OL area, having a minimum grain size of 2.85 lm. Increasing the percentage of overlapping resulted in limited change in the grain size in OL area, but provided more subgrain formation of LABs in the TMAZ.

Liu . H . J and Hou . J . C [6] investigated with the Effect of Welding Speed on Microstructure and Mechanical Properties of Self-Reacting Friction Stir Welded 6061-T6 Aluminum Alloy was self-reacting friction stir welded at the fixed rotation speed, and the effect of welding speed on the microstructure and mechanical properties of the joints was investigated, and the following conclusions were drawn from the experimental results and analyses.The tensile strength of the defect-free joint increases with the welding speed, and the maximum tensile strength is equivalent to 69% of that of the BM.

Magdy M. El-Rayes and Ehab A. El-Danaf [7] deals with The Influence of Multi-Pass Friction Stir Processing on The Microstructural And Mechanical Properties Of Aluminum Alloy 6082. The effect of increasing the number of passes led to an increase in the SZ- grain size, more dissolution and re-precipitation with simultaneous intense fragmentation of second phase particles all of which are attributed to accumulated thermal cycles. Increasing the number of passes is accompanied by an increase in the average misorientation angle.

III. SELECTED WORKPIECE MATERIALS FOR WELDING PROCESS

3.1. Aluminium Alloy 6063

Aluminium alloy 6063 is a medium to high strength heat-treatable alloy. It has very good corrosion resistance and very good weld ability although reduced strength in the weld zone. Material 6063 shown in fig 3.It has medium fatigue strength. It has good cold formability in the temper T4, but limited formability in T6 temper. Not suitable for very complex cross sections. Material dimension shown in fig 4.

Fig. 3 Procured of Material 6063

3.2. Physical Properties of AA 6063

Physical properties of AA 6063 shown in table 1.

Table 1: Physical properties of AA 6063

PROPERTY	VALUE
Density	2.70g/cm³
Melting Point	600 °C
Thermal Expansion	23.5 $x10^{-6}$ /K
Modulus of Elasticity	69.5GPa
Thermal Conductivity	200 W/m.K
Electrical Resistivity	0.035 x10^-6 Ω .m

3.3. Mechanical Properties of AA 6063

Mechanical properties of AA 6063 shown Table 2.

Table 2: Mechanical properties of AA 6063

Property	Value
Proof Stress	50 Min MPa
Tensile Strength	100 Min MPa
Elongation A5	27%
Shear Strength	70 MPa
Hardness Vickers	25HV

3.4. Chemical Composition of AA 6063

Chemical composition in % for grade AA 6063 shown in table 3.

Comment: Al is a basis; the percentage of Al is given approximately.

Table 3: Chemical Composition of AA6063

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.6	0.35	0.1	0.1	0.45-0.9	0.1 max	0.1	0.1	Remaining

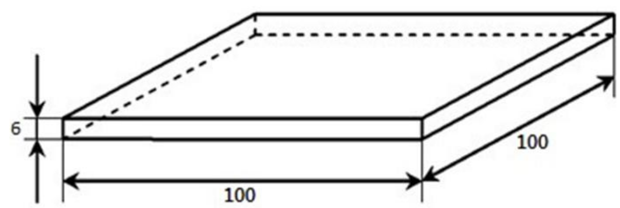


Fig. 4 Material Dimensions

IV. EXPERIMENTAL SETUP AND PROCEDURE

Experimental setup of tool design, aluminium alloy and procedure given in flow chart fig 5.

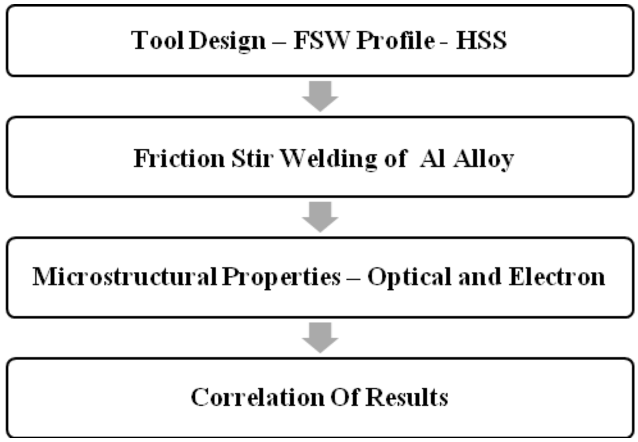


Fig. 5 Process Flow Chart

V. SELECTION OF TOOL MATERIAL

5.1. High Speed Steels (HSS)

- Hardened to various depths
- Good wear resistance
- Relatively Tough
- Suitable for high positive rake angle tools

