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# Effect of process parameters on corrosion resistance of AA 6101 T6 Al alloys welded by Friction stir welding

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***Abstract*** *- Corrosion is always a limiting factor for deciding life of a material. The 6xxx series Al alloys are considered to have better corrosion resistance compare to other grades. Even then welded samples has some effect of pitting in salt bath. In present paper the welding of plates was carried out using a well-known solid state welding process called as Friction Stir Welding (FSW). The process is widely used for joining Al alloys in marine, aerospace, automobile and railway industries. The welding was carried out on conventional milling machine with different tool rotational speeds and traversing speeds. The corrosion tests of base metal and welded samples were carried out in 3.5% NaCl solution at room temperature using cyclic polarization measurement. The pitting effect at different zones like heat affected zone (HAZ) and thermo mechanically affected zone (TMAZ) was studied and results were presented graphically. The impact of process parameters was observed on corrosion resistance after FS welding than base metal. The material characterization of welded samples was also done.*

***Keywords*** *- pitting corrosion, friction stir welding, cyclic polarization, TMAZ, HAZ.*

## I. Introduction

Friction stir welding (FSW), being a popular process adopted by fabrication industries, was a development of The Welding Institute, UK [1]. The process is advantageous and problems like porosity, hot cracking in case of fusion welding processes (GTAW or GMAW) can be eliminated [2].

In FSW process, a cylindrical rotating tool is plunged into the abutting edges of the work-piece to be joined, whereby the shoulder has intimate contact with the top surface of the material while the pin is fully penetrated into the material [3], as shown in Figure 1.

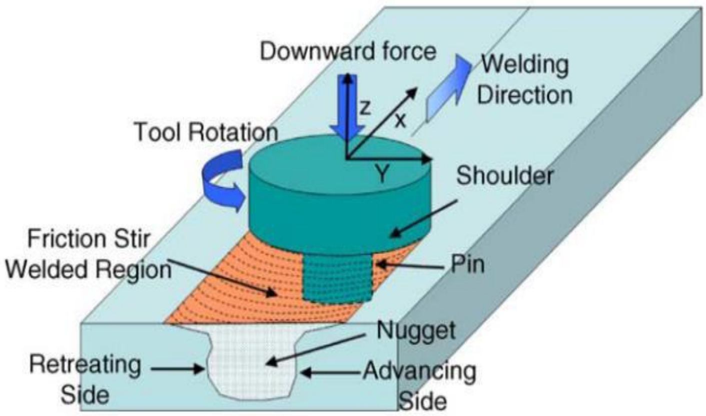


***Figure 1. Schematic illustration of FSW process [3]***

Corrosion of any material is not acceptable and need to be studied properly. Generally, it has been found that the weld zones are more susceptible to corrosion than the parent metal. Friction stir (FS) welds of aluminium alloys such as 2219, 2195, 2024, 7075 and 6013 did not exhibit enhanced corrosion of the weld zones [4]. FS welds of aluminium alloys exhibit intergranular corrosion mainly located along the nugget's heat-affected zone (HAZ) and enhanced by the coarsening of the grain boundary precipitates. Coarse precipitates and wide precipitate-free zones promoted by the thermal excursion during the welding are correlated with the intergranular corrosion.

Jariyaboon et al. [5] studied the effect of welding parameters (rotation speed and travel speed) on the corrosion behavior of friction stir welds in the high strength aluminium alloy AA2024–T351. It was found that rotation speed plays a major role in controlling the location of corrosion attack. A comparison of the corrosion resistance of AA6060T5 and AA6082T6 joints made by Friction Stir Welding (FSW) and Metal Inert Gas (MIG), respectively, is reported by Stefano and Chiara [6]. Tests were conducted by putting the welded and polished samples in an acid salt solution.

 

The other researcher Litwinski [7], found that, the weld travel speed/cooling rate has an appreciable effect on the weld corrosion resistance. Z. Chen studied the microstructure characteristics and corrosion behavior of friction stir welded AA5086 and AA6061 Al alloys, and reported that FSW improves the corrosion resistance and the HAZ had better corrosion resistance than other regions [10].

