Design, Fabrication and Beta testing of Four point Bend Immersion (FPBI) apparatus for the study of Stress Corrosion Cracking (SCC)

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***Abstract* — The design, fabrication and beta-testing of the FPBI apparatus have been discussed. The calibration and Beta testing of the apparatus has been accomplished using sheet specimens. The utilization of the apparatus for the study SCC behavior has been emphasized. The prototype and the final fabrication using Teflon have been described. The apparatus after fabrication was immersed in the desired corrosive solution and connected with GAMRY instruments for the Electrode Kinetic Measurement (EKM) in order to study of SCC behavior of the specimens. Standard sheet specimens of Aluminum alloys were used for testing the apparatus. Stresses of known value were applied for the SCC analysis. The graphical results were obtained for both stressed and non-stressed specimens of the same material. The results showed that the apparatus worked as per the requirements as proved by the enhanced corrosion rate of the stresses specimens as compared to their counter parts.**

***Index Terms*—Aerospace materials, Electrode Kinetics, Stress Corrosion Cracking, Failure analysis**

I. INTRODUCTION

STRESS Corrosion Cracking(SCC) and corrosion are major problem in metals and alloys.In order to solve corrosion problem, we need to develop a systematic solution by measuring phenomena related to it. .[1][2] The goal of our experiments were to first to develop an appropriate setup that can clearly distinguish the effect of stress involved in SCC, so that it can be characterized using appropriate corrosion testing instruments. [3][4] After consulting various testing standards and modeling the desired experimental parameters, the design of the apparatus was finalized.[5,6] The next step was to choose the appropriate material for the fabrication of the FPBI apparatus. For EKM, the apparatus was connected and calibrate with GAMRY instruments, SCC behavior was studied and the graphical results obtained were compared with that of the non-stressed specimens, so that the relative change in corrosion behaviour with respect to the stress can be determined.[7][8] Graphical results were obtained using Potentiodynamic module of GAMRY (DC105™).

II. PROCEDURE

2.1 Standards and Materials

In order to authenticate our experimentation, the specimens were made and tested in the FBPI apparatus as per standards defined by American Society for Testing and Materials (ASTM). The standard followed was ASTM G-39 and the material used for testing was AA2024-T3. The dimension of sample for corrosion study without stress in GAMRY was (10mm X 10mm) and for the SCC behaviour, sheet specimen of dimensions (190mm X 52mm X 2.5mm) was used.

2.2 Designing of FPBI apparatus

Although the idea was taken from ASTM G-39, but dimensional analysis and fabrication of the apparatus was done by the authors. First the design was refined using CAD models and then a mild steel prototype was fabricated for mechanical jigging due to ease of machining of steels (as shown in fig 3). The final setup was made of Teflon as it does not corrode in variety of corrodents, even at high temperature. [9]

2.3 2D and 3D CAD models

2D and 3D CAD models of the FPBI apparatus were made using AutoCAD 2014 software. This was done to develop a prototype model of the desired apparatus, so that pre-fabrication analysis can be done. The designs are shown in the following figure 1 and figure 2 respectively.

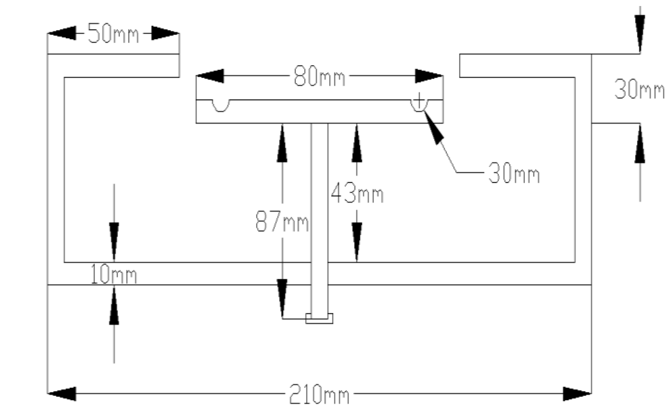

Figure 1: 2D front view of FPBI apparatus

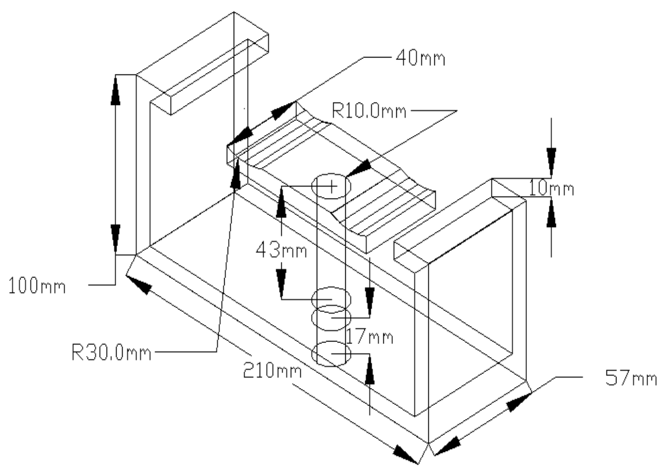

Figure 2: 3D view of FPBI apparatus

2.4 Fabrication of FPBI apparatus

After finalizing the design, a mild steel prototype was made using welding and machining techniques so that a mechanical feasibility and dimensional analysis can be performed as shown in figure 3.