5.2. Two Basic Types of HSS

- Molybdenum (M-series)
- Tungsten (T-series)

5.2.1. M-series - Contains 10% molybdenum, chromium, vanadium,

tungsten, cobalt

- Higher, abrasion resistance
- H.S.S. are majorly made of M-series

5.2.2. T-series - 12 % - 18 % tungsten, chromium, vanadium & cobalt

- Undergoes less distortion during heat treating
- HSS available in wrought ,cast & sintered (Powder metallurgy)
- Coated for better performance
- Subjected to surface treatments such as case-hardening for improved hardness and wear resistance or steam treatment at elevated temperatures
- High speed steels account for largest tonnage

VI. TOOL PREPARATION

Tool preparation here means the formation of the tool profile with machining and heat treatment. FSW Tool shown in fig 6.The tool to be prepared must be selected accordingly. The tool preparation consists of the following steps

i. Machining of the Tool
ii. Heat Treatment of the tool

Fig. 6 Friction Stir Welding Tool

Machining involves the facing and turning operation. It is made up complex shapes according to the design. It may be threaded, tapered, conical etc. This machinated product will require heat treatment to increase the hardness and tensile strengths. According to the type of the material and strength the machined tool requires heat-treatment which is primarily heating the composite material at controlled temperatures in order obtain strain hardening. A heat treatment will produce a high quality tool.

Table 4: Dimensions of the Tool

Tool	Tool Profile	Probe Diameter	Pin Length	Shoulder Diameter	D/D Ratio
High Speed Steel	Cylindrical	6 mm	5 mm	20mm	3.3333

Table 5: Welding Parameters

S. No.	Material	Tool Rotational Speed (Rpm)	Tool Transverse Speed (Mm/Min)
1	AA6063- AA6063	450	20
2	AA6063- AA6063	450	40
3	AA6063- AA6063	560	20
4	AA6063- AA6063	560	40
5	AA6063- AA6063	710	20
6	AA6063- AA6063	710	40

VII. RESULT AND DISCUSSION

In experimental work we have taken mechanical tests for friction stir welding of aluminium alloy 6063. The welding speeds used in our experiment are in the range of 450-710rpm. The tool traverse speeds used in our experiment are in the range of 20-40mm/min.

7.1. Tensile Test

Table 6: Tensile test parameters

S. No	Tool Rotational Speed Rpm	Tool Traverse Speed mm/min	Point of fracture
1	450	20	Weld metal
2	450	40	Parent metal
3	560	20	Parent metal
4	**560**	**40**	**Weld metal**
5	710	20	Weld metal
6	710	40	Weld metal

Table 7: Tensile test observations

Identification	Thickness mm	Width Mm	CSA mm^2	Tensile load KN	Tensile stress N/mm^2
1	5.86	13.26	77.70	11.67	150.19
2	5.93	13.96	82.78	12.36	149.31
3	5.91	13.49	79.73	12.18	152.77
4	**5.85**	**12.72**	**74.41**	**11.88**	**159.66**
5	5.82	12.97	75.49	10.95	145.05
6	5.88	14.11	82.97	11.73	141.38

