Corrosive Behaviour of Friction Stir Al Alloy Welding Technique: A Review

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Abstract Friction stir welding (FSW) is a technique under which solid state joining process principal working upon the materials for infusing strength. As reported by myriad scholars FSW emphatically used in automobiles, air craft structures, ship building etc. With priority to consume alloys used aluminum as base metal. Due to their cost effectiveness and lighter in weight. We discussed alloys of 2xxx, 5xxx, 6xxx, 7xxx series to ascertain the corrosion nature of prime material. Aluminums may be heat treated or non-heat treated so we discussed the impact of various corrosive techniques for strengthening the alloys. This article elaborate about the corrosion behavior of the material over HAZ, NZ, TMAZ regions of welded part and ascertain the various process parameters under intergranular corrosion testing (ICG) & Electrochemical impedance spectroscopy (EIS) technique under varying circumstances. Purpose of this paper is to enhance the fundamental skill of researchers in future for effectively dealt with the improvement of Aluminum alloys.

Keywords: Aluminium alloys, corrosion test, EIS, ICG, FSW

1. Introduction
The Welding Institute (TWI) in 1991 invented Friction stir welding sort of technique which has basically working upon solid state joining principle[1,11]. The main reason behind this invention was alloys like Al, Cu which has been immensely used in automobiles, air craft structures [2], ship building as these metals are cost effective and lighter in weight, these Al alloys known as difficult to weld in simple fusion welding technique shows poor efficacy whereas in automotive and aerospace arena structures are subjected to cyclic loading and high frequency vibration, hence we prefer FSW technique for corrosive behavior. Figure 1 illustrates the working principal of tool rotation which ultimately results in blending of the material around the tool pin due to heat yielded at that zone. Tool transverse motion is subjected to spread the mixed material surrounding the area of tool pin. Meanwhile in weld zone (WZ) culmination of extrusion process is attained by axial thrust under plastic state material [3].
M. Jariyaboon et al. observed that in AA2044 T351, HAZ grain boundary agitation caused to intergranular attack while in the NZ due to S phase particles precipitation cathodic reaction is imparted. By varying rotational speeds (high –low) he found the corrosion attack by cathodic and anodic reaction in high and low speed respectively [11]. Shrinivasan et al.[2] elucidate the corrosion and SCC behavior in weld nugget(WN) and TMAZ(Thermo mechanical affected zone)/HAZ(Heat affected zone) region. As he observes joint efficient nearly 70 %, he observes mitigation in the galvanic drive and displaying the nobler free corr. Potential. The micro-structural analysis on TMAZ yielded by plastically deformed material during the welding process, HAZ spotted due to weld thermal cycle rather than plastic deformation and the stir zone (SZ) obtained as recrystallization occurs with plastic deformation in this zone as exhibit by the Fig 2.
FSW sometimes in Al alloys cause porosity in the weld metal. Even though the other solid state joining process such as friction taper plug welding and friction hydro pillar processing has been invented due to tapered plug without shoulder as stress concentration working upon the material.

Aforesaid discussion comes under significance of material and there composition as all examined circumstance founded upon the material characteristics and its properties. Tensile behavior of material has its foreseen dominance during measurement of hardness and strength of, moreover the process parameter designated for the testing immensely depends upon its conspicuous predefined composition exhibit in figure 3.

![Micro tensile specimen](image)

**Fig 3: Micro tensile for AA 5083 cold rolled Hot tempered specimen and test fixture[4]**

In corrosion test we observe about the corrosion of aluminum using methods such as immersion test while keeping a close watch over adequate solution for the sinking of weld part in prescribed manner. Other than this we can also ostensibly go through various process such as, polarization techniques, electrochemical impedance spectroscopy (EIS), stress corrosion cracking (SCC) test, and cyclic spray tests. Meanwhile, cyclic polarization and electrochemical impedance spectroscopy (EIS) tests are scarcely reported while on the other side intergranular corrosion (IGC) and exfoliation corrosion which characterized by uncertainty and imperceptibility are common Corrosion forms of aluminum alloy. Many researchers have observed electron back scattering diffraction (EBSD) and/or orientation imaging microscopy (OIM) technique to characterize microstructure and texture evolutions of welded joint. The main objective of this work is to perform a review on the effect of the influence of FSW on the Al alloys by observing tensile and corrosion behavior with microstructure characterization.

