

An impact of different particulate reinforcements on the corrosion resistance of an aluminum alloy (AA2618) matrix composite

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ABSTRACT

The corrosion resistance of matrix composites made of aluminum alloy (AA2618) has been investigated in a number of settings, as has the impact of different types of particle reinforcements. A variety of AA2618/SiC, AA2618/TiC, and AA2618/fly ash composites were cast in specimens using metallic permanent molds. The percentages of these composites were measured in vol%, which ranged from 0% to 30%. In order to investigate the gravimetric and potentiostatic corrosion rates in conditions typical of these composite specimens in service, including one mole hydrochloric (1MHCl), sodium hydroxide (1MNaOH), and sea water, the cast specimens were cut to various dimensions. The test findings reveal that when the volume percentage of these particles added to the alloy matrix rose in these settings, the corrosion penetration rates (both gravimetric and potentiostatic) of the composite samples also increased. This is because, by serving as anodic sites, these particles encourage localized corrosion inside the alloy matrix. Particle clusters that produce high stress triaxiality in some areas were shown to be connected with dislocation movements in composite matrices, and their existence in the alloy matrix aided in their infringement. As the ratio of dislocation particles in the alloy matrix grew, the stress levels inside the composites rose, making them more susceptible to corrosion. Composites submerged in sea water had the least amount of corrosion attack compared to AA2618/SiC immersed in NaOH, which showed a significant increase in corrosion attack.

Keywords: Reinforcement, Particulate, Particles, Corrosion resistance, Aluminum alloy, Matrix composite.

1. INTRODUCTION

Material breakdown via electrochemical or chemical reactivity with its surroundings is corrosion. Materials also naturally revert to their most thermodynamically stable state [1]. Humanity faces various corrosion issues. It harms equipment, buildings, and the environment around corroded structures. Dry and moist corrosion exist. In the absence of aqueous phases on the metal surface, gases cause dry corrosion. Wet corrosion occurs when metal surfaces

have aqueous phases [1]. Aluminum forms a thin, persistent oxide covering that protects it from corrosion in neutral, moderately acidic, and alkaline conditions. Electrochemical, chemical, and environmental variables including polarization, pH, and corrosion product solubility impact oxide film stability. Aluminum is particularly active and oxidizes to Al^{3+} in acid solutions below 3 pH.

It becomes aluminate ions in alkaline conditions over pH 9. Aluminum passivates in pH 4–9 solutions by instantly covering its surface with an oxide coating and resisting corrosion [2]. According to Pourbaix [3], "in practice, the corrosion behavior of aluminum is determined essentially by the oxide film with which it is almost always covered in the corroding media." A change in this oxide film's hydration and porosity commonly causes corrosion resistance issues. Aluminum oxide (Al_2O_3) has several forms, including α -alumina (rhombohedral system), β -alumina (hexagonal crystals), γ -alumina (cubic crystals), and δ -alumina (rhombohedral crystals) [3]. However, amphoteric aluminum hydroxide gel exists. This means it reacts as an acid or base. Aluminum hydroxide gel crystallizes incrementally into hydrated products, including bohmite (rhombohedral crystals), bayerite (in the monoclinic system), and hydrargillite (in the monoclinic system) [3]. Pourbaix [3] added that "the various hydrates formed during the ageing are characterized by an increasing stability and an accompanying variation in all their properties, in particular their solubility in acids, bases, and pure water". Complex mechanisms govern aluminium alloy corrosion in diverse conditions. Scholars researched these phenomena using protective oxide layers in various conditions and reported: Wood [4] found that anodic barrier films are not pure oxide. Water and solution anions, pores, defects, and fissures are present. He defined "pores" as high-resolution microscope-visible capillaries and cavities. Thin areas or holes in the protective coating at second phase particle and gas bubble locations are flaws. The existence, configuration, density, and distribution of micro and macro defects including vacancies and voids, inclusions, second phase particles, oxide film crystal structure, and electrolyte composition, potential, and temperature affect oxide film stability [4].

Localized corrosion of aluminum in halogen-containing electrolyte may occur without barrier protective layer gaps, defects, or fractures, according to Szklarska-Smialowska [5]. She found that Al_2O_3 had an 8.5-nm grain boundary thickness, 0.36 nm chloride ion diameter, and 0.31 nm water molecule diameter [5]. In a chloride-containing electrolyte, chloride ions may arrive at the metal-passive film contact instantly. The oxide film's flaws allow chloride ions to reach aluminum metal. Chloride ion concentration, temperature, voltage, and oxide film defect size affect chloride ion transit to the metal-passive film interface [6]. Szklarska-

