A STUDY ON CORROSION BEHAVIOUR OF ALUMINIUM 6061 ALLOY BY FRICTION STIR WELDING

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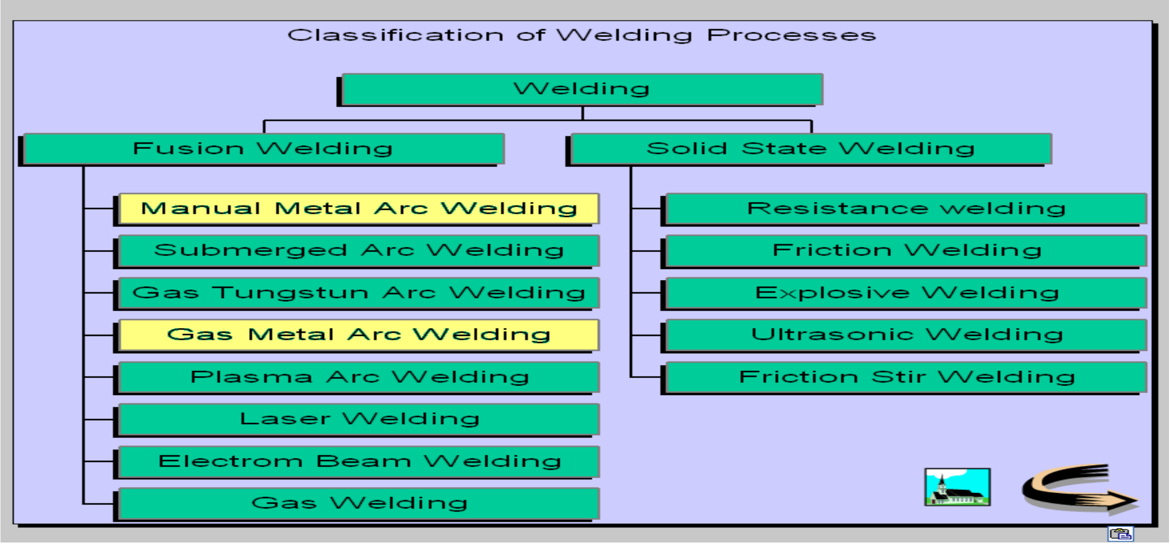
INTRODUCTION:

Alloys have become one of the most widely range used materials in marine and aerospace industries because of their good mechanical properties, high strength, high toughness, better corrosion resistance and recycling capabilities. AA6061 is one of the most used in the 6000 series alloy, especially in the usage of transportation components, machinery equipments, recreational products and consumer durables. The highlight of the AA6061 usage in this project is about the common usage of this material in marine frames and various pipelines. Basically, this type of aluminum alloy contains magnesium and silicon as its major alloying components. These major compositions contribute to the higher strength of the material via precipitation hardening.There are a lot of methods in the welding process in our subject of interest is a solid state type welding. The context of solid state welding is that it does not involve the melting of the materials being joined. The energy from the impact plasticizes the materials, forming a weld, even though only a limited amount of heat is generated. Friction Stir Welding (FSW) process is one type in these categories alongside ultrasonic welding, explosion welding, cold welding and electromagnetic pulse welding.

In the end, the joint is achieved when localized heating from the rotating tool and translation leads to movement of material from the combination of the front/back of the pin softens the material around the pin.

CLASSIFICATION OF WELDING PROCESSES :



GAP ANALYSIS:

Compared to other welding processes, corrosion resistance was high in friction stir welding. Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes will conclude changes to the corrosion properties of the AA6061 and cracking often occurs without filler metals.

FSW have advantages compare to the metal inert gas welding because of solid state process. However, the effect is this process induces dramatic changes in microstructures.

The high corrosion resistance of Al alloys are largely depends on the heterogeneity of their microstructure.

OBJECTIVE :

- To prepare a strong butt weld in Aluminium 6061 alloy using Friction Stir Welding.
- A study on Corrosion Behavior of Aluminium 6061 alloy by Friction Stir Welding (FSW), at different speed.
- A view of microstructure on the Corrosion Behavior of Aluminium 6061 alloy at different speed.
- Knowing the values of Corrosion potential (Ecorr) and Current density (Icorr) of nugget region for different speed.

