ROLE OF INTERMETALLIC COMPOUND ON CORROSION OF ALUMINIUM/STEEL TRANSITION JOINT USED IN NAVAL APPLICATIONS

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Abstract

Transition joint is used as a joining medium to mitigate galvanic effect between steel ship hull and aluminium alloy superstructure. During service, transition joint was detrimental particularly at AA1050 layer. The results revealed that heat from welding caused formation and expansion of intermetallic compound, Al_3Fe and Al_5Fe_2, along Al/Fe interface. These intermetallic compounds acted as cathode in comparison to aluminium and be an anode compared with steel. Once corrosion takes place, aluminium adjacent to intermetallic compound was attacked preferentially. This phenomenon could lead to the deterioration of transition joint and ship structure.

Keywords: corrosion, transition joint, intermetallic compound, welding

Introduction

Shipbuilders use transition joint (TJ) as a medium for joining steel ship hull and aluminium alloys superstructure. The TJ is aluminium-clad steel that produced from explosion welding process. It composed of three metal layers of Al-Mg alloy (AA5083), commercially pure aluminum (AA1050) and carbon steel as shown in Figure 1(a). Although TJ is used to mitigate galvanic corrosion between steel ship hull and aluminium superstructure, the deterioration of TJ itself was found especially at AA1050 layer as presented in Figure 1(b). The review of literature (Tricarico et al. 2009; Seven 2008) stated that joining TJ with steel ship hull and aluminium superstructure leaded to the reduction in mechanical property of TJ because of the expansion of intermetallic compound (IMC). Nevertheless, reports on corrosion of TJ had not been found yet. Therefore this study aimed at studying corrosion behavior of TJ after welding with steel and aluminium.

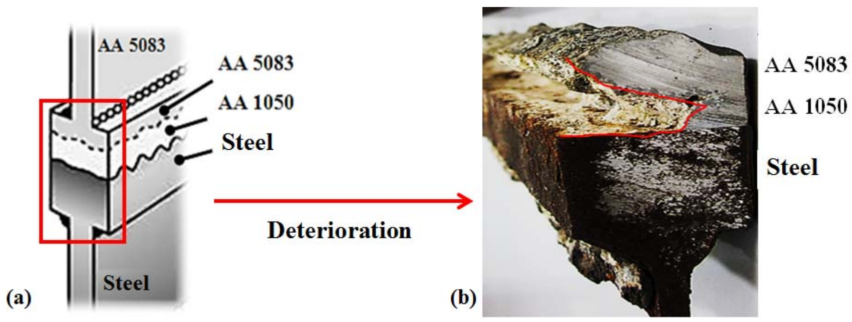


Figure 1 (a) schematic diagram of TJ (b) appearance of deteriorated TJ

Materials and Methods

The transition joint (As-clad) and transition joint welded with AA5083 and steel (welded TJ) from The Royal Thai Naval Dockyard were investigated in this study. They were then cross-sectioned and metallographic prepared by grinding and polishing down to 1 μm. Their microstructures were examined by optical microscope (OM) and scanning electron microscope (SEM). Amount of intermetallic compound in area percentage was analyzed by image analysis method (ImageJ software). Immersion in 0.1 M NaCl and examination microstructure every 1 hour for 24 hours was employed to define corrosion initiation site. Detection of micro-anode and micro-cathode area was achieved by immersion in 0.1 M NaCl containing cerium compound for 1 hour. Afterwards the micro-cathode, Ce-deposited area, was detected by Energy Dispersive X-ray Spectroscopy (EDS). Salt spray testing follows ASTM B117 was also performed to study corrosion behaviour in marine environment.

Results

Appearance and microstructure of as-clad and welded transition joints.

Figure 2(a) and 2(b) show appearance of as-clad and welded transition joint correspondingly. For welded TJ there was an alternation (ripple-liked) at the interface between steel and AA1050 in comparison to as-clad TJ. Optical micrographs at Al/Fe interface of as-clad TJ compared with welded transition joint illustrates in Figure 2(c) and 2(d) respectively. Ripple-liked interface resulted from the expansion of intermetallic compound during joining TJ with steel and aluminium (Tricarico and Spina 2010). Image analysis indicated that the amount of intermetallic compound (IMC) in as-clad TJ was about 2.86% by area whereas in welded-TJ was about 13.26%. The extension of IMC in welded-TJ was 363% in comparison to as-clad TJ.