## II. Experimental work

The main objective of this work was to study the effect of process parameters (tool rotational speed and welding speed) on corrosion behavior of friction stir welded Al alloys. For this purpose AA6101 T6 Al alloy plates of 6 mm thickness were cut into size 100 mm x 100 mm and machined all sides to right angle. The plates were clamped in a specially designed jig type fixture, in a butt configuration. The welding was carried out across the rolling direction using hexagonal pin, concave shoulder non-consumable tool made of wear resistant steel.

The EDS analysis was carried to know the content of the base metal as sown in Fig. 2 and the chemical composition of the AA6101-T6 material is given in Table 1.

***Table 1. Composition of AA 6101 T6 Alloy***

| Element | Si | Fe | Mn | Mg | Al |
|---|---|---|---|---|---|
| Weight % | 0.31 | 0.16 | 0.06 | 0.46 | 98.97 |

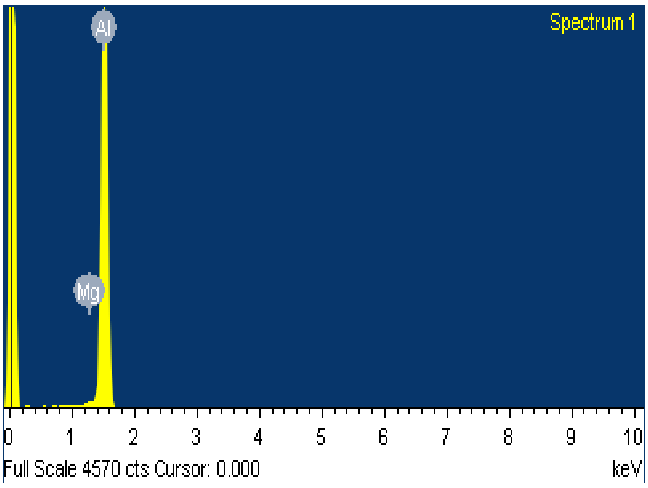


***Figure 2. EDS Analysis of AA 6101 T6 Alloy***

A vertical milling machine was used for FSW in the present study. The welding parameters namely rotational speed (rpm) and traverse speed (welding speed) selected for this experimentation are based on the literature review and entire work which was carried out on this alloy. The welding process parameters and tool dimensions are given in Table 2.

***Table 2. Welding parameters and Tool dimensions***

| **Process parameters and tool details** | **Values** |
|---|---|
| Rotational speed (rpm) | 545, 765, 1070 |
| Welding speed (mm/min) | 50, 78, 120 |
| Tool shoulder diameter, *D* (mm) | 20.0 |
| Pin diameter, *d* (mm) | 6.0 |

### 2.1 Corrosion Studies

Polarization studies were carried out using potentiostate supported with software and the scan rate and potential range for the scan was finalized on the basis of OCP of the material. Scan rate defines the speed of the potential sweep in mV/sec. In this range the current density v/s voltage curve was almost linear. A linear data fitting of the standard model gives an estimate of the polarization resistance, which is used to calculate the corrosion current density Icorr and corrosion rate. The tests were performed using MYGAMRY software. Studies were carried out on base metal and welded samples. AA6101-T6 Al alloy and FS welded samples were used as working electrode (WE), a saturated calomel electrode immersed in the salt solution was used as reference electrode (RE), and a carbon electrode was used as an auxiliary electrode (AE).

Samples were prepared carefully having 0.25 cm2 area and using exposure window exposed to 3.5%NaCl solution [8] over the TMAZ and HAZ of weld joint and base metal. The potentiodynamic scan was performed with scan rate of 10mV/sec using potentiostate supported by corrosion measuring software.

## III. Results and Discussion

FSW is essentially a hot working process, where a large amount of deformation is induced into the work piece due to heat and the flow of material caused by active participation of shoulder and probe of the FSW tool. The FSW results into generation of the microstructure of friction stir welded joint which is totally different from base metal. These changes occurred lead to different corrosion behavior of the weld.

### 3.1 Corrosion observations

A passive oxide film generally developed readily on the aluminium alloys, when exposed to air or water. However the corrosion rate could be very high due to the presence of chloride ion [8]. Further the corrosion behavior of Al alloys largely depends on heterogeneity of their microstructures. In this study, electrochemical corrosion test was carried out by Cyclic Polarization of base metal and the FSW welded samples of AA6101-T6 alloy using 3.5% NaCl solution, corrosion potential (Ecorr) and corrosion current (Icorr) are also evaluated at HAZ and TMAZ.