NEED OF FRICTION STIR WELDING :

- Very little loss of material through exclusions.
- The heat zone being very thin, therefore dissimilar metals are easily joined.
- Here, Tensile strength is better in nugget zone.
- Annealing of weld zone is not necessary.
- Low initial capital cost.
- Low cost power requirements.
- High quality welds.
- The process is clean.

FRICTION STIR WELDING :

- Heat is generated by rubbing one metal against the other by the application of pressure.
- The frictional heat, thus generated, makes the metals plastic, and at this stage, forging pressure is given to cause upset and completion of welding.
- Many dissimilar metal combinations can be welded.
- The process is ideally suited for mass production and full automation

KEY BENEFITS OF FRICTION STIR WELDING:

METALLURGICAL BENEFITS :

- Solid phase process
- Low distortion of work piece
- Good dimensional stability & repeatability
- No loss of alloying elements
- Excellent metallurgical properties in joint area
- Fine microstructure
- Absence of cracking
- Replace multiple parts joined by fasteners

ENVIRONMENTAL BENEFITS :

- No shielding gas required
- No surface cleaning required
- Eliminate grinding wastes

- Eliminate solvents required for degreasing

ENERGY BENEFITS :

Improved materials use (E.g. Joining different thickness) allows reduction in weight.
Decreased fuel consumption in light weight aircraft, automotive ship applications.
Only 2.5% of the energy needed for a laser weld is adequate for FSW

ADVANTAGES :

- Solid phase process
- No shielding gas required
- Improved materials use (E.g. Joining different thickness) allows reduction in weight
- Excellent metallurgical properties in joint area
- Only 2.5% of the energy needed for a laser weld is adequate for FSW

LIMITATION :

- Work pieces must be rigidly clamped.
- Backing bar required.
- Keyhole at the end of each weld.

APPLICATIONS :

- Automotive (Wheel rims)
- Aerospace(Fuel tanks of space vehicles)
- Shipbuilding(Hulls and superstructures)
- Defence (Helicopter landing Platforms)
- Recreation(Sailing boats)
- Transportation (Aluminium bridges)
- Containers (Truck bodies)

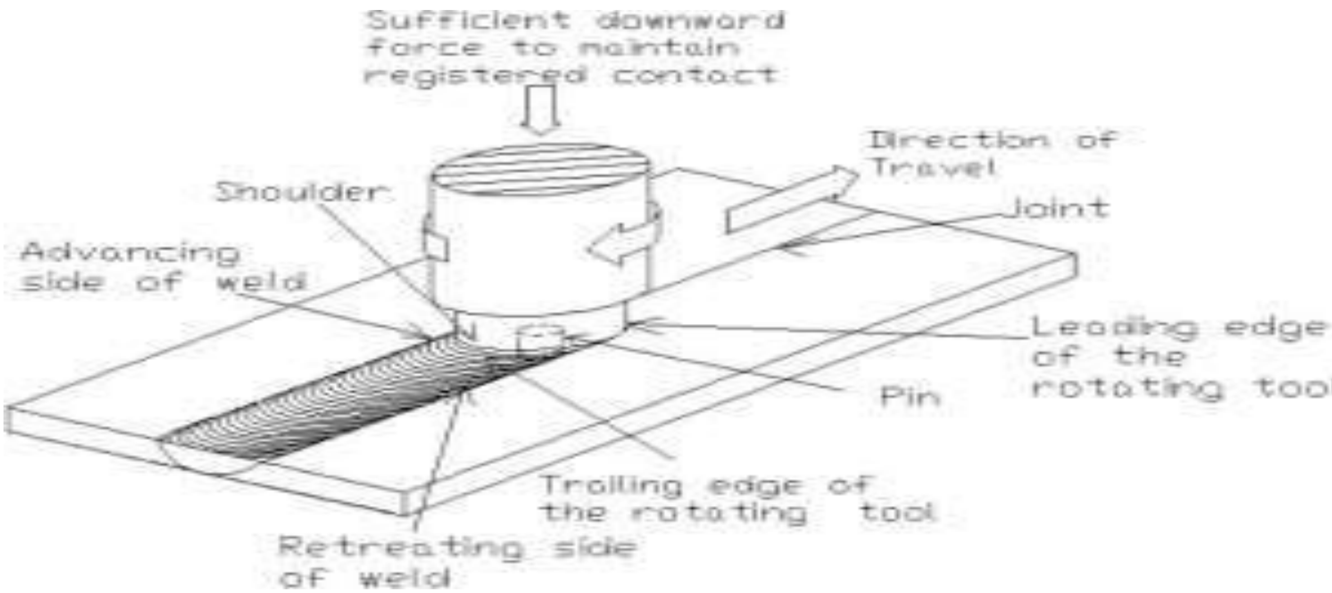
THE IDEAS OF FRICTION STIR WELDING :

