Corrosion behavior of hybrid coconut shell powder and silica carbide reinforced aluminium composite towards aggressive biofilm attack

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Abstract. This study enveloped innovative uses of a hybrid agro waste and silica carbide incorporated with aluminium as a new hybrid composite materials for marine application. In this study, the purpose of adding coconut shell powder (CSP) from the agro waste and silicon carbide (SiC) as reinforcement aluminium composites materials for combating corrosion problem. The CSP was incorporated into the molten aluminium alloys varies from 0%, 5%, 10%, 15% and 20% of weight percentages. The corrosion behaviour was determined by weight gain measurement (WGM), electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization (PP). As a results, 5% CSP reinforcement in hybrid aluminium composites contribute to excellent corrosion resistance performance by shifting the polarization curve towards the positive region, increases the value of polarization resistance, $R_p$, and reduces the $I_{corr}$ value. It can be concluded that, by adding CSP into aluminium composite has significantly increase the corrosion resistance towards a severe biofilm attack.

1. Introduction

Corrosion has been recognized as the greatest issue worldwide as well as in Malaysia [1]. Nowadays, there are many types of hybrid metal composites reinforced with natural fiber and SiC used in the various industry [2-5]. Over the years, the great achievement has been witnessed in material engineering and material science through the development of hybrid aluminium composites from the natural green fiber. Furthermore, magnesium was added for improving wettability between the aluminium matrix and the reinforcement. Present discussion on hybrid composite ensures that the application and implementation of hybrid composites in various different fields seem to be practicable [6-7]. Previous study on the various aspects of hybrid composite application provides solid assumption regarding the influence of various different parameters on the hybrid composites performances.
method of fabricating for hybrid aluminium composites also add the credit. The development of composites production or fabrication includes the aspect of technique apply and degree of difficulty. Stir casting, powder metallurgy, spray atomization and co-deposition, plasma spraying, squeeze casting and compo-casting were the best developed methods for composite production [8-10].

2. Materials

The reinforcement used for aluminium matrix was pure SiC particles average range particles size within 30 µm and processed CSP about 425 µm consequential from controlled sieving of coconut shell. Magnesium powder was added for its role in cultivating wettability between the aluminium matrix and the reinforcement, increase strength through the solid solution and improve strain hardening ability. Hybrid materials composites were fabricated using stir casting method.

3. Methodology

The corrosion behavior was determine using Weight Gain Measurement (WGM), Electrochemical Impedance Spectroscopy (EIS) and Potentiodynamic polarization (PP). WGM was carried on followed the ASTM G31. The coupons were immersed in seawater solution accordingly for 35 days. Every 7 days interval, the coupons were withdrawn and dried at ambient temperature accordance with ASTM STP 1188, EIS test was conducted to calibrate the system impedance for a range of frequencies. The experiment was carried by Autolab PGSTAT302N controlled by NOVA software. The data from EIS test were collected and tabulated in Nyquist plot and the value of estimated polarization resistance \( R_p \) obtained. Meanwhile for PP, the potentials were scanned from -1.7 V to 0.01 V and a slow scan rate of 10 mV/s was used. The test was carried out at room temperature. The result from potentiodynamic polarization measurement was represented in a Tafel plot. From the experimental data obtained, the value of current density \( I_{corr} \) and the current potential \( E_{corr} \).

4. Results and discussion

It was observed that, there was an appearance of a milky white as depicted in Figure 1 for all samples as claimed by Bodunrin et al [11]. The inferior performance of single reinforced and CSP reinforced hybrid aluminium composites was clearly due to the electrochemical process during the immersion test which promoted pitting corrosion. The composites produced acting as an active anode. Corrosion of the composite is initiated by segregation of reinforcement interface, interfacial reaction, high dislocation density around reinforcement phase [15-16].

![Figure 1](image.png)

**Figure 1.** Milky white (corrosion deposit) appearance on the sample surfaces.

The average weight gain of the single reinforced hybrid aluminum composites for immersion week 1 is 0.0048 g followed by 0.0032 g, 0.0033 g, 0.0065 g and 0.0056 g for week 2 to week 5, respectively. The percentage of weight gain for all CSP reinforced hybrid aluminum composites is less than 0.2%. The weight gain for single reinforced hybrid aluminum composites reaches the highest at 0.34% in week 4. These results suggest that the trivial 1% weight gain of the composites is not significant. Once the weight gain is higher, it shows that the reaction on the surface is aggressive, leading to the
reduction of metal thickness. Meanwhile, weight gain percentage less than 0.1%, this composite had the much longer lifespan to survive in the marine environment. Bodunrin et al. [11] revealed that the composites with calcined CSP and SiC less corrode over the time exposure. The increased weight in average range observed in CSP reinforced hybrid aluminum composites was due to the microbially influenced corrosion (MIC) on the sample surfaces [14]. As depicted on Figure 2 (i) and Figure 2(ii), the largest value of $R_p$ on immersion week 2 is 23,944.1 Ω.cm$^2$ for 15% CSP-reinforced hybrid aluminum composites. In the week 5 of immersion, it is clear that 15% CSP reinforced hybrid composites recorded 22,057.4 Ω.cm$^2$, slightly decrease than the Week 2 reading. However, 5% CSP reinforced hybrid aluminum composites recorded the highest $R_p$ value that is 52,551.8 Ω.cm$^2$ in the Week 5, increasing rapidly from 13,679.3 Ω.cm$^2$ in week 2. It is then followed by 15%, 10%, 20% and 0% CSP reinforced hybrid aluminum composites.