At a given rotation speed, the width of the reactive region decreases with increasing welding speed whereas at a given welding speed, the width of the reactive region increases with increasing rotation speed. Moreover, there is significant difference in corrosion rate as a function of welding parameters from test.

The effects of rotational speed and welding speed on corrosion behavior of all FSW samples are discussed below separately.

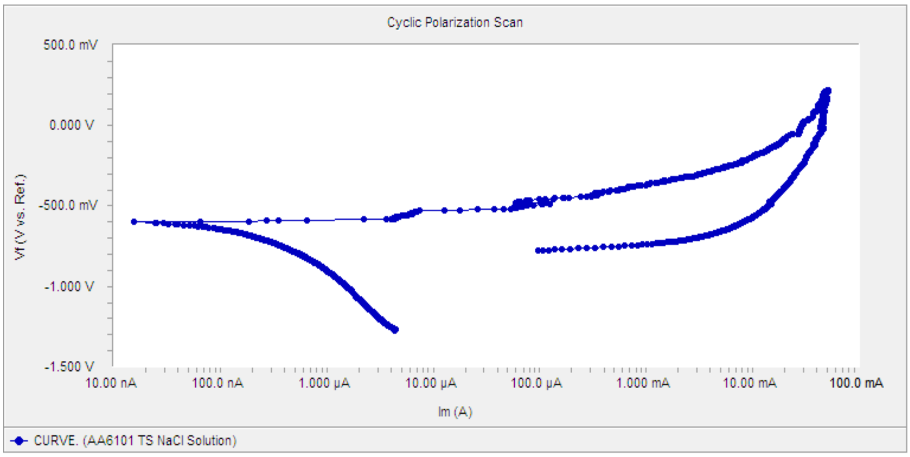


*Figure 3. Cyclic polarization curve for base metal in 3.5%Nacl solution*

The cyclic polarization curve of base metal having grade AA 6101 T6 aluminum alloy was obtained by performing cyclic polarization test on given base metal in 3.5%Nacl environment. The curve obtained shows positive hysteresis (Fig.3). Here $E_{pit}<E_{corr}$ which indicate that pitting will occur and damage passive film which is not repairable and it will further corroded under pitting manner [9].

### 3.2 Cyclic polarization studies at TMAZ region with constant tool rotational speed

*Table 3. Corrosion analysis at TMAZ region of FSW joint at rotational speed of 545 rpm*

| Sample code | Tool rotation speed RPM | Welding speed mm/min | $I_{corr}$ (µA) | $E_{corr}$ ( mV) | $E_{pit}$ ( mV) | Corrosion rate (mpy) |
|---|---|---|---|---|---|---|
| E1-T1 | 545 | 50 | 0.156 | -804.0 | -866.9 | 267.2e-3 |
| E2-T2 | 545 | 78 | 1.090 | -762.0 | -861.9 | 1.877 |
| E3-T3 | 545 | 120 | 0.933 | -724.0 | -827.9 | 1.704 |

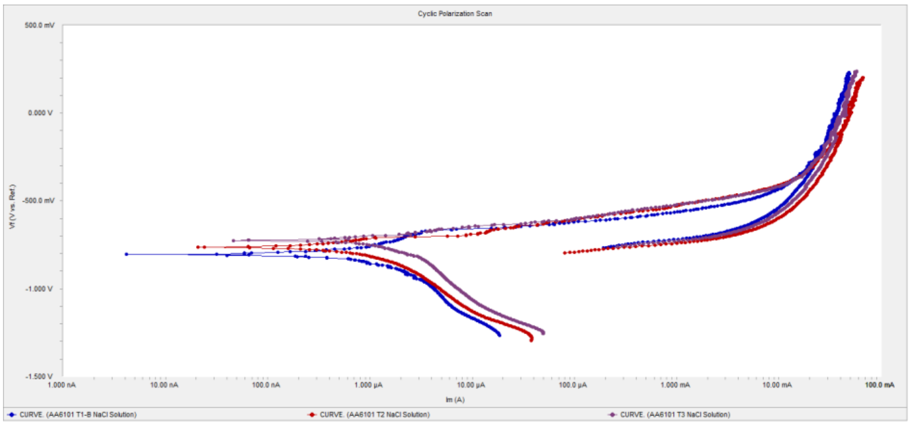


*Figure 4. Effect of welding speed on corrosion at rotational speed of 545 rpm at TMAZ*