2. **Role of Material composition**

Friction stir welding of various Aluminum Alloys has been used by the researchers prolong in joining, but its other composition too have important role to discerning strength of joints[1-5]. Below table 1 shows that Cu, Mn, Si, Zn, and Mg have the next prime content other than aluminum as a base metal, as these element individually improvised the work material properties irrespective of their composition in the in situ processed composition. As a catalyst Cu expedite chemical reaction with less activation energy, it has ample corrosive resistance and high thermal conductivity. Alike Cu other element has also explicitly shown good corrosion resistance.

Proton et al characterized welding feed rate at 500mm/min by observing tribological layer for controlled wear in diffusion of Al/Mg alloy[1]. AA2219, hot rolled tempered material undergo for keyhole repairing by filling of FSW operation performed which reason to running down the defects during using of FFSW process preceded by friction stir processing[2].
Table 1. Material composition used with base metal Aluminium.

| Sample material | Ni  | Cr | Mg | Zn | Cu | Mn  | Fe | Mg | Ti | V | Si | Sn | Li | Zr | Pb | Ca | Al |
|-----------------|-----|----|----|----|----|-----|----|----|----|----|----|----|----|----|----|----|----|----|
| AA2050[1]       | 3.5 | 1  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1  | BM |
| AA2219[2]       | 5.95| 0.27| 0.12| 0.06| 0.01| 0.05| 0  |  |  |  |  |  |  |  |  |  |  | BM |
| AA6061[3]       | 0.18| 1  | 0.05| 0.27| 0.03| 0.3 | 0  |  |  |  |  |  |  |  |  |  |  | BM |
| AA7055 T6[5]    | 0.04| 7.6-8.4| 2.26| 0.05| 0.15| 1.8-2.3| 0.06| 0.1|  |  |  |  |  |  |  |  |  | BM |
| AA7023[6]       | 0.018| 0.077| 2.127| 4.227| 1.353| 0.138| 0.943| 0.015|  |  |  |  |  |  |  |  |  | 0.089| 0.01| BM |
| AA5083[6]       | 0.064| 5.349| 0.112| 0.438| 0.491| 0.33 | 0  |  |  |  |  |  |  |  |  |  |  | BM |
| AA6061T6[10]    | 0.003| 0.01| 0.01| 0.061| 0.156| 0.43 | 0.008| 0.08| 0.52|  |  |  |  |  |  |  |  | BM |
| AA7005[8]       | 0.1 | 1.3 | 4.5 | 0.02 | 0.3 | 0.02 | 0.03 | 0.03 | 0 |  |  |  |  |  |  |  |  | 0.1 | BM |
| AA2024T351[12]  | 1.42 | 0.06| 4.43 | 0.61 | 0.08 | 0.06 |  |  |  |  |  |  |  |  |  |  |  | BM |

Table 1. Material composition used with base metal Aluminium.

Al composite (Si 17% vol-4.26Cu-1.61 Mg wt%) subjected to T4 tempering and thereafter this composition plays under greater weld speed, by measurement of hardness and precipitation of the joints by TEM we can effectively achieve fast FSW[3]. As displayed in Fig 3 Al 5083(Al-4.5 Mg-0.6Mn) material cold rolled but welded further going in to micro tensile test at strain rate 0.2 mm/min on the other side indentation testing for hardness commences with R1/4 200 mm diamond tip [5]. Wang et al observed for stress strain curve indentation data espouse the well polished surface for artificial neural network analysis. Gharavia et al worked with two dissimilar alloys AA 5083 H111 & AA 6082 T6 base metal weld parameters such as speed (rotational & welding), vertical force, shoulder and pin diameter, tool pitch angle help to extricate plastic behavior properties with ASTM E8M & ASTM E21 standards [4].