Recently, Aluminum alloyhave been used widely for automotive, shipbuilding andaircraftproducts,railway rolling stockindustriesandmostlikely others.Thefrequentusageofaluminum invariety offieldislargely duetothefact thataluminumarelightinweightcomparedtoothermaterial,easy tomachineand have relativelyhigh tensile strength.However, aluminum alloys such that 6061 are difficult to join by conventionalfusionweldingmachines.Hencerealizingafusion-weldedjointin suchalloyswithoutimpairing themechanicalpropertiesisadifficulttaskfor the weldingengineer.Consequentlytheweldingengineerhastorely onrivetsand fasteners with substantial increase in fabrication cost and structure weight. In productsoffusionweldingprocessessuchasTungstenInertGas(TIG)andMetal Inert Gas(MIG), hotcracking oftenoccurswithoutfiller metals.These problems can be eliminated byFriction StirWeldingprocess.

THE PROCESS OF FRICTION STIR WELDING :

FSW use the fundamental of using non-consumable rotating tool with its design and configurations been established associated with the material properties

In order to friction stir weld a butt or lap joint, a specially designed cylindrical tool is rotated and plunged into the joint line.The tool has a small diameter pin with a concentric larger diameter shoulder. When descended to the part, the rotating pin contacts the surface, at the same time heats the material because of rapid friction, and softens a small column of metal. As the pin penetrates beneath the surface, part of this metal column is extruded above the surface. The tool shoulder and length of entry probe control the depth of penetration.



FRICTION STIR WELDING MICROSTRUCTURAL ZONES :

As mentioned before, FSW process consists of 4 main types of microstructural zones due to the aftermath of theprocess whichare

1. Unaffected material/parent metal/ base metal
2. Heat affected zone (HAZ)
3. Thermo – mechanicallyaffected zone(TMAZ)
4. Weld Nugget

1. Unaffectedmaterial/Parentmetal

Materialremotefrom theweld, which has not been deformedand althoughit mayhave experienced athermal cycle from the weld is not affected bythe heat in terms of microstructureor mechanical properties.

2. Heataffectedzone(HAZ)

Theregionwhichislieclosertotheweldcentrecomparedtotheparent metal.AHeatAffectedZones(HAZ),themetalexperiencedthermaltransientand significantchangesintemperature.Inotherhand,HAZ zonesdidnotexperienceany plasticdeformation.

3. Thermo–mechanically affectedzone (TMAZ)

TMAZ consistoftworegions.ThemainTMAZzoneiswhich zoneadjacent to theweld nugget affected by heat (C region). This regionhaschangesin temperatureandplasticdeformation,butitwillnotexperienceany recrystallization. TheotheroneTMAZis theweld nugget region.

4. WeldNugget

Weld nugget were the fullyrecrystallized, fine grain region in the weld center,surroundedbyTMAZregion.Themicrostructureofweldnuggetby rubbing the rear faceof theshoulder, and the material mayhave cooled below its maximum.Therearealsoterms associated withFSWtodescribe the regionssurrounding theweldorprocessedregionwhichareadvancing sideandtheretreatingside.

CORROSION MECHANISM :

Aluminiumalloysarewidely usedinstructureswhereahighstrengthtoweightratio isimportant,suchasinthemarineframesapplication.Aluminiumhas anatural corrosionprotectionfromitsoxidelayer,butifexposedtoaggressiveenvironments itmay corrode.Still,ifcorrectly fabricated,constructionsofaluminiummay be reliable and havelongservicelife.