Smialowska found that chloride ions' penetration of the barrier film and arrival at the metal-passive film interface do not determine aluminum alloy pitting corrosion rate. It said that forming and maintaining solution acidity in pre-existing flaws at the metal-passive film interface determines rate. The acidity of pit solutions dissolves aluminium and propagates pits. Szklarska-Smialowska [6] found that metastable pits repassivate when metal dissolution and hydrolysis do not provide enough hydrogen ions to maintain low pH. In acidic pits, aluminium and other alloying element oxide coatings are insoluble or partly soluble, causing repassivation. Insoluble or partly soluble oxides exacerbate aluminium alloy pitting or passivate metastable pits. Metastable pit passivation raises the alloy's repassivation potential. Other researchers who studied aluminium alloy and composite corrosion in diverse settings include: According to Hosni Ezuber et al. [7], weight loss experiments showed minimal corrosion rates for marine aluminium alloys, highlighting their environmental benefits. They added that polarization plots demonstrated pitting attack on alloys after extended environmental exposure. Jun Cheng et al. [8] demonstrated high corrosion resistance of the alloy in marine environments and that tribological behavior in sea water depended on tribo-pair characteristics. In chloride conditions, Cl⁻ions in the solution cause crevice and pitting corrosion of the alloy, according to Garrigue L. et al. [9]. Alkaline media, notably sodium hydroxide NaOH, are the most harmful for aluminum corrosion, according to Manish Gupta et al. [10]. According to Sarawathi Y. L. et al. [11], Al/SiCp composite exhibited substantial corrosion attack in 3.5w% NaOH solution compared to cast iron. In analysis of aluminum 0.8% binary alloy corrosion susceptibility in certain acidic and alkaline conditions, Ede S.E et al. [12] corroborated this trend. They added that aluminum alloy displaces hydrogen in solutions slowly with dilute hydrochloric acid but quickly with concentrated acid. Hydrochloric acid reduces or helps produce AlCl₃ in solution. The molar acid content determines the rate of amphoteric salt production. Segregation of ceramic particles in the matrix, which is frequent in as-cast composites, caused increased corrosion susceptibility in aluminum alloy composite specimens with a high weight percentage of ceramic particles [13]. Segregation causes pit nucleation and corrosion. The scientific research above provides little insight on how particle reinforcement affects AA2618 corrosion resistance. Following these, this study examines the effects of titanium carbide, silicon carbide, and fly ash particles in the matrix of aluminium alloy (AA2618) on its corrosion resistance in simulated hydrochloric acid, sodium hydroxide, and sea water environments where this composite material is normally exposed during service.

2. METHODOLOGY

The research study used gravimetric weight loss analysis. The corrosion rate, which refers to the speed at which a material is eroded due to chemical reactions, is a significant metric in corrosion analysis. The corrosion penetration rate (CPR) refers to the amount of material lost per unit of time due to corrosion. The formula for this calculation is

$$CPR = \frac{KW}{\rho At}$$

Where W is the weight loss after exposure time t, ρ and A are the time, density, and exposed specimen area, and K is a constant. The magnitude of K is determined on the system of units used. The CPR may be readily represented as mil per year (mpy) or millimeter per year (mm/yr). In the first scenario, $K = 534$ gives the CPR in mpy (where 1mil = 0.001 inch), while W, ρ , A, and t are stated in milligrams, grams per cubic centimeter, square inches, and hours, respectively [1]. This experiment included 57 specimens and three conditions. The surroundings included one mole of hydrochloric acid (1M HCl), one mole of sodium hydroxide (1M NaOH), and seawater. These conditions were chosen to mimic the typical situations that most aluminum alloys and composites are subjected to while in service. In each setting, 19 specimens were submerged and one was removed every seven days (168 hours). The removed specimens were washed with detergent to remove grease stains and rusted particles, then rinsed in distilled water, cleaned, and dried with acetone in the open air. The final weight of each test specimen was obtained using an electronic digital analytic weighing scale, which allowed the corrosion penetration rate to be calculated based on weight loss. The experiment lasted 42 days, or 1008 hours in total. Potentiostatic corrosion rate measurements were performed on the samples using an electrochemical analyzer type CH660E. The device is a potentiostatic setup that measures sample corrosion rates using open circuit potential against time (OCPT) and Tafel extrapolation charts to calculate certain corrosion metrics. In this experiment, the electrochemical analyzer calculated the cathodic slope, anodic slope, cathodic intercept, anodic intercept, limiting polarization, corrosion current, corrosion rate in mil per year, corrosion rate in Angstrom per minute, and corrosion rate in gram per hour of samples immersed in one mole sodium hydroxide, one mole hydrochloric acid, and sea water environments. The potentiostat utilized in this study maintained a constant electrode potential (i.e., the material under investigation) and provided the current required to maintain the potential. Figure 1 shows a potentiostatic setup with three electrodes. 1. The working electrode, W, denotes the item under investigation; 2. The counter electrode, C; and 3. The

reference electrode, R. The reference electrode is normally electrolytically connected to the working electrode via a salt bridge that includes a thin tube near the latter.

