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A Review on Corrosion Studies of Titanium Alloys

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Abstract

Titanium and its alloys are used for manufacturing for some parts of automobiles, aerospace and artificial implants of human body. These alloys undergo various manufacturing processes like machining, joining, casting depending on the application. When components are made with titanium and its alloys during service, they are subjected to various conditions. There is a need to study the corrosion behaviour of these alloys in various mediums to access the resistivity. Hence in this paper an attempt is made to summarise the works done by earlier researchers on corrosion studies of titanium and its alloys.

Keywords: *Titanium, Corrosion, Scanning Electron Microscope.*

INTRODUCTION

Corrosion is a spontaneous and continuous electrochemical process occurring on metallic surfaces and contributing to economic losses and pollution of our environment. Alloying is considered a proper scientific approach to improve the chemical and mechanical properties of a metal. The degradation of metals and their alloys occurs in man-made as well as natural environments. Among the numerous metal alloys employed as construction materials, titanium based alloys occupy an important position in the family of metallic materials for their useful applications in aerospace, chemical, petrochemical and biomaterial industries.

Titanium and titanium alloys are recognized as one of materials with extremely highcorrosion resistance but in some specific conditions pitting corrosion of titanium canoccur. In mostenvironments the welds of titanium and titanium alloys possess the same corrosionresistance as the base metal. Nevertheless, when titanium welds are exposed to marginalor active conditions they can be subjected to accelerated corrosionattacks compared tobase metal.

A study of the corrosion resistance of titanium is basically a study of the properties of the oxidefilm. The oxide film on titanium is very stable and is attacked only by a few substances including hot concentration reducing acids, most notably, hydrofluoric acid. Titanium is capable of healing this film almost instantaneously in every environment where a trace of moisture or oxygenis present because of titanium’s strong affinity for oxygen.

The objective of the paper is to present various works done by earlier researchers on corrosion studies of titanium and its alloys in various mediums.

LITERATURE REVIERW

This chapter discusses about the works reported by past researchers on corrosion behaviour of titanium and its alloys.

John A. Mountford Jr. [1] discussed the properties of titanium, the how and the why the metal is so suitably qualified for use in seawater and all water environments, and the advantages that titanium provides in marine service. S. Lalik et al. [2] performed pitting corrosion of titanium weld joints using HCl solution at elevated temperatures. It is observed that good corrosion resistance is found in 6% and 10% HCl. Surface condition of corrosion sample is presented in Figure.1.

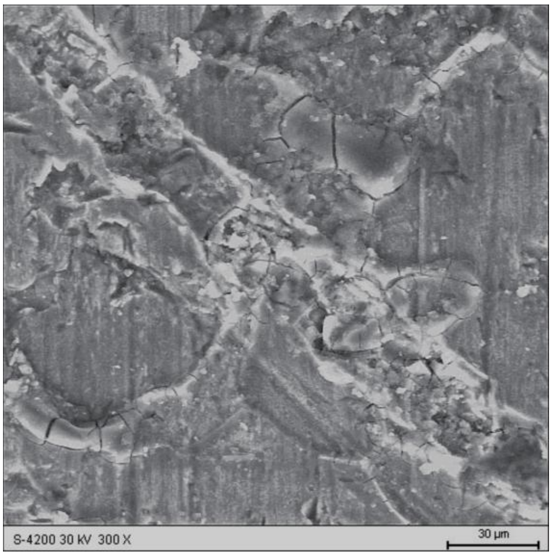

Figure 1: *Evaluation of joint surface condition after corrosion tests in 6% HCl water solution at temperature of 50°C [2]*

Yanping Zhu et al. [3] investigated the effects of cryo-treatment on the microstructure, corrosion behaviour, and mechanical properties of Ti before and after laser welding. Potentiodynamic polarization measurements were employed to investigate the corrosion behavior in an artificial saliva solution. Electrochemical results showed that the laser-welded Ti after cryo-treatment exhibited the most obvious passivation behaviour of all the specimens. Robert P. Houser [4] studied the performance of various titanium alloys with respect to corrosion rate and crevice corrosion susceptibility in high temperature, high pressure brine environments. He also studied the ability to weld and form titanium alloys intended for brine solutions. Crevice corrosion is shown in Figure.2.

Figure 2: *Crevice Corrosion of Alloy 625 [4]*

Ali AbdunnabiAbdurrahim [5] evaluated the corrosion behaviour (rates) of carbon steel welds using both traditional and novel electrochemical scanning techniques with in two different chloride environments. Linear polarisation resistance (LPR), corrosion potential (E_{corr}) zero resistanceammetry (ZRA), cathodic polarization (CP) and the scanning vibrating electrode technique (SVET), were used to semi-**quantitatively** assess the corrosion activity of the different microstructures, i.e., weld metal (WM), heat-affected zone (HAZ) and parent plate (PP) respectively. S. T. Auwal et al. [6] reviewed laser beam welding of dissimilar titanium alloys focusing on the influence of the processing parameters, microstructure-property relationship, metallurgical defects and possible remedies.