PITTING CORROSION :

Pittingisahighly localizedtypeofcorrosioninthepresenceofaggressivechloride ions.Pitsareinitiatedatweaksitesintheoxidebychlorideattack.Pitspropagate accordingto thereactions

$Al = Al^{3+} + 3e^-$ (1)

$Al^{3+} + 3H_2O = Al(OH)_3 + 3H^+$ (2)

while hydrogen evolution and oxygen reduction are the important reduction processesat the intermetallic cathodes, as sketched in figure1:

$2H^+ + 2e^- = H_2$ (3)

$O_2 + 2H_2O + 4e^- = 4OH^-$ (4)

Asapitpropagates,theenvironmentinsidethe pit(anode)changes.Accordingto reaction2thepHwilldecrease.Tobalancethepositivechargeproducedbyreaction 1and2,chlorideionswillmigrateintothepit.TheresultingHClformationinside thepitcauses acceleratedpitpropagation.Thereductionreactionwillcause local alkalinisationaround cathodicparticles.Aspreviously mentionedaluminiumoxideis notstable insuchenvironment,andaluminiumaround the particleswilldissolve (alkaline pits). The active aluminiumcomponentof the particleswillalsodissolve selectively,thereby enrichingtheparticlesurfacewithFeandincreasingitscathodicactivity. Etching of the aluminiummatrix around the particles may detach the particlesfromthesurface,whichmayrepassivatethealkalinepits.Thismay also reducethedrivingforcefor theacidicpitscausingrepassivationofsomeinthelong run.

COMPOSITION OF ALUMINIUM PLATE :

Thus the following table below shows the chemical composition of AA6061 aluminium alloy

- Silicon minimum 0.4%, maximum 0.8% by weight
- Iron no minimum, maximum 0.7%
- Copper minimum 0.15%, maximum 0.4%
- Manganese no minimum, maximum 0.15%
- Magnesium minimum 0.8%, maximum 1.2%
- Chromium minimum 0.04%, maximum 0.35%
- Zinc no minimum, maximum 0.25%
- Titanium no minimum, maximum 0.15%
- Other elements no more than 0.05% each, 0.15% total
- Remainder aluminum (95.85–98.56%)

Density: 2700 Kg/m3

FRICTION STIR WELDING MACHINE :

Friction stir welding (FSW) is a highly important and recently developed joining technology that produces a solid phase bond & It used when the original metal characteristics must remains unchanged as much as possible. It uses a rotating tool to generate frictional heat that causes material of the components to be welded to soften without reaching the melting point and allows the tool to move along the weld line. In this process, one piece is held stationary and the other is rotated in the chuck of a friction of a welding machine. As they are brought to rub against each other under pressure, they get heated due to friction. When the desired forging temperature is reached throughout the rubbing cross-section of the work pieces. The rotation is stopped suddenly and the axial pressure is increased to cause a forging action and hence welding.

IMPORTANT SPECIFICATIONS OF FSW MACHINE

Spindle	-	ISO 40
Spindle motor	-	440V AC Drive.
Spindle speed	-	0 to 3000 rpm (infinitely variable)
Z axis stroke (Auto)	-	300 mm
Z axis stroke	-	25 mm (Manual – hand wheel)
Z axis thrust	-	5 kN (Min) – 50 kN (Max)
X axis stroke	-	600 mm
X axis feed	-	0 to 500 mm/min.
X axis thrust	-	2.5 kN (Min) - 25 kN (Max)
X axis rapid traverse	-	5000 mm/min
Y axis stroke (manual)	-	200 mm
Table	-	600 mm x 350 mm
Hyd. Power pack motor	-	2.2 kW / 440V
Guide ways 'Y'	-	Hardened & ground steel strips
Slide 'Y'	-	Turcite coated

WELD TRIALS :

Four sets of welding trials were made at the base material AA 6061, only by varying the tool rotation speed and keeping downward force and welding speed constant, the values of the parameters are given in Table

Specimen Code No.	S800	S900	S1000	S1200
Tool rotation speed (rpm)	800	900	1000	1200
Welding Speed (mm/min)	40	40	40	40
Downward Force (KN)	5	5	5	5

WELDED PIECES FOR CORROSION TEST AND MICROSTRUCTURE:

Hence the welded samples of nugget region for different speed was carried out for a corrosion test and microstructure. From the samples, the centre portion of nugget region in the area of 20mm*20mm has been cutted using Plasma Arc machining for a study on corrosion test as well as a view on microstructure.