Figure 3: FPBI mild steel prototype

The encouraging feasibility resulted in the final fabrication of the apparatus using Teflon in which mechanical joining was done for the assembly as shown in figure 4.]This was the most essential part of the experiment as without this apparatus, we could not stress and test the specimens as per the requirements of the ASTM. Moreover, after advancing from corrosion testing to SCC testing using GAMRY, we had to calibrate it with the GAMRY instruments for proper results.

Figure 4: FPBI apparatus

2.5 Calibration and Connection of the FPBI apparatus with GAMRY

In order to calibrate and connect our apparatus with the GAMRY to study SCC behaviour of our specimens, the authors used external single strand copper wires for making connections. [10][11] The sheet specimen for SCC was connected to GAMRY, by first soldering the wire to the specimen surface for electrical connections and then insulating the entire specimen with epoxy except the central, most stressed region of the specimen as shown in figure 5. The exposed area of this most stressed region was 100mm^2. The reason for covering the specimen and the connections with epoxy was due to the fact that when this specimen will be immersed in the corrodent for a long period of time, the exposed connections of copper or the exposed soldered region would also start corroding and the current and potential readings of the GAMRY would involve values from three materials i.e. copper, Solder and AA 2024, but we require values only from AA 2024. Also, the area of non-insulated sheet specimen was very large, which would generate a large amount of current during corrosion, which would result in system overload.[11-15] Hence to avoid this, only the central, most stressed region of the specimen was left non-insulated, while the remaining sheet was insulated with epoxy. So now, we would get the readings for corrosion from the maximum stressed region only, which was logical from failure point of view. [16][17]After the insulations, the system was connected and calibrated using dummy specimen of AA 2024 and the resulting curves and corrosion rates were verified from literature.

2.6 Stress Calculations

The stress in the specimen was applied by rotating a screw at the base of the FPBI apparatus. The amount of stress was calculated as per the formula by ASTM G-39 as shown below:

$$\sigma = \frac{12Ety}{3H^2 - 4A^2}$$

Where,
σ = Maximum Tensile stress
E= Modulus of Elasticity
t = Thickness of the specimen
y = Maximum deflection between outer supports
H = Distance between outer supports
A = Distance between inner and outer supports

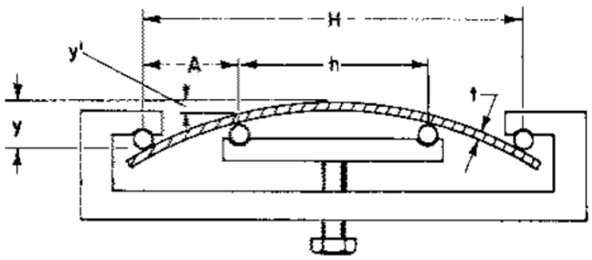

Figure 5: FPBI schematic

2.7 General Corrosion Analysis

In order to study the general corrosion behaviour, we simply needed to revert back from calibrated GAMRY setup to the conventional GAMRY setup. The polished specimen of AA 2024 was also insulated with epoxy and then immersed in the GAMRY flask containing brine solution as shown in figure 6. All connections were checked and then Potentiodynamic curves were obtained along with the corrosion rate in mills per year (mpy).[18][19]This data was recorded along with the curves for comparative analysis with stress application for SCC.

Figure 6: General Corrosion Study of with GAMRY setup

2.8 SCC analysis

In order to study the SCC behaviour, we now reverted from the conventional GAMRY setup to the modified and calibrated with FPBI apparatus. Polished, insulated with epoxy and stressed sheet specimen of AA 2024 was mounted in the FPBI apparatus, which was then immersed in the brine solution as shown in figure 7. All connections were checked and potentiodynamic curves were obtained along with the corrosion rate in mills per year (mpy).This data was recorded along with the curves for comparative analysis.

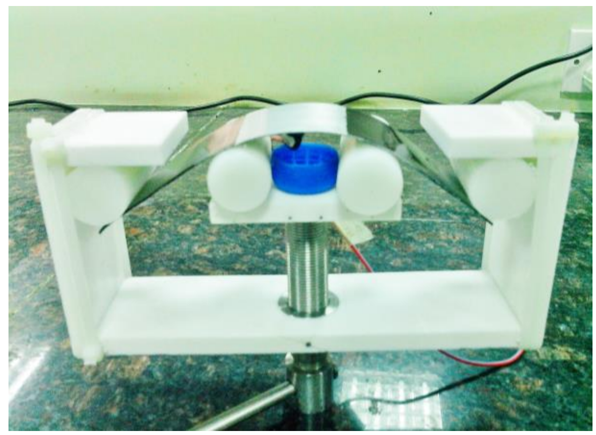

Figure 7: AA2024 Stressed Sheet Specimen for SCC

III. RESULTS

2.9 Composition and Hardness

Before testing of the specimens, we needed to perform some initial characterizations of the specimen like hardness and composition. The hardness of the AA 2024-T3 sheet specimen was done using Vickers hardness tester and after three iterations, the average value came out to be 135VHN.The composition was checked using energy dispersive X-rays spectroscopy (EDX) and the results are shown in Table 1.