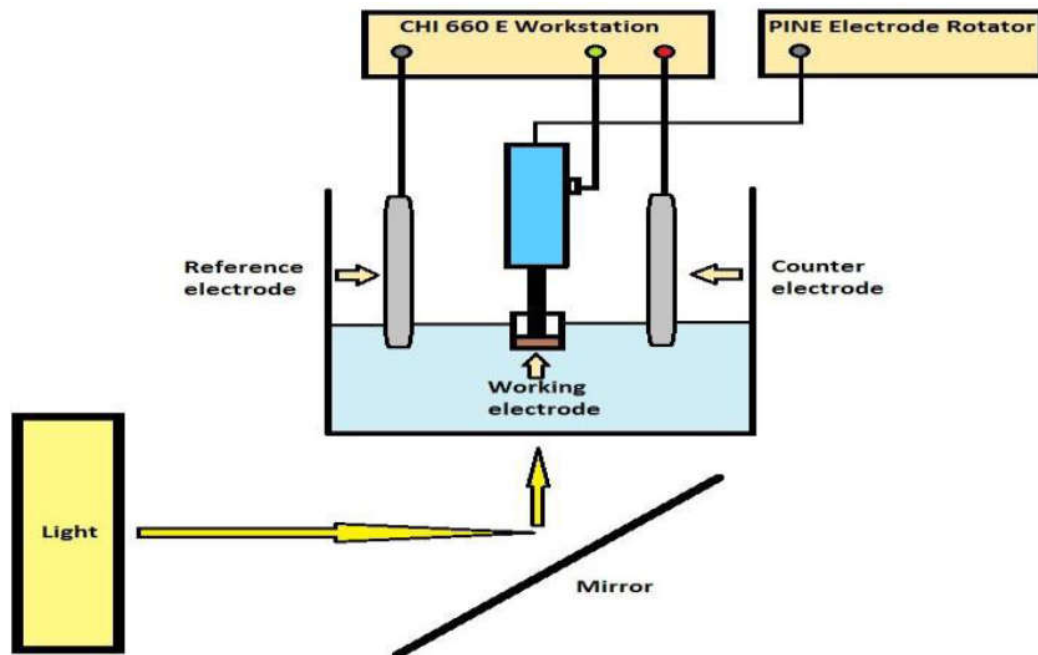


Fig 1: Potentiostat setup [1]

3. RESULTS AND DISCUSSIONS

The figures below show the results of the corrosion penetration rates of the composites and control sample in three different environments. Each environment contained a one mole concentration of hydrochloric acid solution (1M HCl), sodium hydroxide solution (1M NaOH), and sea water. The results were obtained using the gravimetric analysis method. The corrosion rates (mpy) versus the exposure duration (hrs) of AA2618/SiC composites submerged in a solution of hydrochloric acid at a mole concentration of 1M HCl for 1008 hours are shown in Figure 1. With a high corrosion rate at the beginning of the experiment and a declining rate towards the conclusion, the results showed an active-passive pattern throughout. This is a typical tendency of metals that passivate. Corrosion rates dropped significantly during the trial, reaching an all-time high at the first environmental exposure point. The specimens with 30vol% and 25vol% silicon carbide (SiC) particles showed high corrosion susceptibility, while the control, 5vol%, and 10vol% specimens showed low susceptibility to corrosion attack. This suggests that increasing the volume percent of SiC particles had a negative impact on the corrosion resistance of these composites. One possible explanation for this behavior is because anodic points are formed at the matrix-SiC particle contacts. Internal structures of the specimen are more likely to experience localized types of corrosion due to this phenomena, such as stress corrosion cracking (SCC), pitting corrosion, galvanic corrosion, for example.

Localized corrosion was shown to be more likely as the percentages of these reinforcing particles inside the matrix rose. Particle clusters cause high stress triaxiality in certain areas, which in turn increases the dislocation density within the composite matrix [15]. Particles also act as points of interference for dislocation movements within the composite matrix. High levels of stress inside the composites are a consequence of the rise in dislocation density. As a result, at the conclusion of the experiment, the samples' morphology had developed pits, cavities, and defects, suggesting that they had experienced both uniform and localized corrosion. According to research by T. W. Clyne and P.J. Whithers, which is prevalent in as-cast composites, the increased corrosion susceptibility seen in specimens with a high weight % of ceramic particles is due to the ceramic particles segregating within the matrix. By creating anodic sites, this segregation aids in the formation of pits, which in turn allow corrosion. Surface differences caused by the ceramic reinforcements in the matrix might exacerbate pitting corrosion by encouraging film defects. For AA2618/fly ash and AA2618/TiC composites submerged in 1MHCl solution for 1008 hours, respectively, the corrosion rates are shown versus exposure time (hours) in mpy (Figure 3). Figure 1 shows that the graphs are trending in an active-passive manner as well, however adding different volumes of fly ash and titanium carbide to the composites had no influence on their corrosion susceptibility. After the testing, the composites' surface morphology showed no signs of pit development. Composites made of AA2618 and fly ash were less likely to corrode over time compared to the others. This means that when the composite is submerged in a hydrochloric acid environment, the fly ash particles enhance cathodic polarization in contrast to the titanium carbide (TiC) and silicon carbide (SiC) present in the matrix.