2.1 Corrosive behavior

2.1.1. Immersion testing method. To measure the progress of corrosion damage attained due to corrosive environment, as well as other parameters (i.e. media to holding time in days/ hrs) accelerated the corrosion. In cyclic tests alternative drying and immersion methods entails though electrochemical instrumentation and connections remains in a queue in order to facilitate the measurements. In this test Appropriate acceleration may be obtained by the prolonging (i.e. retains the work piece from hours to days w.r.t time). However, pressure, concentration of salt, temperature, acidic solution are the factors which assist to exposed immersed material. It can be further classified in two categories [14]

2.1.2. Alternate immersion test. As from the title of this test specimen immersed in a solution cyclic process for a span of time. Thereafter sample undergoes drying and dipping process in the solution for number of times.

2.1.3. Simple immersion test This test comprises smaller lot of material specimen which is subjected to the media in respective test. Along with this weight losses put up on thaw for a period of time. This method incorporated with three electrodes in an electrochemical arrangements with test specimen used as a working electrode, platinum grid as the auxiliary electrode and saturated calomel as the reference electrode [15], M. Jariyaboon et al.[25] undergoes in FSW over AA2024-T351 to
investigate susceptibility to corrosion of both in the nugget and HAZ regions, did. Immersion in a solution of 57 g/l (0.98 M) NaCl and 10 ml/l 30 vol.% H₂O₂ (0.09M) studied the susceptibility to intergranular corrosion according to the ASTM G110 [82], while on another side to measure the intergranular corrosion depth welds section immersed transversely and with assistance of OM (optical microscope) put up longitudinally (rolling direction parallel) for proper observation [11]. In resemblance of K.A. Matori et al dipped AA6061-T6 sample in aerated 0.6 mol L⁻¹ NaCl aqueous solution at 30°C with keeping pH = 6.5. In the concentration of HNO₃ held at 30sec degreased working electrode dipped, further rinsing with de-ionized liquid immersed into NaCl Solution for taking ultimate observation in weld regions, and found intergranular attack associated with pitting corrosion [17].

2.1.4. Gel visualization method. This technique employed to locate corrosive susceptibility via concentrated changes in pH level. Due to pH level fluctuation solution colour incessantly varied which help to identify net value of anodic and cathodic fields across the transverse region of weld. P. Bala Srinivasan et al during Characterisation of microstructure of AA2219 sample observes that, On one side anodic field reflexes orange/yellow shades due to acidic reaction yielded by hydrolysis of cations of Al, meanwhile in cathodic fields blue/green shades prevails which reason to yield the alkalinity by decrement of oxygen [16]. This methods underways after polishing in which gel obtained by 3 g of Normapur agar agar powder during measurement of Tribocorrosion of FSW for Ti6AL4V sample in [26] intermingle in 100 mL of 0.7 M NaCl solution heated at 80°, thereafter addition of 15 mL of pH indicator further laid on a cooled platform [15,26].

2.2 Intergranular corrosion method.

Centralized attack on the grain boundaries while the rest region of the structure remains unaffected is known as intergranular corrosion. This corrosion is generally affiliated with chemically separation effects (tendencies of impurities congested at grain boundary region). Precipitation phases create zones of weak corrosion resistance across most nearest vicinity. During this operation the specific elements segregates of it help to form the compound in the boundary. In the meantime corrosion hit over grain boundary phase thus made the anodic zone on grain boundary relative to the rest surface. As most of the Al base alloys susceptible to IGC on behest of either anodic phases or due to depleted zones of Cu nearby to boundaries in Cu alloys [13].

Sometimes during extrusion of Al alloys ingot pertaining to the elongated or flattened grains which are prone to the distortion. Along these boundaries’ corrosion build up which exerted pressure between the grains and it ensue a lifting or leafing effect. When deformation conspicuously propagate through the end grains of machined edges, holes or grooves and therefore significantly promotes through an entire region, which is termed as Exfoliation Corrosion [13].

During investigating Corrosion behavior of spray formed 7055-T6 aluminum alloy joint while welded by underwater FSW, Yong Zhao et al covered the specimen with gelatin exposed under IGC test, whereby sample dipped in 0.97 mol NaCl+0.3 mol H₂O₂ and distilled water for 6 hr at 35°C. On same instant exfoliation corrosion test done as per GB/T22637-2008 standard [4]. P.B. Srinivasan et al. in characterization of corrosion behavior of AA 2219 sample undergoes for measuring the Parent, TMAZ/HAZ and nugget regions by Gill AC potentiostat with an Ag/AgCl electrode as a reference electrode (by having KCl Sol. With a Potential of 0.199 V respective to the std Hydrogen electrode) with keeping reference code ASTM G 110-92, in addition this procedure help them to analyses of galvanic corrosion effects underscore inter-granular corrosion testing [2].