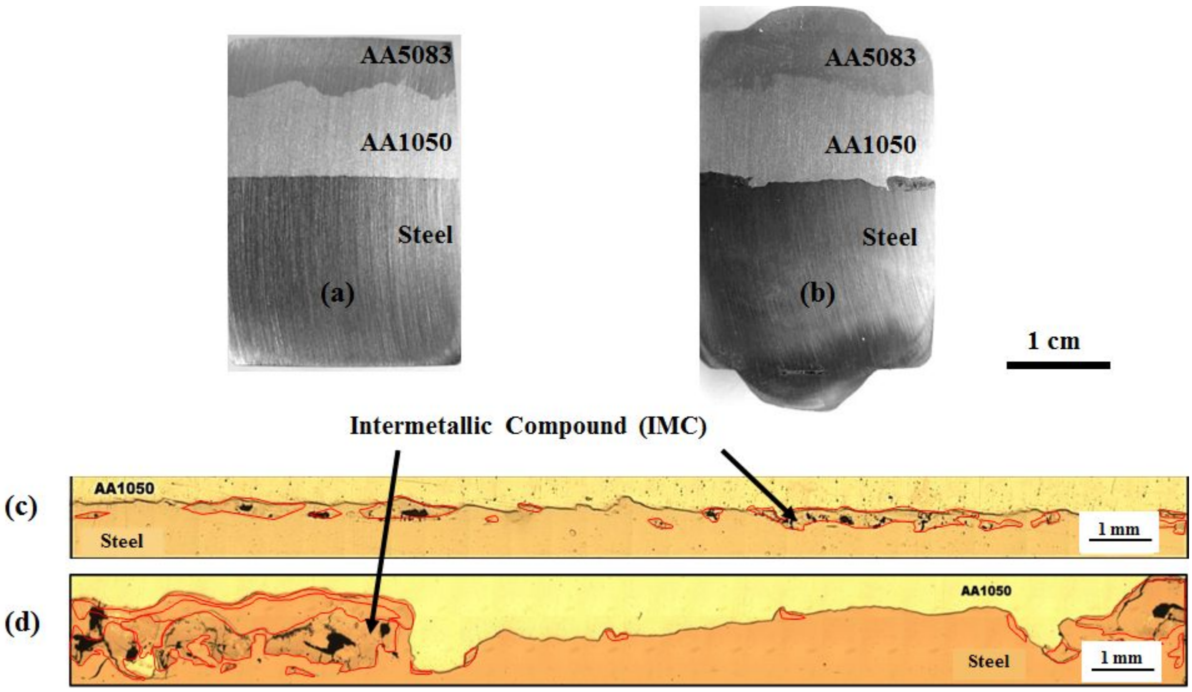
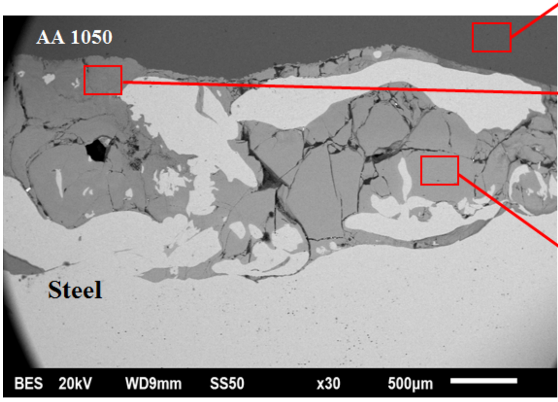


Figure 2 Appearance of (a) as-clad and (b) welded-TJ, optical micrographs of (c) as-clad and (d) welded-TJ at Al/Fe interface. The intermetallic compounds are circled.