SAMPLE PREPARATION FOR CORROSION TESTS :
Section of the welded parts were cut off from the specimen of different speed. Best etchant compositions 40ml of HNO_3, 30ml of HCL, 2.5ml of HF, 42.5ml of H_2O were used. For electro etching of the specimens were placed in anode and an Al plate at the cathode. Initial and final potential with respect to open circuit were -1250 to +250 V with a scan rate of 1.00 mV/s. They were fully cleaned with alcohol and H_2O. Samples were immersed in a corrosion cell containing an aqueous solution having 3.5% Nacl solution.

ELECTROCHEMICAL CELL :
Inorderofobtaining thecorrosionratesofthesample,polarizationresistance testingwouldbeanoption.Thetestsbeendoneby takingthecurrentreadingsofthe cellduring ashortandslowsweepofthepotential.Forstandardpurposes,thesweep wastakenfrom(-1250to+250)mVrelativetoOpenCircuitPotential (OCP).The testsperformedby

usingACMPotentiostatsupportedbycorrosion measurement software(Version 5) equipped with the ACM setup.

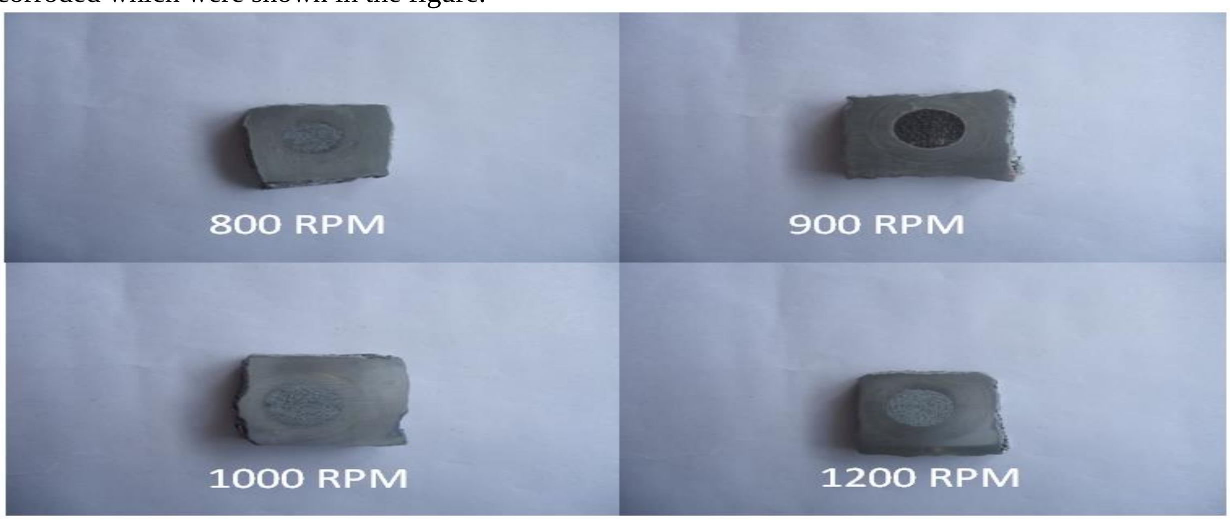
Scanrate definesthe speedof the potentialsweepinthe range of mV/sec. Thesearehelpfulforthepurposeofgetting theresultsbecauseofalmostlinearly curvebetweencurrentdensity andvoltagecurve.Theestimationofthepolarization resistanceisgivenby thelineardatafitting ofthespecimen,whichthenusedfor calculation ofthecorrosion current density(Icorr)and corrosion rate.