3. Electrochemical impedance spectroscopy (EIS).

As we aware about Impedance, which is a measurement to a circuit's propensity to resist/ impede the flow of an alternating current (A.C). It’s expressed by
\[ \mathbf{z} = \frac{\text{Vac}}{\text{Iac}} \]  

**Eq. 1**

Where:

- **Vac**:- actual voltage in volt.
- **Iac**:- actual current in amp.

The size of the impedance of electrochemical cell mechanism expressed by the ratio of the span of the voltage sine wave (volt) to that of the current sine wave (amp), which reason to evaluate the magnitude (|Z|), or amount of the impedance (ohm) of this system. For characterization we need to calculate magnitude |Z|, phase \( \theta \), and the frequency \( f \) (Hz) [29]. Electrochemical techniques used on conductive materials like metals, batteries, to analyse metallic corrosive nature as well as containing the propagation of corrosion over material application in industry and marine, whereas paint coatings on painted metal substrate may also measure the degradation of organic coating reasoned by electrolyte exposure etc. and the steep increment in corrosion rate of the basic substrate due to the descent of the coating and following attack by the electrolyte[29]. Nadine Pébère et al applied EIS and Gravimetry which Contain SrCrO\(_4\) characterizes the interfacial region by keeping frequency from 1x10\(^5\)Hz to 0.03 Hz with the amplitude of ±10 mV, henceforth the outcome dictate water uptake values measured from dielectric constant values in association with Brasher and Kingsbury equation[28] and Sykes equation[29], which at last yielded the conclusion for surpasses gravimetric dielectric constant values [19].

Niu et al evaluated with EIS technique on Al coated 310S stainless steel with or without annealing in resistance of aluminium coating with and without annealing besides molten carbonate undergo scanning probe cyclic polarization of specimens with vertex current density keeping at 0.001 Amp/cm\(^2\) and potential range -0.25 V to -0.2 which concluded that oxygen ion or lithium ion species as cracks and pores permeates through these species which assisted to yield area hindered to form protective scales due to resistance propounded by the aluminide [18].

4. Contribution of process parameter in EIS

4.1 Frequency measurement. On the basis of high, medium and lower range signify the decrement of the immersion time which attributed to high immersion time, charge transfer process and diffusion process presence[26]. A Fourier transformation method used for frequencies under range of 0.01Hz to 1.13 Hz while expedite the measurement with lowering the degree of perturbation of the cell, additional time constant attributed outer porous layer[18], local Ohmic impedance(f> 1kHz)[19] in high frequency.

D.V.Renaux et al [16] by holding Hf range from (10\(^5\) Hz-10\(^3\)Hz), investigate \( C_p \) loop in parallel equivalent circuit in \( R_{HF} - C_{HF} \) terminology whereas first term ascribed charge transfer resistance across the interfaces & barrier oxide film whilst later term ascribe to capacitance to ascertain thickness of barrier layer as well as dielectric characteristic of barrier oxide film, he concluded with \( R_{HF} \) value (100-200Ω cm\(^2\)) hence higher anodizing potential reason to low \( R_{HF} \) value whereas \( C_{HF} \) pertinent to barrier layer thickness with equation mention below-

\[ C_{HF} = \frac{\varepsilon \varepsilon_0 S}{dBL} \]  

**Eq. 2**

here \( \varepsilon \) denote dielectric constant of the barrier alumina layer (value 10) the substrate and the anodizing conditions. \( S \) is the area and is assumed to be equal to the substrate area. \( dBL \) is the barrier layer thickness

\[ \frac{1}{\rho(\xi)} = \frac{\varphi(\xi)}{\rho_c} + \frac{[1 - \varphi(\xi)]}{\rho_c} \]  

**Eq. 3**
and 
\[ \varepsilon(\xi) = \varepsilon_e \varphi(\xi) + \varepsilon_r [1 - \varphi(\xi)] \]

\[ \varphi(\xi) = \frac{\varphi(\xi)\gamma}{1 + \varphi(\xi)(\gamma - 1)} \] ..............................eq.4