![Figure 2. (i) and (ii) Nyquist plot of single reinforced and CSP reinforced hybrid aluminum composites for immersion week 2 and week 5, respectively.](image)

The occurrence can be related to the adsorption of CSP molecules on the sample surface which aligns with the previous studies. The adsorption of CSP molecules on the sample surface influences the size of the surface coverage assigned. This happens due to the corrosion process that has been controlled by the charge transfer process [16]. Moreover, the impedance value of CSP reinforced hybrid aluminum composites is larger than the single reinforced hybrid aluminum composites due to the presence of CSP. From the EIS test, the diameter of semi-circle increases as the time for immersion test increases. In this study, the diameter of Nyquist plots starts to fluctuate, reduce and increase for CSP reinforced hybrid aluminum composites. Higher $R_p$ value suggests better corrosion resistance as has been reported by previous researchers [17-20]. This observation suggests that the presence of inhibitors hinder the adsorption to the metal matrix surfaces. It can be concluded that as the CSP weight percentage increase, the absolute quantity weakened. The 5% CSP reinforced hybrid aluminum composites demonstrate the highest $R_p$ value in the week 5 immersion. As depicted in Figure 3, value for CSP reinforced hybrid aluminum composites shifted to the more electropositive region in comparison to the single reinforced sample. In particular, the Ecorr value for 0% CSP reinforced hybrid aluminum composites is -0.95764 V, followed by 15%, 20%, 10% and 5% CSP reinforced hybrid aluminum composites that shifted to a more electropositive region with reading -0.59459 V.

![Figure 3. Tafel plot of single reinforced and CSP reinforced hybrid aluminum composites for immersion week 3.](image)
Besides, 0% CSP reinforced hybrid aluminum composites has the least $I_{\text{corr}}$ value of 4.28 µA/cm$^2$ followed by 15% (4.37 µA/cm$^2$), 20% (7.19 µA/cm$^2$), 10% (10.2 µA/cm$^2$) and 5% (34.7 µA/cm$^2$), respectively. The lowest $I_{\text{corr}}$ value is shown by 15% CSP followed by 20%, 10% and 5% CSP respectively. There is no significant different of $I_{\text{corr}}$ value for 0% and 15% whereas the prominent different can be seen from $E_{\text{corr}}$. CSP reinforcement revealed that the inhibition takes place within the adsorption on the hybrid aluminum surfaces. This trend coincides with the research done by Vijayalakshmi et al [21]. As the 5% CSP reinforced hybrid aluminum composites show the lowest $E_{\text{corr}}$ value due to the limitation amount of CSP molecules into the hybrid aluminum, it suggests that the presence of inhibitor molecules obstructs the absorption onto the hybrid aluminum surface. The work of Berenji et al [22] shows that the inhibition performance of natural fiber decreased at a specific point known as the limitation factor caused by the shifting of certain functional group among the hybrid aluminum and surroundings; the functional groups of natural inhibitor form protective films on the hybrid aluminum composites. The Tafel plot on week 3 immersion for potentiodynamic polarization mechanism is chosen because it shows the most electropositive value for $E_{\text{corr}}$ which is reciprocal with the $I_{\text{corr}}$ value compared to other immersion timelines. This trend aligns with Hajar et.al. [23].

5. Conclusion

It was found that through WGM, the single reinforced weighs more than CSP reinforced hybrid aluminum composites. The appearance of milky white corrosion deposit can clearly be seen due to localized and uniform corrosion that cause pitting corrosion on the composite surfaces. The inferior performance of single reinforced and CSP reinforced hybrid aluminum composites is because of the electrochemical process that happens during the immersion test that promotes localized corrosion and thus pitting corrosion. EIS study shows that 5% CSP reinforcement in hybrid aluminum composites contributes to excellent corrosion resistance performance. In EIS, 5% CSP reinforced recorded higher Rp value than others in week 5 that is about 52 551.8 Ω.cm$^2$, compared to week 2 with recorded value of 13 679.3 Ω.cm$^2$. The Rp value increases with longer immersion period. In PP measurement, 5% CSP reinforced hybrid aluminum composites shows the lowest $E_{\text{corr}}$ values in week 1 and week 3. Both weeks show the most significant value with the lowest Ec Orr values and the highest Icorr values. Overall, $E_{\text{corr}}$ value of 5% CSP reinforced hybrid aluminum composites is shifted from electronegative region to a more electropositive region.

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