Inthisstudy,thereare three(3)electrodesthatshouldbeintegratedtoundergo the testing.The electrodeswhichinvolvedinelectrochemicalcellwouldbe working electrode(WE),referenceelectrode(RE)andauxiliaryelectrode

Inadditiontothe electrodesarrangement,thereareadditionalareasthatalso needtobeimplemented.Thesampleswouldbefittedtothecontainerofthe weldjoint(containboththermo–mechanically affected(TMAZ)andheataffected (HAZ)),andalsothebase metalshouldbe prepared.After that,thesesampleswould beexposedto3%sodiumchloride(NaCl)solution.Thepotentiodynamicscanwill beundergonewith the settingof 60mV/minscan rate

CORRODED WELD PIECES :

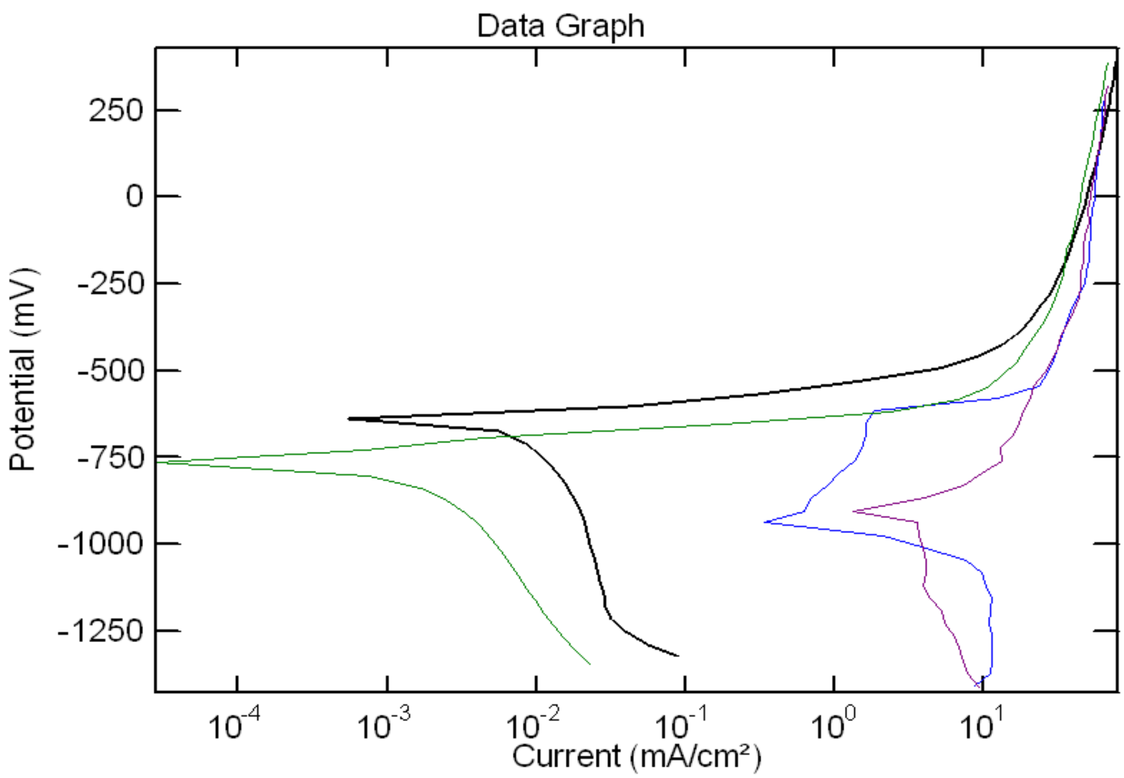
Thus, the figure below shows the images of corroded weld piece of different samples. Therefore, each welded pieces were placed in a cell for the test. After completion of the test, each welded pieces were corroded which were shown in the figure.



RESULTS AND DISCUSSION :

This section deals with the various results obtained from the project. Hence, a study on corrosion behavior of AA 6061 Aluminium alloy is studied in this chapter with the results obtained from the graph. Therefore the graph that should be plotted in computer was obtained from ACM Instruments.

A STUDY ON CORROSION BEHAVIOUR OF AA6061 ALUMINIUM ALLOY :



This study deals with Tafel polarization graph and this graph has been used to observe the corrosion rate on AA6061 aluminium alloy with the help of ACM Instruments. Thus the graph obtained in the computer with ACM Software, which was used to plot cyclic sweep graph.