Fig.4 IS during immersion of AA2024-T3 with 0.5 M NaCl solution at OCP(a) for different time period(b) Hf value comparison later 2 hrs immersion and regression outcome[26]

Following equation eq.3 and eq.4 represents the high frequency characterization of pani film in the normal direction of AA 2024-T3 surface where under normal distribution for resistivity \( \rho(\xi) \) and the permittivity \( \varepsilon(\xi) \), \( \varphi(\xi) \) distribution related to an inhomogeneous water uptake in the Pani film. where the subscripts e and c were attributed to the electrolyte and the Pani coating respectively while Amand at al [30] state power law in eq.3, where \( \gamma \) was the power-law exponent [26].

4.2 Charge Transfer resistance.

In particular Aluminium alloys resistance due to charge transfer (Rct) attained by the reaction between aluminium surface and electrolyte interface[17]. D.V.Renaux et al during anodizing of 1050,7175 & 2618 Al alloys [16] observes that the barrier layer resistance \( R_b \) has a high value(2x10^8Ω cm^2) with behest of Rct & substrate/oxide interface for AA 1050 and degrade further by 1 order of magnitude 7175 alloy & 2 order Magnitude 2618 alloys.Moreover J.G.kim et al [3] taking advantage of Rct with equation 5, where \( R_p \) is polarization resistance, \( R_{film} \) (film resistance) illustrates resistance of electrochemical reaction of Aluminium in alkaline solution[17].

\[ R_p = R_{ct} + R_{film} \] .............................Eq.5
Niu Et al [18] observes ups and down in R\textsubscript{ct} value respectively at 12 hr and after 12 hr during oxides growth blocked charge particles transfer at the interface which resulted peeling off/ cracking of lithium aluminate(LiAlO\textsubscript{2}) as described by other author[31] or during lithiation(for Al\textsubscript{2}O\textsubscript{3}) process significant amount of porous oxides forms as suggested by [32]. He also observes R\textsubscript{ct} value dipped from 941.8 to 310 Ω-cm\textsuperscript{2}.

V. Vignal et al figure out the increase in R\textsubscript{ct} value from 3.34x10\textsuperscript{-4} MΩcm\textsuperscript{2} to 10\textsuperscript{-3} MΩ cm\textsuperscript{2} for far to close region of particles. Aging due to air cause to R\textsubscript{ct} value increases ranges (10\textsuperscript{-3} MΩ cm\textsuperscript{2} to 1M Ω cm\textsuperscript{2}) which results in surge of the R\textsubscript{un} (oxide film resistance)[22]. Evertsson et al observes increment of oxides for AA6063 in thick region while in plane of Al(100) & Al(111) oxide become main factor for increasing the value of potential and R\textsubscript{ct} [24]. Sometimes to measure corrosion rate J. Wysocka et al used an equation on the basis of R\textsubscript{ct} meanwhile system will remain in equilibrium following the fig.5.

![Image](image.png)

**Fig. 5** Representation of R\textsubscript{ct} that resulted after the insertion of citric acid in AA5754 alloy [27]

### 4.3 Dynamic/Local EIS.

Dynamic electrochemical impedance spectroscopy (DEIS) measurement under galvanostatic mode (g DEIS) performed to ensure E\textsubscript{corr} resulting from inhibitor injection[27]. Wysocka et al [27] observes IS within 3Hz limitation which in further strengthen barrier layers & diffusion transfer with frequency ranges upto 100 Hz , this approach helps to analyse formation of Al(OH)\textsuperscript{4} and sorption of Al\textsuperscript{3+}, Al\textsuperscript{3+}, OH\textsuperscript{-} like species in duration for active corrosion process as investigated by other authors[33-35].

LEIS technique examine organic coating degradation as investigated by authors[36-42]. Philippe et al [42] while investigating polymer coated galvanized steel and their defects observed through globally Impedance technique. Jorcin et al done LEI mapping at 5kHz , displayed surrounding scratches zones with low adhesive property during investigating propagation and beginning of delamination at the steel /epoxy vinyl coating interface. V. Vignal et al [22] under this technique on untreated surface of AA2050 t8 alloy in 0.1 M NaCl solution within 100kHz to few mHz[8] frequency, resulted R\textsubscript{ct} and increment of oxide film resistance under alloys surface ageing. [25] et al in LEIS calculation used with AC disturbance signal of 10mV applied to the electrode under 0.5Hz -100kHz frequency. M.ounga et al [81] have been examined a ZnNi with chromate converted to coating diffuse on C steel, according to him LEIS exhibit IM measured at 1Hz was greater at defects centre than on the coated area after holding immersion for 21 days. LEIS.
4.4 Constant Phase element.