 

- The cyclic polarization curve of FSW welded AA 6101 aluminum alloy at TMAZ shows positive hysteresis for different welding speeds.
- At constant rotational speed of 545 rpm, in all the samples, $E_{pit} < E_{corr}$ which indicates that pitting will occur and damage passive film which is not repairable and it will further corrode under pitting manner.
- The corrosion rate is very low at 50 mm/min, and high at 78 and 120 mm/min welding speed (Table 3).
- E1-T1 has best corrosion resistance.
- All sample show passivation after longer time of exposure to corrosion media (Fig. 4).

***Table 4. Corrosion analysis at TMAZ region of FSW joint at rotational speed of 765 rpm***

| Sample code | Tool rotation speed RPM | Welding speed mm/min | $I_{corr}$ (μA) | $E_{corr}$ ( mV) | $E_{pit}$ ( mV) | Corrosion rate (mpy) |
|---|---|---|---|---|---|---|
| E4-T4 | 765 | 50 | 0.639 | -1.180V | -821.2 | 1.097 |
| E5-T5 | 765 | 78 | 75.20 | -710.0 | -944.3 | 129.1 |
| E6-T6 | 765 | 120 | 0.128 | -723.0 | -820.4 | 219.2e-3 |

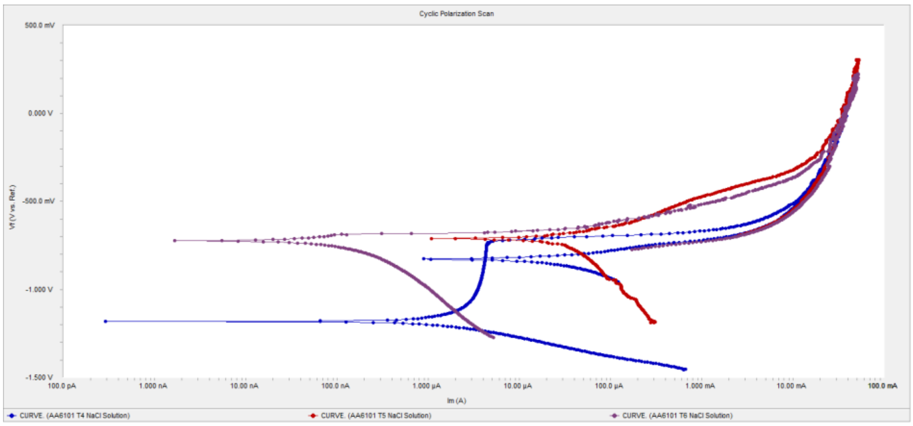

***Figure 5. Effect of welding speed on corrosion at rotational speed of 765 rpm at TMAZ***

- E4-T4 has highest active potential (-1.180V) among all (Table 4).
- Also here $E_{pit} > E_{corr}$ which indicate that pitting will occur but in passive zone and damage passive film can be repaired and it will prevent further corrosion as seen from Fig.5.
- The corrosion rate is very low at 120 mm/min, at rotational speed of 765 rpm.

***Table 5. Corrosion analysis at TMAZ region of FSW joint at rotational speed of 1070 rpm***

| Sample code | Tool rotation speed RPM | Welding speed mm/min | $I_{corr}$ (μA) | $E_{corr}$ ( mV) | $E_{pit}$ ( mV) | Corrosion rate (mpy) |
|---|---|---|---|---|---|---|
| E7-T7 | 1070 | 50 | 0.0858 | -767.0 | -934.4 | 147.1e-3 |
| E8-T8 | 1070 | 78 | 0.255 | -737.0 | -917.2 | 437.8e-3 |
| E9-T9 | 1070 | 120 | 1.080 | -768.0 | -848.4 | 1.852 |