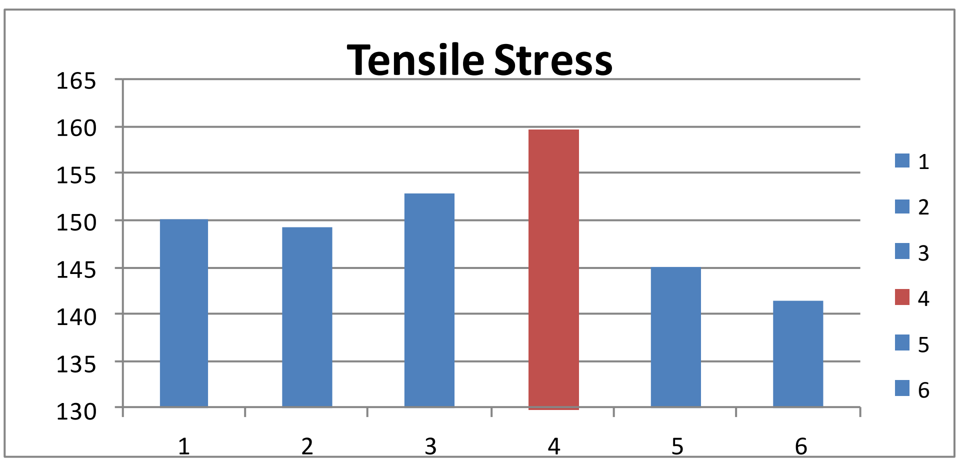


Fig. 7 Tensile Strength of Specimens

From the experiment conducted we found that the cross section area is 74.41 mm^2 i.e. is 23% change from the specimen when the tool rotation speed is 560rpm, feed is 40mm/min. The change in CSA is found to be high on the 710 rpm with 40 mm/min which is 82.97 which is 37% from the specimen. The tensile strength on the specimen 4 is found to be 159.66 N/mm^2wherein the fracture occurred in the weld metal. The specimen 4 has the best tensile strength with rotational speed of 560rpm and traverse speed of 40mm/min.

7.2. Hardness Test

Table 8: Hardness Test Observation

S. No	Tool Rotation Speed Rpm	Tool Traverse Speed mm/min	Test 1 HRB	Test 2 HRB	Test 3 HRB	Load kg	Ball intender Inch
1	450	20	50	42	47	100	1/16
2	450	40	54	70	59	100	1/16
3	560	20	51	70	59	100	1/16
4	560	40	39	32	45	100	1/16
5	710	20	55	51	43	100	1/16
6	710	40	31	37	32	100	1/16

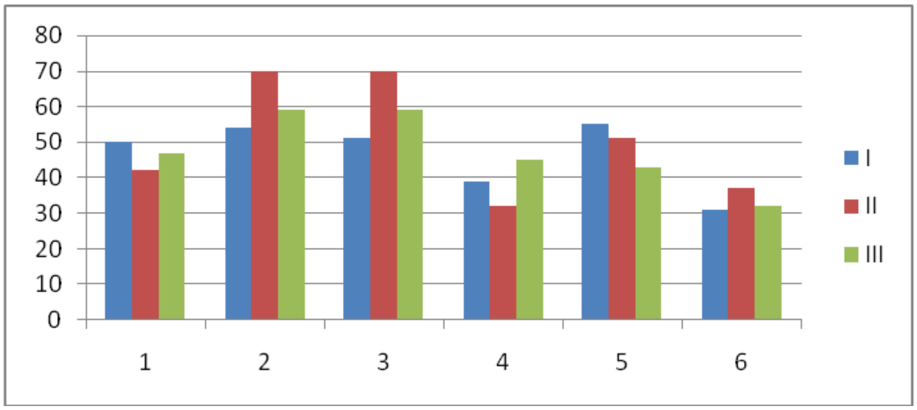
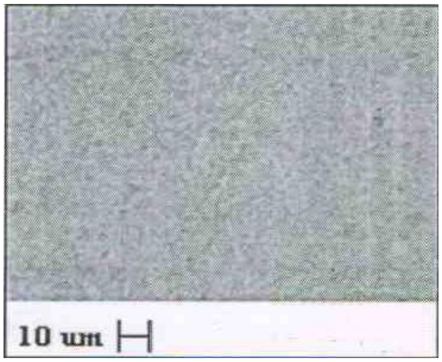