MitsuoIshii et al.[7] discussed about the corrosion resistance of titanium and its alloys by introducing a review paper cited from ASM International, Materials Properties Handbook: Titanium Alloys. Animesh Choubey et al.[8] carried out corrosion studies in Hank's solution for Ti and Ti-based alloys (in weight %) Ti-15Al, Ti-5Al-2.5Fe, Ti-6Al4V, Ti-6Al-4Fe, Ti-6Al-4Nb, Ti-13.4Al-29Nb and Ti-13Nb-13Zr. Potentiodynamic polarization experiments conducted at 37°C indicated stable passive polarization behaviour for all the alloys. The electrochemical behaviour of 316L stainless steel was also studied for comparison purposes. Corrosion rates were determined by the Tafel extrapolation method. The corrosion rates of the Ti-alloys were comparable but lower than that of 316L stainless steel.

Jing Liu [9] evaluated corrosion characteristics of titanium (ASTM Grade 2) in copper pressure leaching environments at room temperature and pressure up to high temperatures and pressures (230 °C, 430 psi. Anodic oxidation and controlled chemical oxidation methods are used to improve the corrosion resistance of Ti. Electrochemical and mass loss measurements are performed to evaluate the corrosion resistance of pre-oxidized titanium, compared to that of titanium with no prior oxidation, to generate a best practices guide for the hydrometallurgical industry.

Nikolay Vasilev Ferdinandov et al.[10] carried out corrosion behaviour of Ti-6Al-4V alloy and Ti-6Al-4V welds in solution containing Br- was evaluated quantitatively using potentiodynamic polarization tests. The influence of the structure and its change during welding on corrosion behaviour was discussed. Figure.3 indicates the tested sample at 1M KBr.

Figure 3: *Tested in 1M KBr surface of specimen after polarization*

F. El-TaibHeakal and Kh.A. Awad [11] studied the passivation and dissolution behaviour of Ti and Ti-6Al-4V alloy in HBr solutions over a wide concentration range from 0.01 M to 8.0 M using open-circuit potential, electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization measurements. It is revealed that Ti metal has a stronger propensity to form passive film in HBr solutions better than its Ti-6Al-4V alloy. Solomon B. Basame and Henry S. White [12] investigated potential-dependent breakdown of the native oxide film (20 Å thick) on titanium in aqueous Br^- solutions and in solutions that contain a mixture of Br^- and anions that inhibit oxide breakdown (i.e.,Cl^-I^- $SO42^-$ $Fe(CN)6^{4-}$ and $Fe(CN)6^{3-}$. In neutral pH solutions the oxide film stable having Br^-, resulting in the formation of stable corrosion pits at relatively low potentials (1.4 V vs. Ag/AgCl).

T. R. Beck [13] carried out stress corrosion cracking of titanium: 8% Al-l% Mo-l% V alloy notched tensile specimens in chloride, bromide, and iodide solutions'. R. Beck [14] carried out pitting corrosion of titanium foil in chloride, bromide, and iodide solutions under potentiostatic conditions. I.Dugdale T and J. B. Cotton [15] carried out experiments on anodic polarization of Halide solutions on Titanium. No pitting corrosion is observed in mixed halide/sulphate solutions above a critical concentration of sulphate and

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though the halogen gas is evolved, the anode behaves as if it were in contact with Apure sulphate solution.
F. Garfias Mesias et al. [16] used electron microscopy (SEM), energy dispersive X-ray analysis (EDX), atomic force microscopy (AFM), and in situ confocal laser scanning microscopy (CLSM) in evaluating ecursor Sites for Pitting Corrosion of Polycrystalline Titanium.EDx spectrum is shown in figure.4.

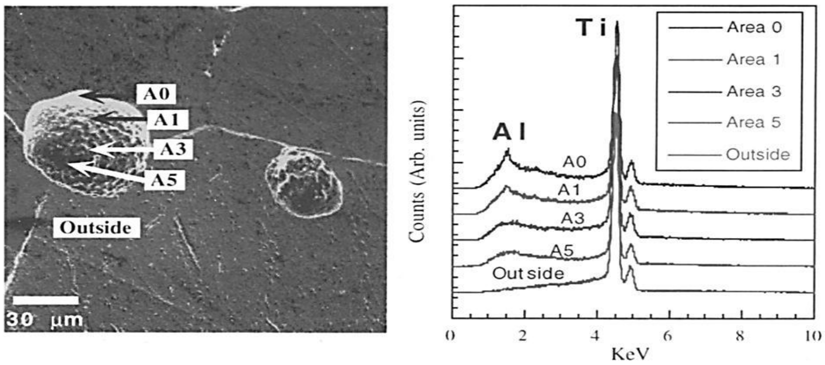

Figure 4: *EDX spectrum at different locations inside the pit generated in a bromide solution.*