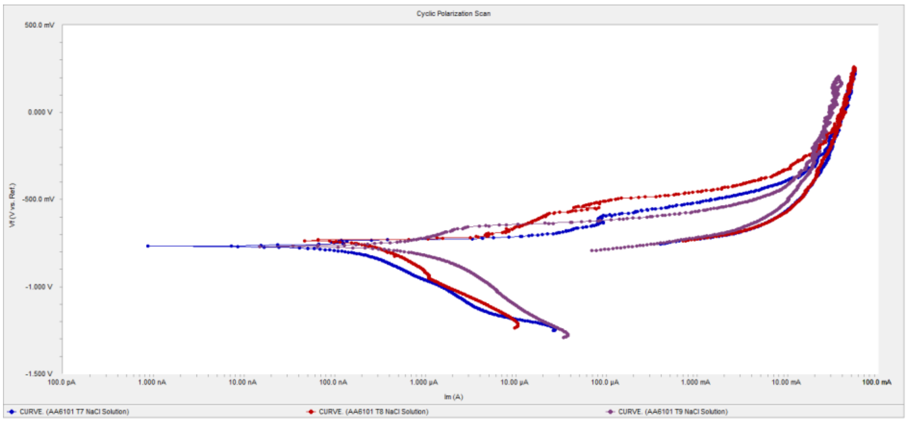

***Figure 6. Effect of welding speed on corrosion at rotational speed of 1070 rpm at TMAZ***

- All sample show passivation after longer time of exposure to corrosion media (Fig. 6).

 

- The corrosion rate increases with increase in the welding speed.

### 3.3 Cyclic polarization studies at HAZ region with constant tool rotational speed

***Table 6. Corrosion analysis at HAZ region of FSW joint at rotational speed of 545 rpm***

| Sample code | Tool rotation speed RPM | Welding speed mm/min | $I_{corr}$ (µA) | $E_{corr}$ ( mV) | $E_{pit}$ ( mV) | Corrosion rate (mpy) |
|---|---|---|---|---|---|---|
| E1-H1 | 545 | 50 | 0.430 | -1.040V | -838.7 | 737.7e-3 |
| E2-H2 | 545 | 78 | 2.060 | -822.0 | -883.3 | 3.538 |
| E3-H3 | 545 | 120 | 3.610 | -783.0 | -829.6 | 6.198 |

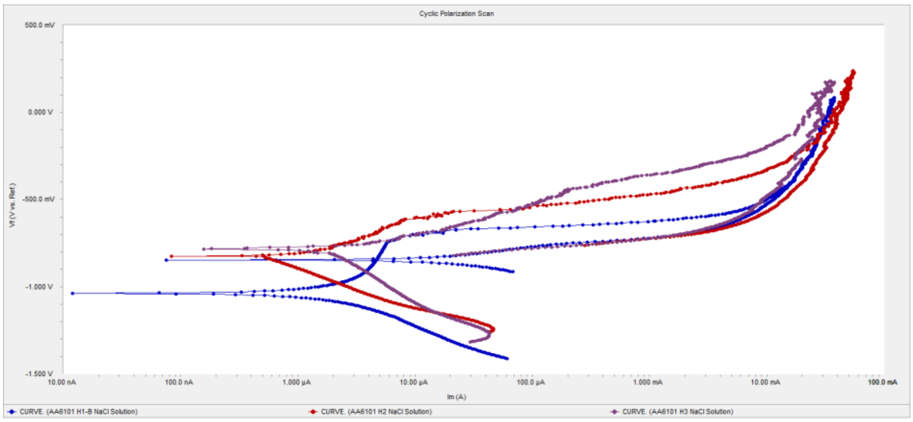

***Figure 7. Effect of welding speed on corrosion at rotational speed of 545 rpm at HAZ***

- All sample show passivation after longer time of exposure to corrosion media (Fig. 7).
- The corrosion rate increases with increase in the welding speed in HAZ region.
- E1-H1 has highest active potential (-1.040V) among all (Table 6).
- Also $E_{pit}$ > $E_{corr}$ which indicate that pitting will occur but in passive zone and damage passive film can be repaired and it will prevent further corrosion.