Fig. 8 Hardness Graph for Samples

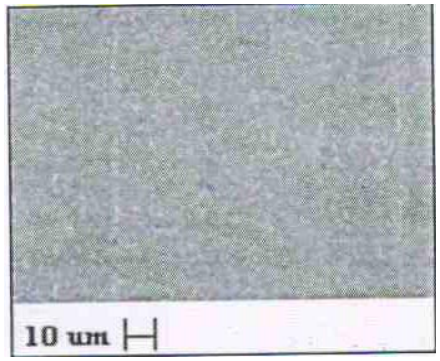
From the experiment conducted we found that the hardness is high in specimen 2&3i.e 70HRB when the tool rotation speed is 450rpm, feed is 40mm/min and 560rpm with 20mm/min. The hardness is high due the fracture occurring at the parent metal than the weld area. Since the fracture occurred on the parent metal the hardness value is not viable for the test. The specimen 5 has the high hardness of 55HRB where in the fracture occurred in the weld metal. The specimen 4 has the optimal hardness of 45 HRB wherein the fracture occurred on the weld metal and hence it enhances the corrosion property of the metal.

7.3. Microstructure Test

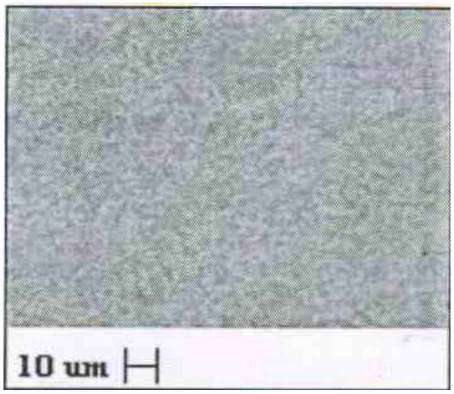
The grain distribution and the structure is closely packed face centered cubic lattice due to FSW. HAZs were observed on both sides, and there were distinct boundaries between the other zones. While the HAZs consisted of the coarsened grains compared with the BM due to increasing the weld temperature, the TMAZs displayed the deformed and elongated grain structure around the WNZs because of both insufficient plastic deformation and rising weld temperature in this region. The WNZs were characterized by fine and equiaxed -recrystallized grains due to intense plastic deformation and thermal exposure during the FSW process.



Sample 1



Sample2



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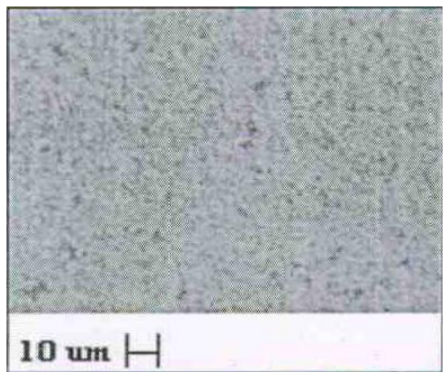
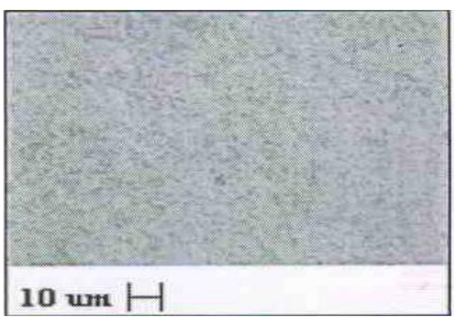


Sample 4



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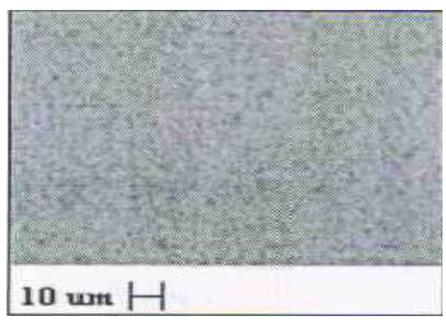

Sample 6

The specimen 4 which has rotational speed of 560rpm and traverse speed of 40mm/min had the grain structure of 13 micro-meter. The grain size of the base metal is found to be as 13.5 micro meter. The welded plate specimen 4 has grain size is reduced after FSW. The grain structure is closely packed and hence it enhances the corrosion property of the metal.