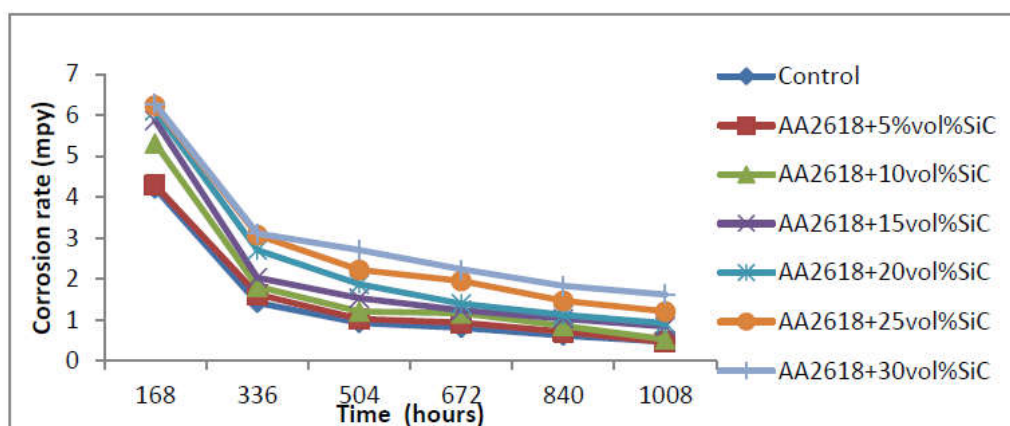


Figure 1: Corrosion rate (mpy) vs exposure time (hrs) of AA2618/SiC immerse In 1MHCl solution using gravimetric analysis method

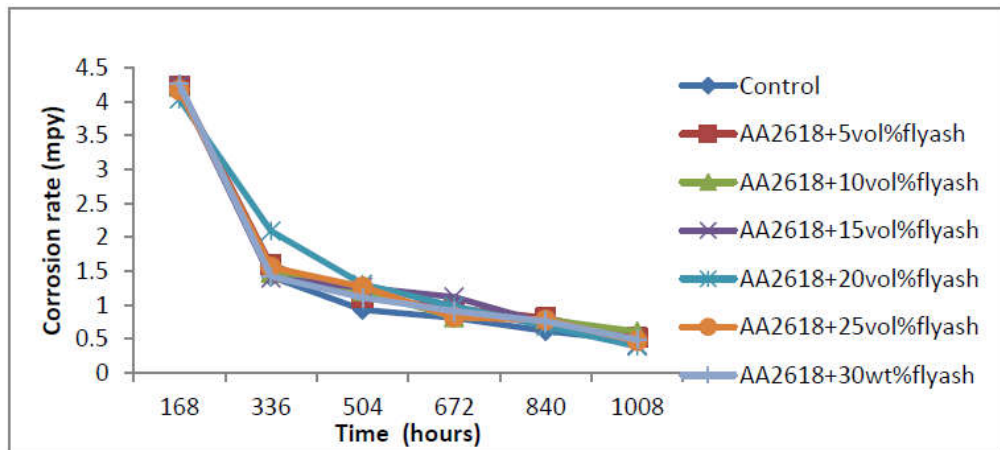


Figure 2: Corrosion rate (mpy) vs exposure time (hrs) of AA2618/fly ash immersed

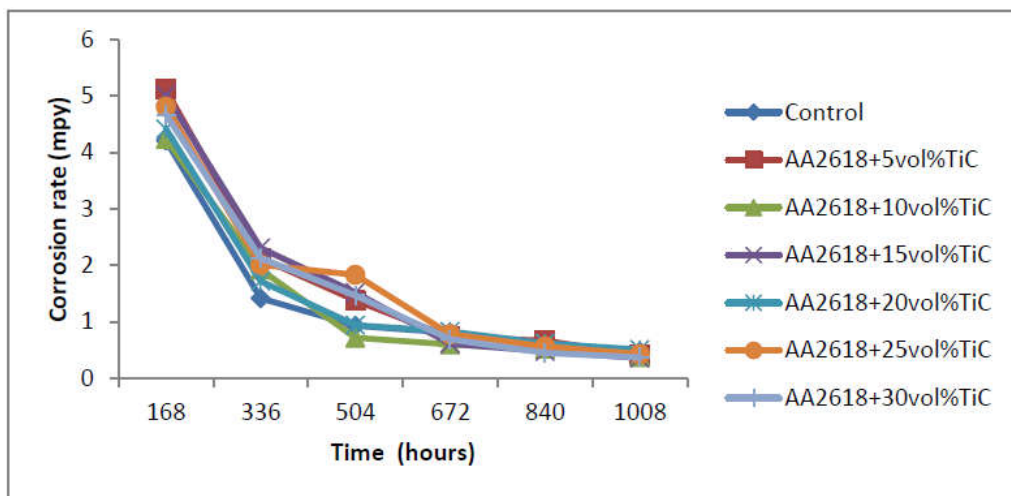


Figure 3: Corrosion rate (mpy) vs exposure time (hrs) of AA2618/TiC immersed in 1MHCl solution using gravimetric analysis method