Table 1: Sample Composition

Element	Weight %
Cu	4.56
Mg	1.33
Fe	0.52
Mn	0.46
Al	Base Metal

2.10General Corrosion Behavior

The general corrosion behaviour was recorded from the graphs obtained from GAMRY modules. The results of the general corrosion of AA 2024 are shown in figure 8.

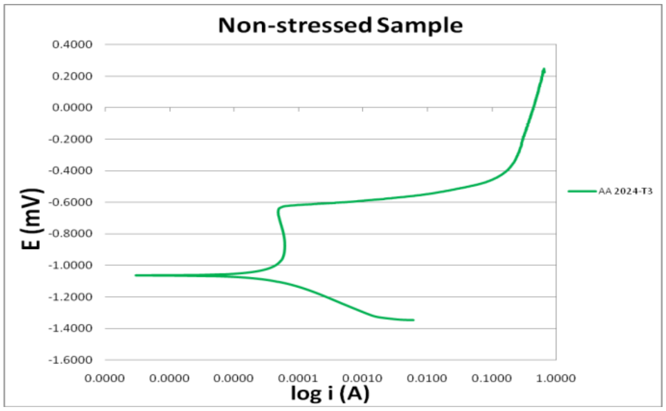

Figure 8: Potentiodynamic Test Result for General Corrosion

2.11SCC behaviour

The SCC behaviour was recorded from the graphs obtained from GAMRY modules. The results of the AA 2024 sheet specimens for SCC are shown in figure 9.

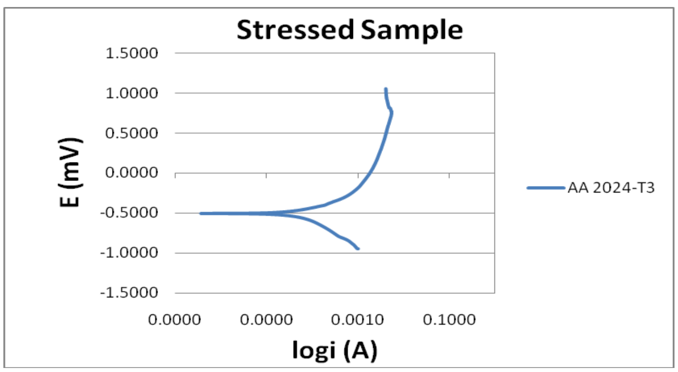

Figure 9: Potentiodynamic Test Result for SCC

IV. DISCUSSION

The composition and hardness was up to the mark and showed that the material was in T3 condition at the time of testing. Both the experimental results of the stressed and non-stressed specimens, when compared showed a pronounced reduction in corrosion resistance of the stressed specimen which was verified from the potentiodynamic curves.[12,14,15]

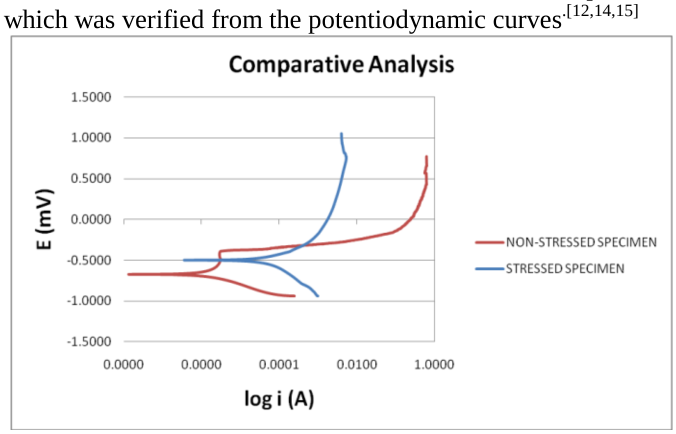

Figure 10: Comparative analysis of potentiodynamic curves

V. CONCLUSION

The FPBI setup is designed for stress application in corrosive environment on the sample in order to observe it visually and electrochemically. This apparatus is not limited to Aluminum copper alloys, rather it can be used for SCC testing of all metals and alloys with their respective environments. This apparatus is portable and can also be used for both field and laboratory testing. For a country like Pakistan, where there is lack of resources, the FBPI calibrated with GAMRY will provide a good incentive in research and testing related to SCC behavior.

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