***Table 7. Corrosion analysis at HAZ region of FSW joint at rotational speed of 765 rpm***

| Sample code | Tool rotation speed RPM | Welding speed mm/min | $I_{corr}$ (µA) | $E_{corr}$ ( mV) | $E_{pit}$ ( mV) | Corrosion rate (mpy) |
|---|---|---|---|---|---|---|
| E4-H4 | 765 | 50 | 0.461 | - 830.0 | - 931.9 | 790.2e-3 |
| E5-H5 | 765 | 78 | 0.605 | - 1.010V | - 865.1 | 1.038 |
| E6-H6 | 765 | 120 | 1.300 | - 733.0 | - 813.9 | 2.238 |

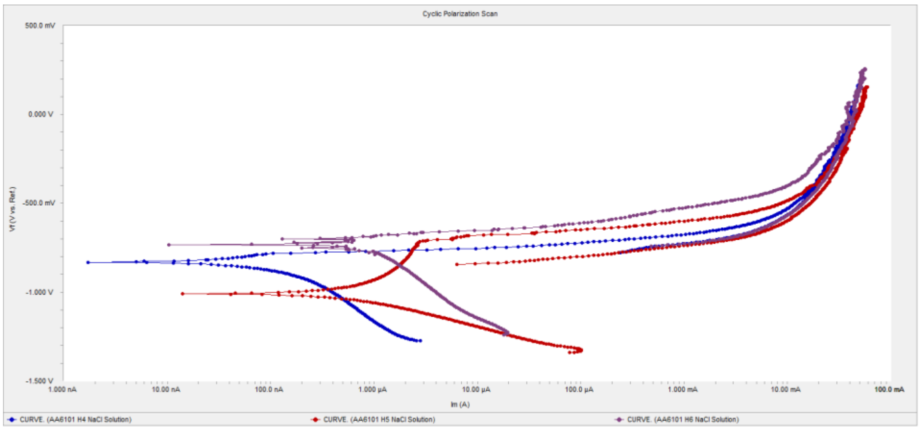

***Figure 8. Effect of welding speed on corrosion at rotational speed of 765 rpm at HAZ***

- All sample show passivation after longer time of exposure to corrosion media (Fig. 8).
- The corrosion rate increases with increase in the welding speed.
- E5-H5 has highest active potential (-1.010V) among all (Table 7).
- Also here $E_{pit}$ > $E_{corr}$ which indicate that pitting will occur but in passive zone and damage passive film can be repaired and it will prevent further corrosion.

 

***Table 8. Corrosion analysis at HAZ region of FSW joint at rotational speed of 1070 rpm***

| Sample code | Tool rotation speed RPM | Welding speed mm/min | $I_{corr}$ (μA) | $E_{corr}$ ( mV) | $E_{pit}$ ( mV) | Corrosion rate (mpy) |
|---|---|---|---|---|---|---|
| E7-H7 | 1070 | 50 | 0.214 | -858.0 | -831.1 | 366.4e-3 |
| E8-H8 | 1070 | 78 | 0.227 | -932.0 | -880.6 | 390.0e-3 |
| E9-H9 | 1070 | 120 | 0.411 | -1.000V | -854.0 | 705.7e-3 |