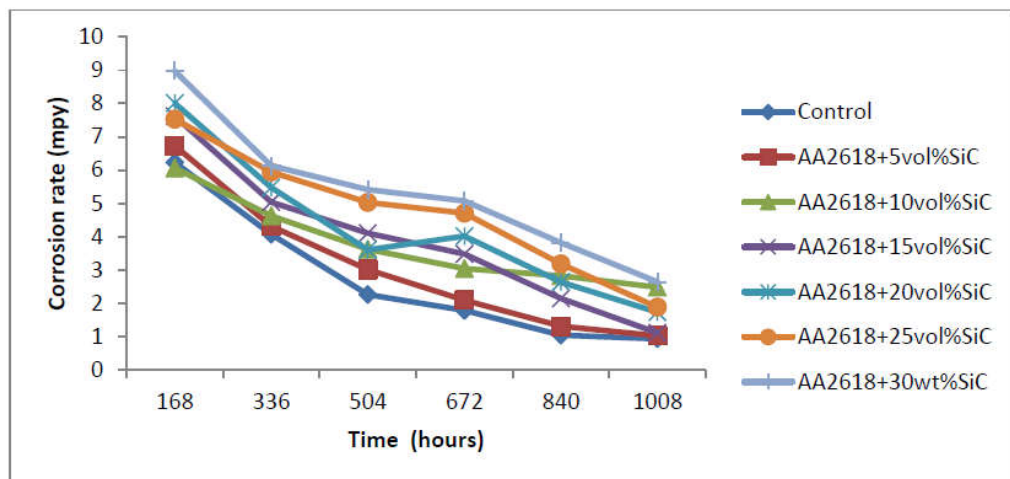


Figure 4: Corrosion rate (mpy) vs exposure time (hrs) of AA2618/SiC immersed in 1MNaOH solution using gravimetric analysis method

In a dilute hydrochloric acid environment, S.E. Ede et al. observed that these composites displayed active passive trend behavior. According to the research, aluminum alloy displaces hydrogen in solutions at a slower pace with concentrated hydrochloric acid

than with diluted acid. Hydrochloric acid's role as a reducing agent in promoting the solution-based production of AlCl_3 is therefore suggested. It is the acid's molar concentration that determines how quickly this amphoteric salt forms. In conclusion, these composites and alloys exhibit corrosion behavior trends that are consistent with passivating metals in laboratory settings. At the outset, there is a significant corrosion rate (active zone), but as exposure time grows, the rate gradually decreases until it reaches a limit where it is almost nonexistent, or until cathodic polarization of the alloy begins (passive regions). After being submerged in a sodium hydroxide solution (1MNaOH) for 1008 hours, the corrosion behavior of the alloy and composites is shown in Figures 4, 5, and 6. Corrosion rates of composites followed similar patterns. Figure 4, which shows the corrosion behavior of AA218/SiC composites, shows the highest level of corrosion attack. The addition of fly ash and titanium carbide did not enhance corrosion attack on these composites, despite the high corrosion rates seen in figures 5 and 6. As previously mentioned, this behavior is consistent with figures 2 and 3. Extensive corrosion has attacked the specimens, as seen in Figure 4. The causes for this may be seen in Figure 1. Possible contributing factors include SiC's very brittle, gritty, and hard character. This refractory substance, when mixed with the AA2618 matrix, puts stress on the matrix, which speeds up the process of anodic point creation. As a result, the composites will be subject to more corrosion. Titanium carbide and fly ash are less brittle, have smaller, slipper particles, and are malleable. They settle well into the AA2618 matrix when used as reinforcement material, preventing the matrix from being overstressed. In addition, compared to silicon carbide (SiC), their densities are lower. They are superior than SiC—which is denser, coarser, and very brittle—because of these qualities. Sodium hydroxide (NaOH) is a powerful electrolyte that ionizes entirely in solution, which is one of the reasons why these composites are so vulnerable to corrosion attack in NaOH settings. It easily dissolves in the presence of hydrogen gas to produce sodium aluminates (III) when it combines with aluminum alloys or composites. In an excess of NaOH solution, the resulting amphoteric hydroxides may re-dissolve to create complex salt. This procedure maintains the active condition of these composites. Because of this, the composites submerged in this environment exhibited the greatest corrosion rate.