COMBINED RESULTS FOR DIFFERENT SPEED

PARAMETERS	800rpm	900rpm	1000rpm	1200rpm
Pitting Potential Ecorr (mV)	-787.56	-935.27	-765.17	-904.65
Ba (mV) Bc (mV)	306.6548 632.53974	372.0214 110.31121	100.89214 67.013114	381.10067 159.88503
Current Density	5.1495189	2.1083807	0.8364889	2.4770553

Icorr (mA/cm2)				
Corrosion Rate (mm/year)	60.043391	24.583719	9.75346	8.882465
Corrosion Rate (mils/year)	2363.913	967.86294	383.9945	137.1049

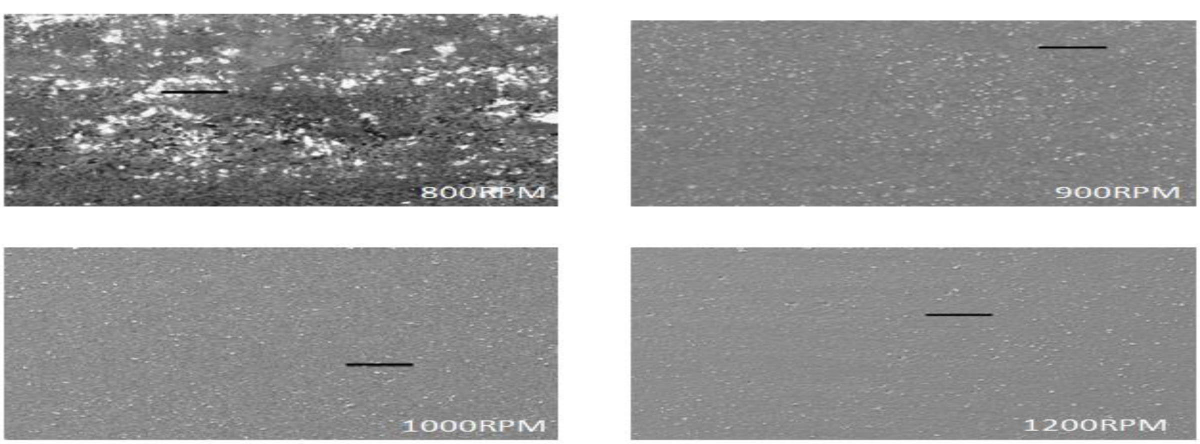
From the tabulation, the main parameters such as pitting potential, current density, anodic voltage ,cathodic voltage and corrosion rate of different welded samples of 800, 900, 1000, 1200rpm has been differentiated.

A VIEW ON MICROSTRUCTURE OF AA6061 ALUMINIUM ALLOY :

As friction stir welding is a solid state type of weldment, the joints are almost free from any defects. In other hand, fusion welding will result in several problems such as solidification cracks, slag inclusion and porosity which in return will jeopardize the base quality of the product.

Aluminiumalloy AA6061 were analyzed using Scanning Electron Microscope (SEM) to reveal and compare the quality of the weldment in different region. The figure shows microstructure for nugget region of different welded samples of 800, 900, 1000, 1200 rpm. The SEM was used to study the second phase precipitates and the visualization on creation of pitting prior to the immersion on 0.1M NaCl solution.

From the above figure it shows that, the corrosion can be determined to localize mainly in the nugget region. The predominant pitting creation is also existed on nugget region. This is the evidence of cathodic reactivity found in the form of grooves around constituent intermetallic particles. The grooves around constituent particles are the consequence of the cathodic reduction of oxygen, which takes place at the constituent particles and causes an increase in alkalinity in the solution around the particles leading to the dissolution of aluminum matrix.



CONCLUSION :

The following are the conclusions which are arrived from our project.

- By knowing the values of graph, corrosion rate was low in high speed friction stir welding compared to low speed friction stir welding.
- Hence, thereby welding the aluminium alloy at high speed reduces the corrosion rate which has been observed from the graph.
- Therefore, the nugget region shows the better corrosion resistance from the Tafel polarization graph as well as from the Microstructure.

FUTURE ENHANCEMENTS :

- We just show the graph and results for nugget region only. If we compared the nugget region with other zones as follows HAZ, TMAZ, BM.
- It could be easily compared and differentiated from other zone. Hence, the nugget region shows the better corrosion resistance.
- Microstructure of the weld samples of HAZ, TMAZ, BM is also possible for comparison

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