Constant phase element (CPE) is used notwithstanding if a capacitor to imbue non homogeneity in the system but also to measured defects of barrier layers[17]. However H. Krawiec et al during study on AA2050-T8 impact of ageing in air and laser shock observed two capacitive loops on sites while air ageing contributed to surge in Rct at constituent particles sites, small increase of Rox(oxide film resistance) too observed. CPE impedance($Z_{cpe}$) measured with using exponent($\Phi$) and coefficient($T$) using equation 6.

$$Z_{cpe} = \frac{1}{T(j\omega)^{\Phi}} \quad \text{Eq. 6[23]}$$

Three dimension behavior of CPE attributed to changes in the conductivity of oxide layers or in porosity or surface roughness [22], according to M.mard et al CPE behavior observed in Pani/electrolyte interface[43] and found that electrolyte heterogeneous surges through Pani pores[26]. Impedance of interface measured through experiment can be calculated by the following formula-

$$Z_{exp} = R_s + \frac{Z_c R_p}{Z_c + R_p} + Z_1 \quad \text{Eq. 7}$$

He applied above equation to correlate physical entity of Pani coating with CPE parameters. Although impedance relation with CPE can be extrapolate by following eq. [24].

$$Z_{CPE} = \frac{1}{Y_0(j\omega)^n} \quad \text{Eq. 8}$$

Here $Y_0$ pertinent to capacitance, $n$ is factor of value 0 & 1, $\omega$ is angular frequency, $j$ is virtual unit. For evaluating the capacitance of oxide with assistance of equivalent circuit [44] following formulae may be used

$$C = \left(\frac{Y_0 R_{ct}}{Rct}\right)^{1/n} \quad \text{Eq. 9}$$

Where CPE considers as an ideal capacitor [24]

J. Wysocka et al [27] observes CPE while projecting capacitance dispersion, though he found that capacitance dispersion appeared to surface porosity, adsorbed layers of corrosion products, cavitation pits, corrosion, contamination resulted in the heterogeneous surface distribution of charge transfer processes[45-48]. He found at less amount of citric acid concentration enhances corr. Inhibition effect which stemmed out quasi CPE as a outcome and in blend with adsorbed (Iplc) inhibitor passive layer capacitor & Dlc(double layer capacitance discussed by other authors too.[49-52]. Due to formation of islands shape of a adsorbed inhibitor he seems to concluded that passive film assist to gradual adaptation towards desired capacitor behavior.

4.5 Impedance Modulus.

K.R.hebert [23] observes an ionic conductance over anodic aluminium films measured impedance after setting up constant anodized state, he evaluated linearity and stability with Kramers- kroenig analysis[53], which resulted (>2%) residual error and when this error is being pertinent to low freq. than that of inductive loop was higher, whereas variations of oxide thickness and porosity purported to influenced by IS as discussed earlier by authors[54-57]. Curioni et al in IM takes the porous and
barrier anodic oxides with respect to the inductive & capacitive loops width which gestures in IS about alumina growth for porous anodic in sulfuric media, though oxalic acids specify about the state of [24].

Fig. 6 Equivalent circuit used for the fitting of the EI spectra[24]

Wysocka et al[27] during ascertaining IS constraint the freq. at 3Hz in order to keeps frequency time constant low, nonetheless barrier layers and diffusion transport observed at (≥100 Hz). hence the shape of IS resembles with other authors over study of organic corrosion inhibitors[58,59-62]. During evaluating coating corrosion resistance on aluminium Y. Niu et al [18]. he observes well shaped Hf loop besides Lf align in straight line also impedance modulus range widens as time passes (500Ω cm at 2hr, fall upto 250Ω cm in 12hrs then settled at 450Ω cm after 72 hr[80]).