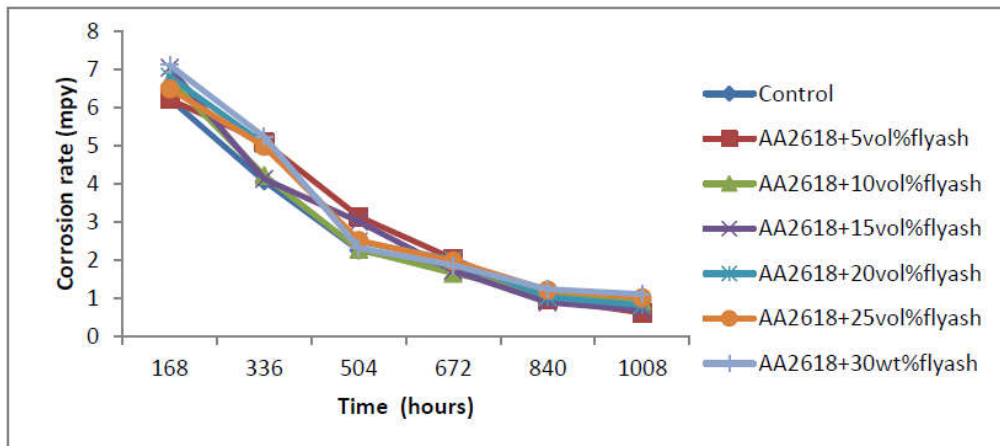


Figure 5: Corrosion rate (mpy) vs exposure time (hrs) of AA2618/fly ash immersed in 1MNaOH solution using gravimetric analysis method

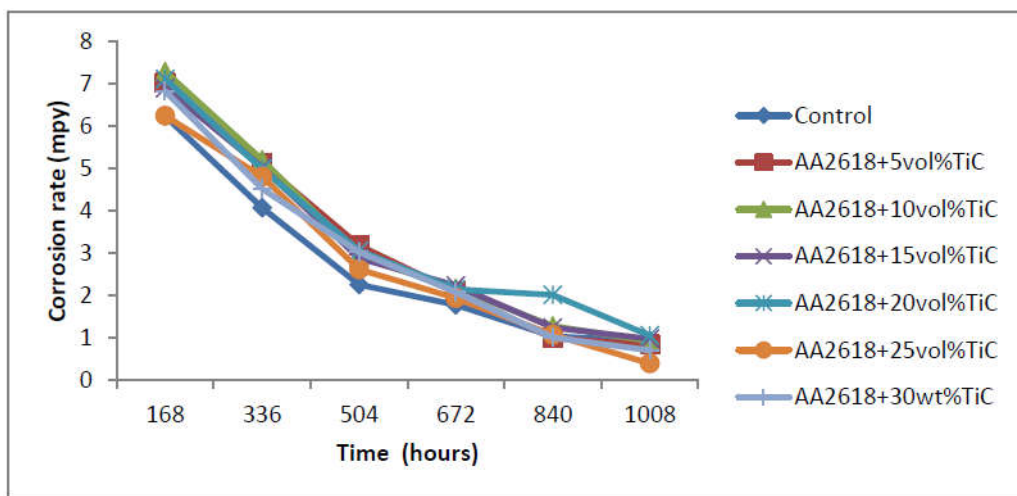


Figure 6: Corrosion rate (mpy) vs exposure time (hrs) of AA2618/TiC immersed in 1MNaOH solution using gravimetric analysis method

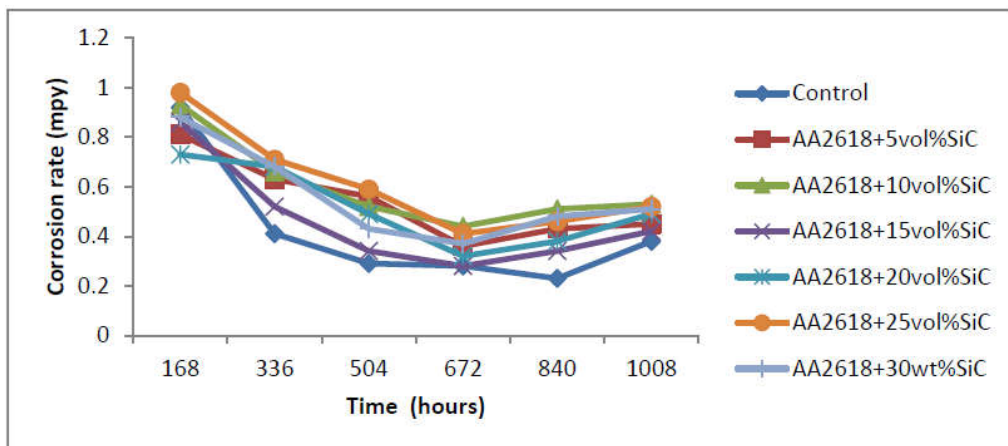


Figure 7: Corrosion rate (mpy) vs exposure time (hrs) of AA2618/SiC immersed in sea water using gravimetric analysis method.

