International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

Corrosion Behaviour of Aluminum Alloys Weldments: A Literature Survey

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Abstract: Aluminum alloys of 5xxx series and their welded joints show good resistance to corrosion in sea water. Metallic corrosion takes place in marine environments. In the ship manufacturing industries, welding is used to join the different aluminum parts of the ship structure, these weldments are generally remaining dip in saline water of sea or remain in salt foggy atmosphere, which gets eroded early when comes in contact with salt-water solution. A literature survey has been carried out to understanding of welding and corrosion of aluminum alloys.

Keywords: 5xxx Aluminum alloys; marine corrosion; welding.

I. INTRODUCTION

Metallic corrosion takes place in wet environments when the chemical or electrochemical reaction between a metal and the surrounding environment results in the oxidation of the metal. For corrosion to occur, electrons are produced by the anodic oxidation of the metal must be consumed in a cathodic reaction. These two processes can take place on different parts of a metal structure providing that there is a conducting path for the electrons between the two, and a continuous electrolyte path for ion transport. Aluminium is highly reactive, with a negative standard electrode potential of - 1660mV, and is therefore unstable in the presence of water. However, aluminium reacts quickly with the oxygen in air or water to form a protective oxide film (alumina, Al□O□) that is stable in pH range 4-9 and prevents corrosion of the metal.

Although surface oxide layer of aluminium acts as an efficient insulator preventing electron transfer to the surface, commercial alloys contain intermetallic particles that have thinner and more conducting oxide layers allowing electrons to pass through, so that anodic and cathodic reactions can take place. There are three main types of localized corrosion that affect aluminium in aqueous environments: pitting corrosion, intergranular corrosion, exfoliation corrosion, whereby the mode of corrosion that takes place depends strongly on the alloy, its processing history and its environmental conditions. Pitting can be a severe form of localized corrosion and is the development of cavities in the surface of the metal. There are two steps in the pitting mechanism, firstly pit initiation, followed by pit propagation. Pitting is often initiated by surface defects or intermetallic particles at the surface and the presence of chlorides which damage the oxide layer.

Intergranular corrosion (IGC), is attack along grain boundaries or closely adjacent regions, without attack of the grain interior, and is caused by a difference in corrosion potential between grain boundary region and the grain itself. IGC can be caused by precipitation of anodically active intermetallic particles on the grain boundaries, which corrode preferentially. Exfoliation corrosion, is another form of localized corrosion that propagates along planes parallel to the rolling direction. It is often as a result of IGC whereby the voluminous corrosion products are unable to dissolve into the environment and instead form along the paths of attack causing internal stresses leading to layers of metal being lifted from the surface. Due its surface oxide layer, high purity aluminium is very corrosion resistant. However, it has insufficient strength for most practical applications. So it is usually alloyed with elements such as Cu, Mg, Li, Zn, Mn, Si. The effect of additional alloying elements is often harmful with regards to corrosion resistance. When the alloying elements are in solid solution the alloy generally remains corrosion resistant, however precipitation and the formation of second phase particles reduces the alloys corrosion resistance by increasing the corrosion potential by providing sites for the cathodic reaction, and also sites for the initiation of localized corrosion. These second phase intermetallic particles can form during solidification and can be anodic, inert, or cathodic to aluminium. Those particles that are more electrochemically active than aluminium act as localized anodes and go into dissolution themselves, while those that are less electrochemically active become net cathodes relative to the aluminium matrix where dissolution will occur.

II. LITERATURE REVIEW

Nearly 25 research papers have been collected from open literature related to welding and corrosion of aluminum alloys. ASTM standards for corrosion testing of 5xxx series aluminum alloys have been discussed.

Thomas [1] focused on this study the relatively new joining technology, friction stir welding (FSW). Friction stir welding can be used to join most aluminium alloys and surface oxide presents no difficulty to the process. On the basis of this study it was recommend that number of lightweight materials suitable for the automotive, rail, marine and aerospace transportation industries can be fabricated by FSW. Squillace et al., [2] compared two different welding processes one is conventional tungsten inert gas (TIG) process and second is friction stir welding (FSW). A micro-hardness measurement allows pointing out a general decay of mechanical properties of TIG joints, mainly due to high temperatures experienced by material. In FSW joint, instead, lower temperatures involved in process and severe plastic deformations induced by tool motion allow rising of a complex situation: by a general point of view a slight decay of mechanical properties is recorded in nugget zone, flow arm and thermo-mechanically altered zone (TMAZ), while in heat-affected zone (HAZ), due to starting heat treatment of alloy under investigation, a light improvement of such properties is appreciated. In flow arm and in nugget zone, however, a light recovery of hardness, w.r.t. TMAZ zone, is recorded, due to the re-crystallisation of a very fine grain structure.