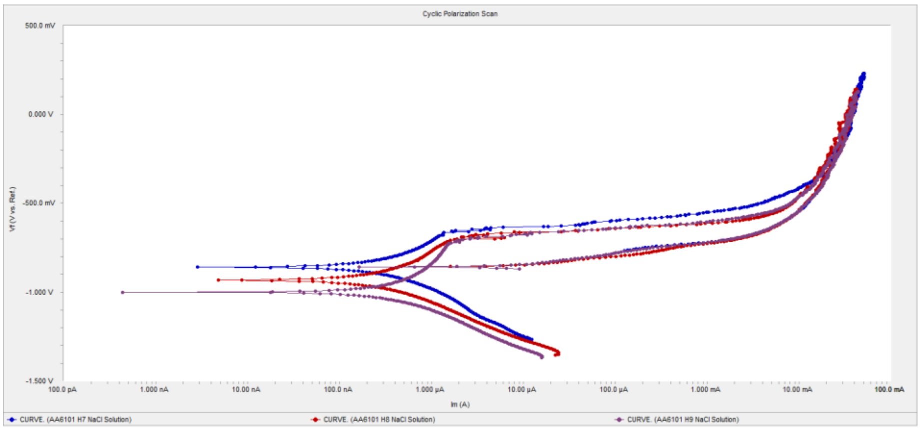


***Figure 9. Effect of welding speed on corrosion at rotational speed of 1070 rpm at HAZ***

- All sample show passivation after longer time of exposure to corrosion media (Fig. 9).
- The corrosion rate increases with increase in the welding speed.
- E9-H9 has highest active potential (-1.000V) among all (Table 8).
- In this case at all the welding speeds a similar trend of curve is observed. It has good corrosion resistance at HAZ region in all conditions at constant speed of 1070 rpm.
- $E_{pit} > E_{corr}$ which indicate that pitting will occur but in passive zone and damage passive film can be repaired and it will prevent further corrosion.

## IV. CONCLUSION

- FS welding results into formation of distinguished zones namely nugget, TMAZ, HAZ.
- HAZ (heat affected zones) and TMAZ (thermo mechanically affected zones) are of more of the interest as they incorporate the most thermal and mechanical stress which make them most likely to be attacked by environment.
- In case of HAZ the passivity film may be or may not be repairable, it depends on the heat input & extent of heat distribution.
- Among all the samples welded with rotational speed of 1070 rpm shows pitting resistance in HAZ.
- At 765rpm rotational speed and 50mm/min welding speed, better corrosion resistance is observed in TMAZ.
- From overall observation, it can also be concluded that at all rotational speed and at low welding speed, pitting resistance is observed.
- In general high rotational & low welding speed results into less distorted HAZ & TMAZ and hence better pitting resistance.

## REFERENCES

[1] C. J. D. W.M. Thomas, E.D. Nicholas, J.C. Needham, M.G. Much, P. Temple-Smith, “Friction stir butt welding, GB Patent No. 9125978.8, International patent application No. PCT/GB92/02203, (1991).,” no. 9125978, 1991.
[2] T. Hashimoto, S. Jyogan, K. Nakata, and Y. Kim, “FSW joints of high strength aluminum alloy,” *Proc. First Int. Symp. Frict. Stir Weld.*, pp. 1–8, 1999.
[3] R. S. Mishra and Z. Y. Ma, “Friction stir welding and processing,” *Mater. Sci. Eng. R Reports*, vol. 50, no. 1–2, pp. 1–78, 2005.
[4] C. S. Paglia and R. G. Buchheit, “A look in the corrosion of aluminum alloy friction stir welds,” *Scr. Mater.*, vol. 58, no. 5, pp. 383–387, 2008.
[5] M. Jariyaboon, A. J. Davenport, and S. W. Williams, “The effect of welding parameters on the corrosion behaviour of friction stir welded AA2024 – T351,” *Corros. Sci.*, vol. 49, pp. 877–909, 2007.
[6] S. Maggiolino and C. Schmid, “Corrosion resistance in FSW and in MIG welding techniques of AA6XXX,” *J. Mater. Process. Technol.*, vol. 197, no. 1–3, pp. 237–240, Feb. 2008.

 

[7] E. Litwinski, “Effect of FSW Process and Parameters on Corrosion Susceptibility,” *Microsc. Microanal.*, vol. 11, no. S02, pp. 1596–1597, Aug. 2005.

[8] F. T. De Abreu, “Evaluation of Corrosion Resistance of 6101 Aluminum Alloy after different precipitation Heat Treatments,” in *21st Brazilian Congress of Mechanical Engineering*, 2011, p. 10 pages.

[9] F. Gharavi, K. A. Matori, R. Yunus, N. K. Othman, and M. Synthesis, “Investigation of the Nugget Zone Corrosion Behavior in Friction Stir Welded Lap Joints of 6061-T6 Aluminum Alloy,” *Mater. Res.*, vol. 17, no. 6, pp. 1563–1574, 2014.

[10] Z. Chen, “Microstructure Characterization, Mechanical Properties, and Corrosion behaviors of Friction Stir Welded AA5086 and AA6061,” *Thesis, Univ. HAWAI‘I MĀNOA*, 2014.

 