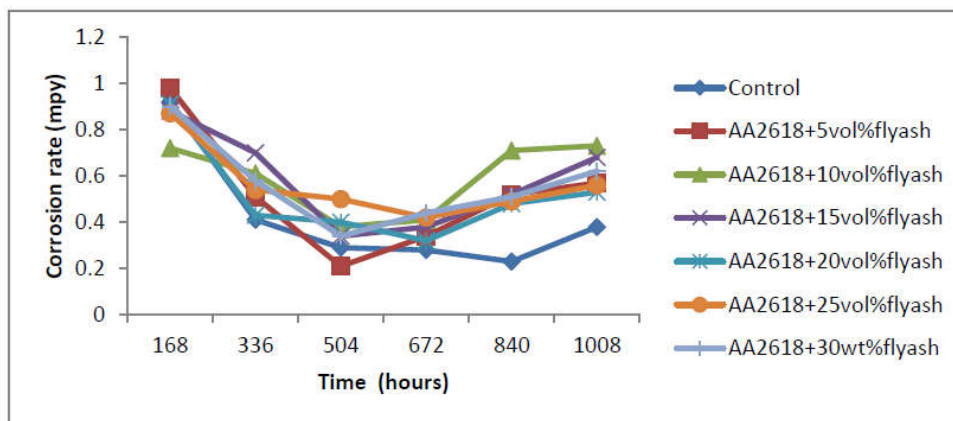


Figure 8: Corrosion rate (mpy) vs exposure time (hrs) of AA2618/fly ash immersed in sea water using gravimetric analysis method

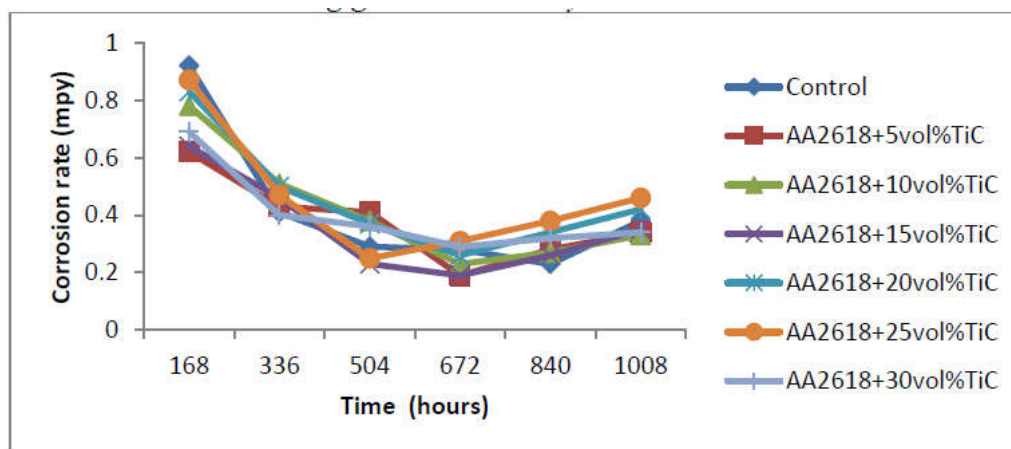


Figure 9: Corrosion rate (mpy) vs exposure time (hrs) of AA2618/TiC immersed in sea water using gravimetric analysis method

The composites submerged in seawater environment show corrosion rates (mpy) vs time (hours) in Figures 7, 8, and 9. The effects of salt water on these composites are crucial in their technical uses. It is a typical operating environment for ships, yachts, submarines, and flying boats that use this composite for the majority of their body parts, such as the hull. When compared to the graphs from other contexts that were previously covered, a careful examination of these graphs reveals distinct tendencies. There was less than one mpy of corrosion here. With its many various mixes of non-aggressive salts like NaCl, MgCl₂.6H₂O, Na₂SO₄CaCl₂, KCl, NaHCO₃, etc., seawater typically has a relatively low corrosion rate in this setting. Therefore, it may be concluded that these materials are not aggressively affected by sea water. The corrosion susceptibility of the composites is unaffected by variations in the volume percentages of these reinforcing particles. In addition, fouling and marine growth, which were seen as an unusual rise in corrosion rates at the conclusion of the experiment in a salt water environment, were caused by the production of thin oxide layers. Due to the films' malleability and porosity, they easily flaked off as their thickness increased on the specimens'

surfaces, exposing them to their active states. The occurrence of this event accelerated the pace of corrosion on the specimen by allowing oxygen to diffuse onto it. Both the solution's composition and the amount of time exposed determine whether this porous layer (fouling) or marine growth will emerge. The graph clearly shows that this change began at the conclusion of the experiment, after the specimens had been exposed to the surroundings for quite some time. Specimens' post-experiment morphological examination revealed the presence of black, porous fouling.