Backscattered electron (BSE) image at Al/Fe interface in Figure 3 presents two different types of IMC. EDS result indicated that the first type (dark grey) of IMC composed of aluminium, silicon, manganese and iron. The principle elements in this IMC type were aluminium and iron at an approximate ratio of 3:1 and aluminium content analyzed by EDS was 75.86 at.%. The previous literature stated that IMC having aluminium content of 74-76 at.% was Al_3Fe. In case of the second type (light grey) of IMC, it composed of aluminium and silicon at a ratio of 2.5:1. Similar literature (Tricarico et al. 2009) reported that this kind of IMC was Al_5Fe_2, of which aluminium content was 69.7-73.2 at.%.



(a) AA1050

Element	Atomic%
Al K	99.40
Si K	0.09
Fe K	0.51

(b) Al_3Fe

Element	Atomic%
Al K	75.86
Si K	0.24
Mn K	0.22
Fe K	23.68

(c) Al_5Fe_2

Element	Atomic%
Al K	69.71
Si K	-
Mn K	-
Fe K	30.29

Figure 3 EDS analysis of welded TJ at IMC and area nearby

Define of corrosion initiation site by immersion test.

Series of optical micrographs at Al/Fe interface of welded transition joint after immersion in 0.1 M NaCl is presented in Figure 4. After immersion for 30 minutes, the attack (black color) at the rim of IMC was observed. Afterwards, the attack was more pronounce inside IMC and propagated into the area nearby. From the result, IMC was probably a corrosion initiation site.