Wang et al., [3] reported the effect of welding processes (FSW and TIG) on the fatigue properties of 5052 aluminum-welded joints was analyzed based on fatigue testing. The results show that the fatigue properties of FSW welded joints are better than those of TIG welded joints. Zhao et al., [4] welded Al–Mg–Sc alloy plates by FSW and TIG welding. The effect of welding processes on mechanical and metallurgical properties of welded joints was analyzed. The results shown that the mechanical properties of FSW welded joint are much better than those of TIG welded joint. Moreover, tensile strength and yield strength of FSW joint are 19% and 31% higher than those of TIG joint, respectively. Due to the low welding temperature during FSW process and the excellent thermal stability of Al_3 (Sc, Zr) particles, the cold working microstructures can be well preserved.

Anjaneya Prasad, and Prasanna P. [5] experimented AA6061 joints welded by Metal Inert Gas (MIG) and Friction Stir Welding (FSW). The FSW was carried out by 3 axis computer numerical controlled milling machine. semiautomatic welding machine MIG 350 carried out the MIG welding with the welding speed of 110mm per min. FSW showed 10-100 times smaller grains than the MIG welding in the microstructure of the weld joints. MIG welding produced the less tensile strength than FSW. The amount of heat input affected the weld material hardness and the width of hardness was determined by shoulder diameter and heat input. The FSW reduced production cost, pre operations and increased the weld quality.

S. Jannet, P.K. Mathews, R. Raja [6] evaluated the mechanical properties of welded joints of 6061-T6 and 5083-O aluminum alloy obtained using friction stir welding (FSW) with four rotation speed (450, 560, 710 and 900 rpm) and conventional fusion welding. FSW welds were carried out on a milling machine. The performance of FSW and Fusion welded joints were identified using tensile, hardness and microstructure. Better tensile strength was obtained with FSW welded joints. The width of the heat affected zone of FSW was narrower than Fusion welded joints welded joints. Properties FSW and Fusion Welded processes were also compared with each other to understand the advantages and disadvantages of the processes for welding applications of the Al alloy.

Grilli et al. [7] focussed on the on the role of intermetallics in pitting corrosion of AA 2219 alloy. Second phase particles were characterized by AES, SAM and EDX. Their behaviour in a solution of NaCl was investigated as a function of exposure time. The results confirmed the cathodic nature of the intermetallics with respect to the aluminium matrix. Corrosion products rich in aluminium and oxygen were found to progressively accumulate around the particles and iron was dissolved from the intermetallic, followed by back deposition. Copper and manganese did not show any major activity.

Boag et al., [8] performed the corrosion studies on AA2024-T3 were immersed for various times up to 120 min in 0.1 M NaCl. The development of corrosion around isolated intermetallic particles was monitored using scanning electron microscopy with energy dispersive X-ray spectroscopy (EDXS). The earliest stages of attack started with localised corrosion of the S-phase particles resulting in dealloying which was followed by trenching around these particles. Jariyaboon et al. [9] observed the effect of welding parameters (rotation speed and travel speed) on the corrosion behaviour of friction stir welds in the high strength aluminium alloy AA2024–T351. The authors found that the rotation speed plays a major role in controlling the location of corrosion attack. Localised intergranular attack was observed in the nugget region for low rotation speed welds, whereas for higher rotation speed welds, attack occurred predominantly in the heat-affected zone.

Paglia & Buchheit, [10] found that the sensitization of the microstructure that occurs during welding is responsible for the corrosion susceptibility of the nugget's heat affected zone region of the welds. The microchemistry of the original alloy and the thermal transience during welding controls the localization, distribution, size of precipitates and precipitate-free zones. The main localized corrosion and environmental cracking is of an intergranular-type.

Kang et al. [11] investigated the surface corrosion behaviour of an AA2024-T3 aluminium alloy sheet after friction stir welding. SEM observations showed that the density and degree of the pitting corrosion in the shoulder active zone were slightly larger compared to the other regions on the top surface.

Proton et al.[12] investigated the corrosion behaviour of the nugget of a Friction Stir Welding joint employing a 2050 Al–Cu–Li alloy. The results showed that the nugget was susceptible to both intergranular and pitting corrosion. Such corrosion behaviour was related to microstructural heterogeneities observed on a microscopic scale.

Hossain et al. [13] have reported that deterioration of the built infrastructure due to marine salts in coastal regions has been, for many years, a significant and ongoing problem. Marine salts adversely affect the durability of the infrastructure and reduce its service life.

Dobrzanski et al. [14] reported that the chloride-rich seawater is a harsh environment that can attack the materials by causing pitting and crevice corrosion.