4. CONCLUSIONS

Corrosion penetration rate tests on both the composites and the control sample revealed that SiC particulate reinforcement negatively affected the corrosion resistance of the composites as the volume percent addition of these particles increased, demonstrating the effects of different reinforcements on the corrosion resistance of AA2618 matrix composites. One possible explanation for this behavior is because anodic points are formed at the matrix-SiC particle contacts. Internal structures of the specimen are more likely to experience localized types of corrosion due to this phenomena, such as stress corrosion cracking (SCC), pitting corrosion, galvanic corrosion, for example. Localized corrosion was shown to be more likely as the percentages of these reinforcing particles inside the matrix rose. In addition, the dislocation density in the composite matrices was enhanced by the presence of these particles, which acted as points of interference for dislocation movements. Particle clusters in these areas caused high stress triaxiality. In every setting where corrosion rate experiments were performed, the addition of fly ash particles did not significantly increase the alloy's susceptibility to corrosion inside its matrix. This is because, unlike titanium carbide (TiC) and silicon carbide (SiC), which did not dissolve in the AA2618 matrix, fly ash particles did dissolve in the alloy matrix, promoting cathodic polarization.

REFERENCES

1. S.E. Ede: Theory of Corrosion and Protection. Obi publication Enugu, Nigeria. (ISBN: 978-8150-37-3) 2012.
2. D. A. Jones, Principles and Prevention of Corrosion, 2nd Ed., Prentice Hall International, Inc., Singapore, 1996.
3. M. Pourbaix, Atlas of Electrochemical Equilibria in Aqueous Solutions, translated by J. A. Franklin, Pergamon Press, Oxford, Londond, Paris, 1966, pp. 168-176.
4. G. C. Wood, "Porous Anodic Films on Aluminum", Oxide and Oxide Films, Vol. 2, Ed. by J.W. Diggle, Marcel Dekker, Inc., New York, 1973, pp. 167-268.

5. Z. Szklarska-Smialowska, "Pitting Corrosion of Aluminum", Corrosion Science, Vol. 41, No. 9, 1999, pp. 1743-1767.
6. Z. Szklarska-Smialowska, "Insight into the Pitting Corrosion Behaviour of Aluminum Alloys" Corrosion Science, Vol. 33, No. 8, 1992, pp. 1193-1202.
7. Hosni Ezuber, A. EL-Houd, F. EL-Shawesh: A study on the corrosion behavior of aluminum alloys in sea water. www.sciencedirect.com, vol 29 issue 4 2008.
8. Jun Cheng, Fei Li, Shengyu Zhu, Yuan Yu, Zhuhui Qiad and Jun Yang: Electrochemical corrosion and tribological evaluation of TiAl alloy for marine application. www.sciencedirect.com vol 115 2017
9. L. Garrigue, N. Pebere and F. Dabosi: An investigation of corrosion inhibition of pure aluminum in neutral and chloride solution. *Electrochimica Acta*, Vol 41, No 7-8 1996
10. Manish Gupta, Jyotsna Mishra and K.S. Pitre: Corrosion and inhibition behavior of aluminum in alkaline medium and sodium silicate. *International journal of advancement in research* 2015.
11. Y. L. Sarawathi, S. Das and D. P. Mondal: A comparative study of corrosion behavior of Al/SiCp composite with cast iron in NaOH environment. www.corrosionjournal.org July 2017, vol 57, issue 7.
12. Ede, S. E., Idogwu S., Agbo A. O. and Odo J. U: Characterization of Corrosion Susceptibility of Aluminium 0.8% Silicon Binary Alloy in some selected Acidic and Alkaline Environment. *Journal of Metallurgy and Materials Engineering* Vol, 7, No. 1, April, 2012, Pp. 6 – 10.
13. T. W. Clyne and P. J. Whithers, *An Introduction to Metal Matrix Composites*, Cambridge University Press, London, (1993).
14. R. Guo and P. K. Rohatgi, "Chemical Reactions between Aluminium and Fly Ash during Synthesis and Reheating of Al-Fly Ash Composites", *Journal of Material Science*, Vol. 29B (1998). Pp. 519-525.
15. A. Levy and J. M. Papazian, "Thermal Cycling of Discontinuously Reinforced SiC/Al Composites", in *Metal Matrix Composites – Processing, Microstructure and Properties*, 12th Riso Inter. Symp., Roskilde, N.Hansen et al. (eds.), Riso Nat. Lab., Denmark, (1991), 475-482.
16. Gareth Hinds from the original work of J G N Thomas: *A handbook on Electrochemistry of Corrosion and Protection of Materials*. Vol 2 Issue 4 2002 pg. 14-19.
17. L.D. Wang, W. D. Fei, M. Hu, L. S. Jiang and C. K. Yao, "A study on an aluminum matrix composite reinforced by both α -eucryptite particle and aluminum borate whisker", *Materials Letters*. Vol. 53 (2002), pp. 20-24.
18. P.K. Rohatgi, D. Weiss and N. Gupta, "Applications of Fly Ash in Synthesizing Low-Cost MMCs for Automotive and Other Applications", *Journal of the Minerals, Metals and Materials*, Vol. 58 (2006), pp. 71-76. www.titaniumcarbide.wikipedia 2015
19. Gareth Hinds from the original work of J G N Thomas: *A handbook on Electrochemistry of Corrosion and Protection of Materials*. Vol 2 Issue 4 2002 pg. 14-19.