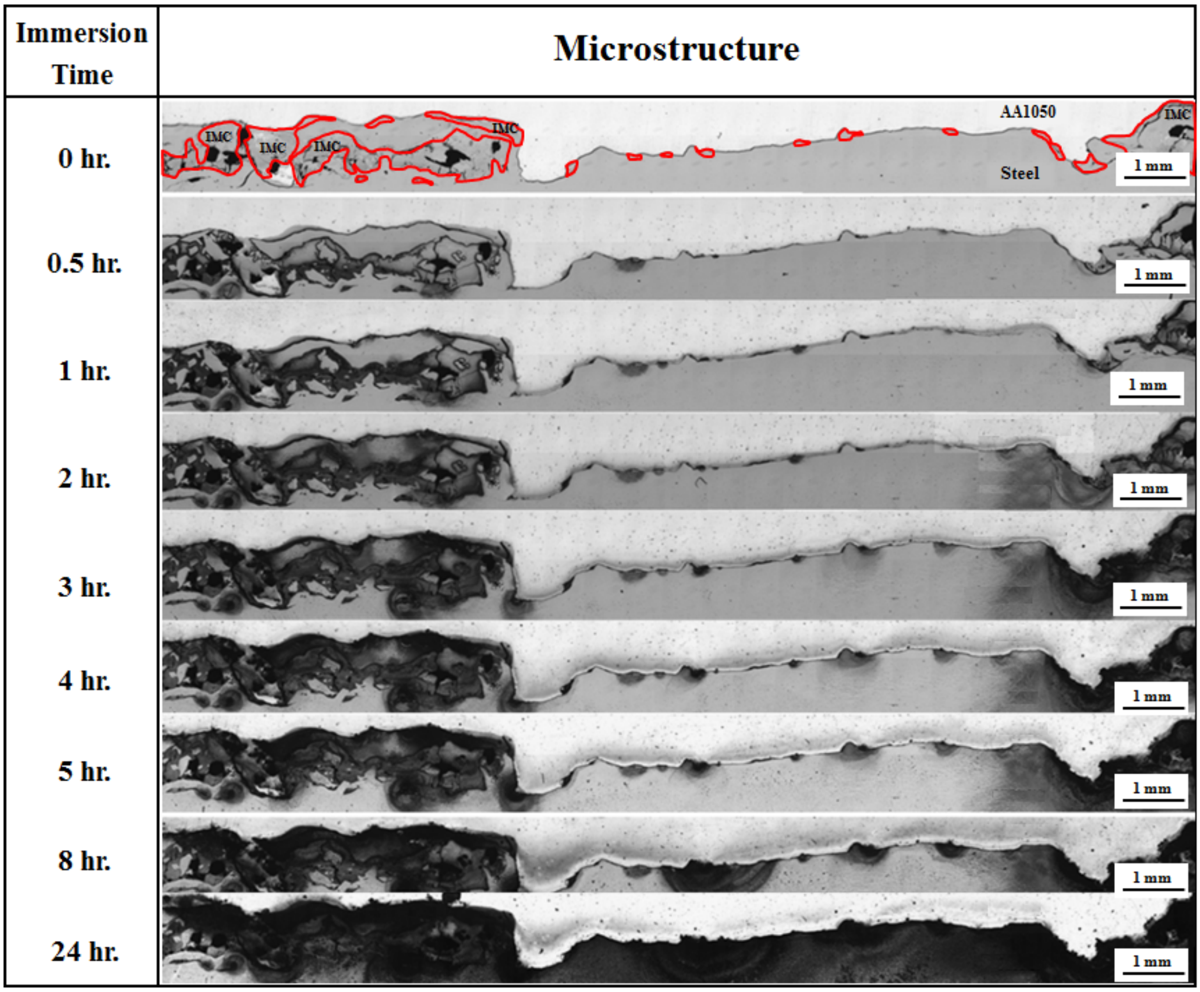


Figure 4 Optical micrographs series of welded-TJ Al/Fe interface after immersion in 0.1 M NaCl at certain period of time

To realize corrosion initiation site, the specimens were immersed in 0.1 M NaCl containing cerium compound for 1 hour. SEM-EDS analysis in Figure 5 revealed that Ce was not detected at Al_3Fe at all (Figure 5(a)) while small amount of Ce was detected at Al_5Fe_2 (Figure 5(b)). In steel zone nearby IMC (Figure 5(c)), high amount of cerium was detected. The investigation was also performed at aluminium zone (result not shown) where none of cerium was detected. It is possible that intermetallic compound acted as anode in comparison to steel and acted as cathode compared with aluminium. The previous researches (Ambat et al. 2006) who studied corrosion behaviour of AA1050 also stated that Al_3Fe was corrosion initiation site as it was an anode in comparison to aluminium matrix.