Shizhong Huo and Xiaoxiong Meng [17] investigated the pit initiation process of commercially pure titanium in bromide solutions.F. El-Taib Heakal et al.[18] demonstrated the usage of cell biology in corrosion control of technical titanium in highly saline solutions. It is understood that glycerol has no effect on the corrosion performance of titanium. The effect of glycerol and β–carotene secreted by the alga revealed that, β–carotene can effectively mitigate the dissolution process of the sample. J.A.Petit et al. [19] studied corrosion pit nucleation on titanium in bromide solutions using ion beam analysis.

T. Shibata and Y.C.Zhu [20] examined oxide films on titanium whichwerepotentiostaticallyformedin0.5M H, SO, solution at various temperatures from 303 to 353 K and different potentials using transmission electron micro scopy, *ex situ* Raman spectroscopy, together with X-ray photo electron spectroscopy. Yashonari Matono et al. [21] studied corrosion behaviour of pure titanium and titanium alloy in the pseudu oral environment. They noticed that pure titanium and titanium alloy were corroded by acid which produced by to streptoconuccs mutans in oral biofilms with 500ppm fluoride on the titanium prosthetic appliance.

E. Almanza et al. [22] analysed the corrosion resistance of the Ti-6Al-4V and ASTM F75 alloys in Hank solution using the Tafel extrapolation technique with scan rates of 0.05, 0.1 and 0.166 mV/s. Figure.5 indicates the MO micropagarhs.

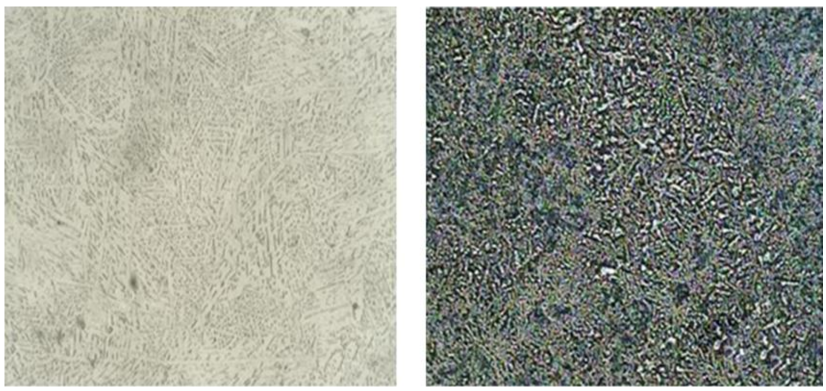

Figure 5: *MO micrographs of Ti-6Al-4V alloy: (a) before and (b) after corrosion test*

Igor N. Skryptun and Oleg G. Zarubitskii [23] carried out isothermal gravimetry at a temperature of 823 K on light metals (aluminium, magnesium and titanium) in molten alkali metal hydroxides (LiOH, NaOH, KOH).

SergioLuiz de Assis et al. [24] investigated the electrochemical behavior of Ti–6Al–4V and Ti–6Al–7Nb alloys, commonly used implant materials, particularly for orthopedic and osteosynthesis applications in Hank's solution at 37 Deg C. N. A. Al-Mobarak et al. [25] studied corrosion behaviour of titanium alloy without vanadium Ti-6Al-7Nb in biological conditions and compared with that of titanium and Ti-6Al-4V alloy. Figure .6 indicates the SEM image after corrosion of Ti-6Al-4V sample.

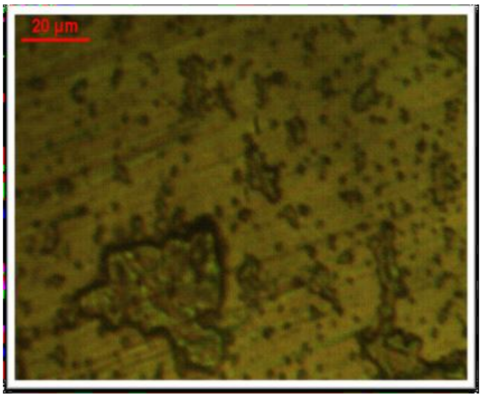

Figure 6: *SEM image of Ti-6Al-4V after Corrosion*

Majid H. Abdul mageed and Slafa I. Ibrahim [26] studied the corrosion behaviour of Ti-6Al-4V alloy using galvanostatic measurements at room temperature in different media which include sodium chloride (food salt), sodium tartrate (presence in jellies, margarine, and sausage casings, etc.), sodium oxalate (presence in fruits, vegetables, etc.), acetic acid (presence in vinegar), phosphoric acid (presence in drink), sodium carbonate (presence in 7up drink, etc.), and sodium hydroxide.