N. Pébère [19] study of the waterborne coating over AA 2024 alloy found that for leaching of Chromates IM is getting lower after holding (24hr to 504hrs) while on AA 2024 corroded surface IM reduces. In general for chromates (CM) & Non chromates (NCM) which are ascribed to leaching of later one become lower value of IM [18]. He concludes about barrier properties of coatings with global impedance plot. Verification of the reproducibility of scratches via controlling bi electrode to working electrode distance (200 μm ± 50 μm) comes under purview of local IS[19]. Impedance spectra (IS) depicts one capacitive loop at high frequency and inductive loop at medium frequency and a last inductive loop at low frequency may be interpreted by a Bockris mechanism [15,18,26]. Sweeping frequency (e.g. 10kHz - 0.1Hz[23]), Kramers kroenig analysis, Z view software[22] used for IS

4.6 Nyquist Curve.

J. Evertsson et al exhibit this plot with taking real Zre & virtual Zim impedance, whereas its magnitude taken applied excitation voltage signal to response current ratio. His plots for Al(100), Al(111) & AA6063 depicts Hf capacitive loop(-Zim) and Lf inductive loop (+Zim), meanwhile Np reveals increment of impedance with anodization potential of Al(100) & Al(111)[24].

Painstakingly the electrochemical properties are best suited in fig.—which illustrate the equivalent circuit alike to elaborated by other researchers [63,64,65]. K. R. Hebert et al investigate transient electrochemical relaxation in the duration of aluminium anodization intercepted high frequency (hf) with assistance of real impedance constant in nyquist plots (Np), he observes rise in current density varies from 1-10Hz and Hf rises for 10-100Hz range [23]. Joanna Wysocka et al have the observation for citric acid corrosion factor in alkaline medium which sought a plot between Np Vs time of exposure exhibit a IS development corresponding to the insertion to citric acid [27].

4.7 Equivalent circuit equivalent circuit.
As depicted in figure 5 has been cast important role to analyse inductive loop or capacitive loop at varying frequency[23], it consist linear electric elements (Rsq, electrode double layer capacitance C, inductor)[23]. An equivalent physical model[26] fig 2 adapted for EIS measurements used for represent substrate / Pani electrolyte interface[27], Solution resistance Rs[15,17,23,24,26], pores resistance Rp[19,20,26], and impedance Zc[15-27] helps to construct.

Fig.7. An equivalent circuit for showing respective interface [26]

equivalent circuit. Equivalent circuit model comprises IS in three parallel branches of capacitance and resistance(C & Rp respectively), in series resistance and inductance (i.e Rs& L)[23].

4.8 Corrosion Potential.

J. Wysocka et al [27] during investigating the role of citric acid while augmentation to the electrolyte observes increment in Ecorr (corrosion potential) due to mediation of anodic system

Fig.8. Shown corrosion potential with respective to 3 stages[27]

for protection of corrosion through formation of passive adsorbing layer. As shown in figure partition under 3 stages by author[27] observes a stated measurement of AA5754 alloys by
the means of g-DEIS, in that overlapped points exhibit citric acid concentration below transition stage resulted to form adsorbed passive layer. Fig. 2 b) stages from 0 to III represent formation of passive film due to adsorption whereby shaded areas exhibit inhibitor coverage on surface[27].

N. Pébère et al [19] during examining self healing tendency on 2024 Al alloy with waterborne coating measure $E_{corr}(0.35V)$ value for Ch more cathodic than NCh as other authors also signify difference between CH & NCh $E_{corr}(0.1V)$ [66]. Hence the propensity of inhibitive action with chromates for AA2024 was main reason for shifting of $E_{corr}$ in cathodic side as already discussed by authors[67-72], this shift of potential limits the deduction of oxygen on the intermetallic particles and causes improvement in oxide film formation. S. Changbin et al observes $E_{corr}$ value of FSW joint was is more +ve than parent material and MIG welding joint while the $I_{corr}$ (corrosion current density) value of the FSW is lower than the parent metal & MIG joint. Therefore he concludes that experiment of static mass loss displays $R_{corr}$ (corrosion resistance) improvement in 6082 Al alloy[1].