Govindaraj Elatharasan [15] studied the corrosion resistance of a friction stir-welded AA7075 alloy was via polarization and electrochemical impedance spectroscopy in 3.5% NaCl. The microstructure of different positions along the thickness of the aluminum alloy plate had been investigated with regard to varying parameters, including rotary speed and transverse speed. The heat-affected zones of the weld exhibited the highest susceptibility to inter-granular corrosion. The results also showed that sound joints in AA7075 can be achieved using friction stir welding. Corrosion resistance decreased with the increase of traverse speed from 0.37 to 0.76 mm/s at a rotary speed of 800 rpm. Corrosion resistance at a rotary speed of 1000 rpm was lower than that at 1200 rpm.

G. S. Frankel [16] studied the susceptibility of welded and unwelded samples of Al 5454 (UNS A95454) in the -O and -H34 tempers to pitting corrosion and stress corrosion cracking (SCC) in chloride solutions.

Welded samples were fabricated using the relatively new friction stir welding (FSW) process as well as a standard gas-tungsten arc welding process for comparison. Pitting corrosion was assessed through potentiodynamic polarization experiments. U-bend and slow strain rate tests were used to determine SCC resistance. The FSW samples exhibited superior resistance to pitting corrosion compared to the base metal and arc-welded samples. U-bend tests indicated adequate SCC resistance for the FSW samples.

D. A. Wadeson [17] studied the corrosion behavior of extruded sections of welded commercial alloy AA7108-T79. In the T79 condition, friction stir welding was carried out at a steady welding travel speed of about 1 m/min.

Following welding, AA7108 exhibited natural aging and, after 30 days, the heat-affected zone (HAZ) recovered its strength to about 90% of the parent material. The welded alloy showed the expected zones associated with friction stir welding, namely, nugget, thermo mechanically affected zone, and heat affected zone. Samples 10mm length in the welding direction and 60mm length in the transverse direction with the weld at the center, were exposed to the test solution for 72 h. A modified ASTM G34, EXCO test employing 15 vol% dilution of a solution of 4.0MNaCl, 0.5M KNO3, and 0.1M HNO3 was used. Intergranular corrosion appeared within the thermo mechanically affected zone (TMAZ) and extended into the HAZ.

Khoshnaw and Gardi [18] studied the effect of ageing time and temperature on exfoliation corrosion of aluminum alloys 2024-T3 and 7075-T6. They observed that with increase in the ageing time for aluminum alloy type 2024-T3, the susceptibility to exfoliation corrosion increase while for the 7075-T6 decreased. The intermetallic compounds formed such as $CuAl_2$ and MZn_2 phase increase with increase in ageing time for both alloys.

Zucchi et al., [19] compared the resistance of friction stir welded with metal inert gas welded AA5083-T3 to pitting and SCC resistance utilizing immersion and slow strain rate testing in a solutions of 3.5 wt.% NaCl + 0.3 g/l H_2O_2 and 4M KCl + 0.5 M KNO_3 + 0.1 M HNO_3 respectively. The results showed the friction stir weld exhibited resistance to both forms of corrosion, where as MIG weld suffered from pitting and SCC.

Haver et al [20] tested the pitting and IGC behaviour of friction stir welded 4 mm thick AA5754-H111 aluminium alloy joined at different traverse speeds (100 and 1000 mm/ min) and fixed tool rotation speed and tilt angle (400 rev/min and 2 degree respectively) utilizing anodic polarization measurement. The electrochemical results showed almost similar corrosion behaviour for both welds compared with the parent alloy.

Davenport et al [21] studied the resistance of the friction stir welded AA7010 aluminium alloy to atmospheric corrosion. The specimen with the weld located at its middle was exposed to the atmosphere for 365 days. The SEM investigation showed the nugget and the HAZ as well as the parent alloy were prone to IGC. The IGC attack was higher in the HAZ and nugget than the parent alloy.

Lumsden et al [22] studied the resistance of the friction stir welded AA AA7075-T651 aluminium alloy to pitting and IGC. The results showed that the HAZ was susceptible to both types of corrosion. The reason was correlated to the presence of copper-depleted regions along the grain boundaries of the HAZ. Cabello et al., [23] made a comparative study on microstructural and mechanical characteristics of fusion welds (TIG) and solid-state welds (FSW) of Al–4.5 Mg–0.26 Sc heat-treatable aluminum alloy. The corresponding mechanical properties are evaluated through micro hardness measurements and tensile tests.

The effect of a post-weld heat treatment on both microstructure and mechanical properties is further examined. The results suggest that hardening precipitates are comparatively more affected by the TIG than by the FSW process. This results in a substantial reduction of mechanical properties of TIG welds.

III. CONCLUSIONS

A. From the Literature, it is Understood That

1) Corrosion behaviour depends upon welding processes applied for joining aluminium alloys
2) Friction stir welding performs better in terms of mechanical properties for aluminum alloys as compared to other types of welding.
3) Friction stir welding process can successfully produce the excellent corrosion resistant joints of aluminum alloys as compared to other types of welding.

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