J.Klimas et al.[27] studied the corrosion resistance of Titanium grade-2 material in Ringer's solution .C.G. Nava-Dino et al. [28] performed corrosion tests to analyse their resistance and predictability to corrosion from green dust samples, SPS (Spark Plasma Sintering) samples and commercial alloying.

The corrosion behaviour in Ringer´s and Hank´s solution was evaluated by SEM (Scanning Electron Microscope). Fractal dimension were used to study corrosion behaviour and corrosion predictability was observed by modelling studies. SEM image and EDS spectra is shown in Figure.7.

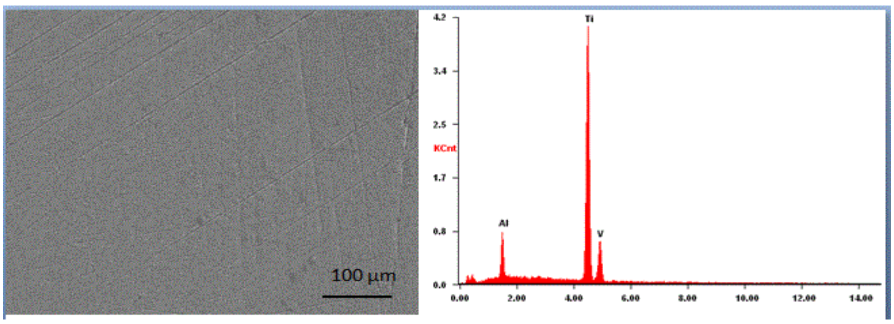

Figure 7: *SEM image and EDS spectra of Ti-6Al-4V commercial samples*

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C. A. D. Rodrigues et al. [29] studied the effect of Ti in the super martensitic stainless steel (SMSS) on the pitting corrosion in welded joints using gas tungsten arc welding. The values of the pitting potentials of SMSS + Ti and SSMS using a cell-pen (designed to reveal the behavior of localized microstructure in a narrow area) were 0.347 and 0.286 V in the non-welded condition, and 0.374 and 0.183 V in the welded condition, respectively.Yanping Zhu et al. [30] investigated the effects of cryo-treatment on the microstructure, corrosion behaviour, and mechanical properties of Ti before and after laser welding. Potentiodynamic polarization measurements were employed to investigate the corrosion behaviour in an artificial saliva solution. Electrochemical results showed that the laser-welded Ti after cryo-treatment exhibited the most obvious passivation behaviour of all the specimens.

Lariça B. Raimundo et al. [31] carried out potentiodynamic polarization test on pure titanium grade 4 (cp-Ti-4), subjected to disinfection with 0.2% and 2% per acetic acid and neutral artificial saliva. TianganLian et al.[32] studied the effects of oxide film on the corrosion behaviour of Titanium Grade 7 (0.12-0.25% Pd) in fluoride-containing NaCl brines. Saeid Yazdani et al. [33] carried out corrosion fatigue properties of the Ti-6Al-4V alloy were investigated via Rotating-Bending standard test method and then the results were compared with the fatique properties of the specimens tested in the same conditions. Figure.8 indicate SEM image of Corrosion fatigue in Ringer's solution.

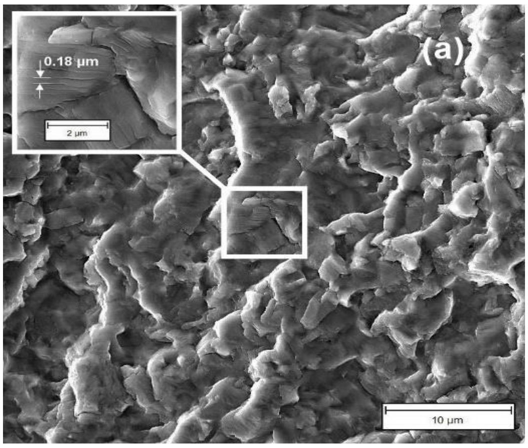

Figure 8: *corrosion fatigue fracture surface in Ringer's solution*

CONCLUSIONS

The following conclusions are drawn from the literature review conducted.

- Titanium and its alloys are resistant to chloride medium at room temperature and also at elevated temperature.
- Titanium exhibits good resistance to both acidic and basic mediums.
- Titanium is subjected to corrosion in KBr solution at room temperature.
- Titanium is sensitive to Fluoride medium and it depletes the oxide layer formed leading to severe corrosion.
- Welded joints of titanium may have a possibility of corrosion attack at elevated temperatures.

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