7.4. Salt Spray Test

The inspections of the samples were placed in the chamber for an interval of every day. The white corrosion product (white rust) and red corrosion product (red rust) have been observed. Initially, the white rust appears on the surface and as and when time progresses the red rust appears. The formation of Al_2O_3oxide layer resists the white rust formation and this oxide layer slowly vanishes due to corrosion pits. The corrosion test was carried out for 5 days in a chamber. The sample was weighed every day before placed into the closed chamber.

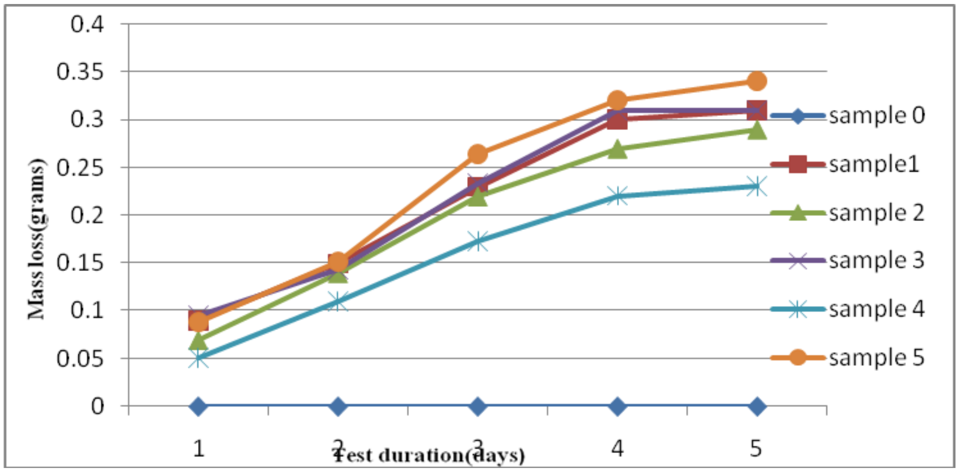

Fig.9 Corrosion - Weight Loss

VIII. CONCLUSION

The aluminium 6063 is welded by friction stir welding process. The material has good surface which required less machining work over the surface for FSW. The tool preparation required a meticulous treatment of the tool is machined to the design. The tool shoulder and pin diameter is important which are designed through reference from journals and standards. The heat treatment is done at 960^0c for 8hours a day and for good properties such as wear resistance and hardness. The sample 4 has high corrosion resistance than the other samples. The tool rotation and the transverse speed enhance material hardness and the tensile strength. The experimentation with various parameters are done in as-welded condition. The processed material are tested under different conditions of rotational speed and transverse speed(450,560,710) rpm with 20 mm/min and 40 mm/min. The tensile strength of the processed material specimen 560 rpm an 40mm/min has 159.66N/mm^2 wherein the base metal had 210 N/mm^2. The tensile strength enhances the corrosion property in the FS Welded condition which retained 75% of the strength from the base metal. The hardness of the specimen is 45 HRB wherein the base metal has 52 HRB. The hardness increase is due to change in grain structure and it can be seen in microstructure. The hardness enhances the tensile property and corrosion property wherein the grain is closely packed as face centred cubic structure. The microstructure of the specimen 560 rpm and 40mm/min can be seen clearly. The grain size of the specimen is 13 micrometer wherein base metal13.5 micrometer. The corrosion test are carried out for the specimens. The test revealed a small weight loss in 25days. The rust is formed with white sedimentation after 6days. The corrosion starts after 6^{th} day and the corrosion rate is accelerated to more exposure. The metal is coated first with salt solution. The White and red rust is formed and there is weight loss in the metal. There is gradual increase in loss of weight up-to a point there after the metal is stabilised and corrosion stops. The optimal value of 560rpm and 40mm/min was found to have low loss of weight than other samples with different parameters. Also this specimen (sample 4) has good tensile property which is supported by hardness and microstructure. From the experimental process the specimen (sample 4) with 560 rpm,40 mm/min is most optimum parameter for the friction stir welded Al AA6063.

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