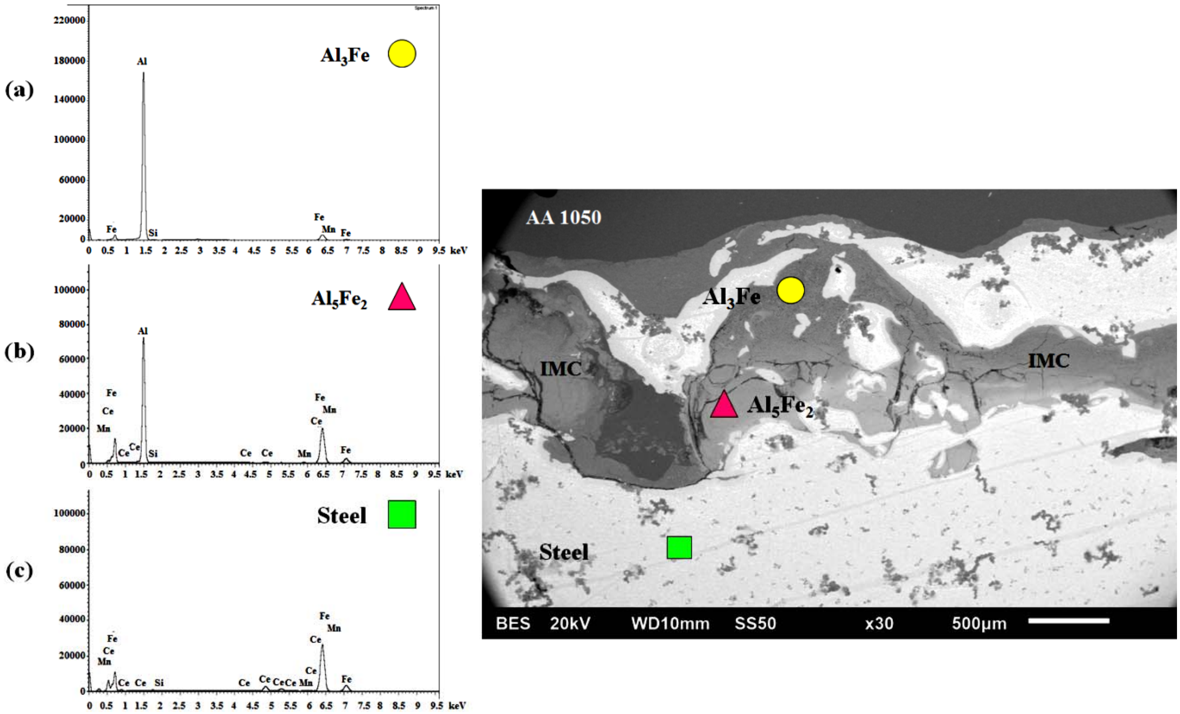


Figure 5 EDS analysis of IMC and area nearby at Al/Fe interface of welded TJ after immersion 0.1 M NaCl contains cerium compound for 1 hour

Corrosion study of transition join in salt spray.

Appearance of welded TJ after exposure to salt spray is shown in Figure 6. The evidence showed that there were some attacks in aluminium side adjacent to Al/Fe interface (circle) especially the area close to IMC. It is likely because aluminium was an anode in comparison to IMC; therefore, it was detrimental.

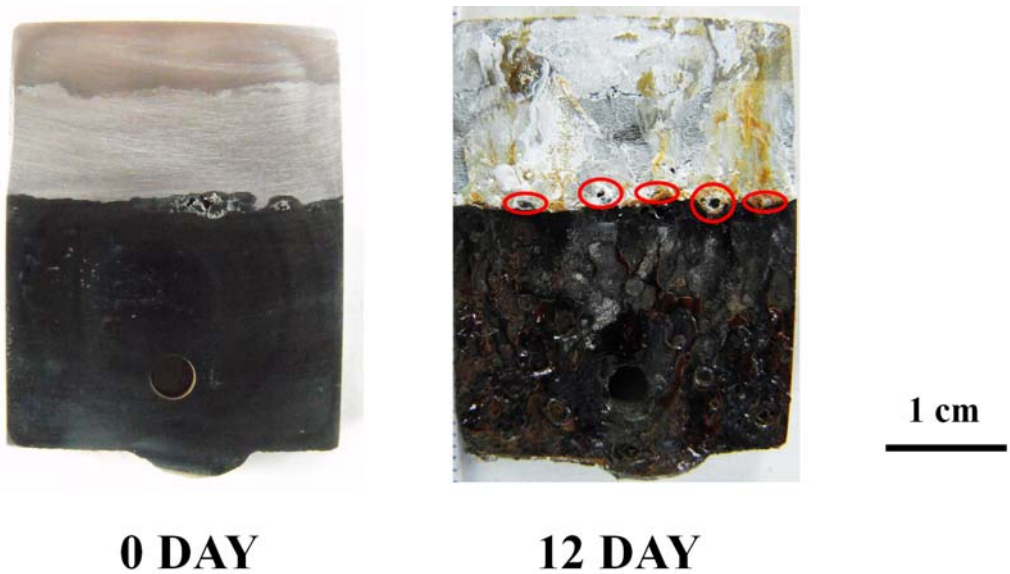


Figure 6 Appearance of weld TJ (a) before and (b) after exposure to salt spray for 12 days

Discussion and Conclusion

The formation and expansion of IMC in the study resulted from thermal during welding that corresponded to the previous work (Tricarico and Spina 2010). Once IMC forms corrosion can take place because of differences in electrochemical potentials between IMC and matrix adjacent. IMC acted as cathode compared with aluminium; thereby, aluminium was preferentially attacked that agreed with the previous work (Ambat et al. 2006). From the result, it can be stated that IMC played an important role in corrosion viewpoint as it accelerated the deterioration of AA1050 layer.

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