4.9 Open circuit Potential.
By holding temperature at 20 ±5° C approximately for each process under this technique researchers follows 2 or 3 electrode cell mechanism [15,19,21]. This method assist to analyse polarization with preceded by immersion of sample in 0.1 M - 1 M NaCl[15,19,20,22,26], while shen et al comparing electrochemical nature of AA 6082 alloys with taking dual welded joints (FSW & MIG) 0.2 mol/L NaHSO3[15] solution held for hrs to stabilizing the open circuit potential $E_{OCP}$ [15,26]. N. Pébère et al did [19] observation for Open circuit potential (OCP) under potentiostatic conditions performed with keeping peak to anodizing for 3.33 sec. interval in order to caught potential transients[23]. stepwise voltage(2V-10V) Vs $OCP(-0.7V$ for Al(100), -0.6V for Al(111), -0.8V for Al 6063) before anodization measured which resulted increment in potential[24].

4.10 Discussion of ICG testing.
X. Zhou et al During investigating local corrosion in AA2024-T351 observed that the grain boundary penetration by immersion in anodic polarization corrosion attack prevail which displays crystallographic pitting in nearby region in AA 2024 alloys[73]. Y. Yang, et al during investigation granular corrosion of β phase in AlMg alloy found that across grain boundary activation energy barrier in heterogeneous nucleation is lesser in homogeneous nucleation in matrix of AA 5083 H131 & H116[74]. A.E. Hughes et al observes that AA 2024 T351 Grain stored energy influence the inter granular attack in grain misorientation as 2nd phase precipitates such as S phase/ h phase remain negated in interface region during intergranular corrosion. Euler colour mapping and grayscale images of grain stored energy exhibit the shear attack of intergranular corrosion, so in conclusion he founds on high energy grain boundary region grain lattice extirmination ensue corrodes transportation [76].

Micrometer scale model for continuum granular simulates intergranular corrosion prevalence on AA5083 surface as a function of DOS, as it explains effects of local acidification, spatial proximity of β phase, chloride concentration, applied potential. M.C. Lim et al observes during modeling of AA5083-H131 that Computational model for galvanic interaction between AA5083 H131 and AISi 4340 steel predicts intergranular corrosion. This model demonstrate the DOS significantly affect electrolyte film, IGC propagation kinetics [77]. Both
models can evaluate anisotropy of IGC kinetics in all S, L, & T orientations of propagation. If we interrelate the relative humidity (RH) with time and then follow up IGC, it will be well observed as here under influence of 45% up to 97% RH and estimate corrosion volumes for AA2024 & AA7050 alloys. Intergranular corrosion susceptibility near nucleated pit compete for cathodic support and anions [78]. X ray tomography measured IGS over AA2024 alloy and found S phase or Fe particles. Hydrogen bubbles size extension indicate cathode and anode reactions on alloy surface. At 315 and 1540 min the droplet reduced in volume and a thin film of gelatinous corrosion covered the alloy surface [79].

4.11. Future research and scope

This study will help the researcher for further strengthen their methodology while having the number of ideas tacit in one platform. As friction stir welding is becoming a prime technique used for various advancements in aerospace and general purpose operations. It has been observed that corrosion propagation in Aluminum alloys may shattered the surface of material. By pursuing immersion test for certain period of time, changing the corrosion potential, varying the charge transfer resistance with evaluating inhibition efficiency may be help us to mitigate this natural corrosion. By shuffling the frequency we can get change in loops in Nyquist and bode plots. This paper may assist the researcher to wholeheartedly examined the intergranular corrosion test on the material and reckon the sort of crack propagation attain at that instance.

5. Summary

This paper ensued the viability of material selection proposed by various authors, such as Cu has cast prominent role to resist corrosion. Many elements assist mechanical working during processing of alloy material to desist corrosion. During the corrosion investigation many authors used myriad methods for in depth examination, i.e immersion test, gel visualization, inter-granular method.

EIS used by many researchers over conductive materials which assist to analysis the propagation tendency of corrosion in metals. They mix EIS technique with or without mechanical working; which further help to scanned cracks and pores in metals. Besides EIS many other process parameter further strengthen the investigation of corrosive behavior, like frequency measurement, charge transfer resistance, dynamic EIS etc.

Many researchers found that corrosion attack was more prominent in grain boundary zone with help of ICG test along with monte carlo simulation, Euler color mapping, X ray tomography.

6. References

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