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Study of Corrosion Penetration Rate on Composite Materials EN AC-43100 (AlSi10Mg (b)) + SiC*

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Abstract: Corrosion Penetration Rate (CPR) is defined in three ways: (1) the speed at which any metal in a specific environment deteriorates due to a chemical reaction in the metal when it is exposed to a corrosive environment, (2) the amount of corrosion lost per year in thickness, (3) the speed at which corrosion spreads to the inner portions of a material. The purpose of this research is to calculate CPR of Aluminum matrix composite materials (AlSi10Mg (b)) with Silicon carbide (SiC*) reinforcement with the variation of matrix composite percentage. A wet corrosion test was conducted by dipping AlSi10Mg(b) and AlSi10Mg(b)+SiC* in the solution of HCl acid, NaOH, NaCl. The wet corrosion tests were also being done in the different pH (1,3,5,7,9,11, and 13). It was found that the highest corrosion penetration rate occured when the specimen dipped on HCl solution when the pH is 1. We also observed that the addition of SiC* could reduce the corrosion rate of materials. Finally, this study showed that composite material, AC-43100 (AlSi10Mg (b)) 85% + 15% SiC*, it is the best material in resist of corrosion attack, it has smallest CPR value that is below the standard of corrosion <0.5 mm/yr.

Keywords: Corrosion Penetration Rate (CPR), composite materials, EN AC-43100 (AlSi10Mg (b)), silicon carbide (SiC*), wet corrosion.

1. Introduction

Material EN AC-43100 (AlSi10Mg (b)) + SiC* is composite material based on aluminium with reinforcement silicon carbide (SiC). Aluminium alloy AlSi10Mg (b) is used as constituting shipbuilding material which based on European Nation (EN) Aluminum Casting (AC)-43100. While SiC* as reinforcement that has been treated by, firstly, heated it to the temperature of 1100^0C and then cooled gradually for 4 hours [1]. This material contains Metal Matrix Composite/MMC). Compare to the other materials; it has several advantages: it has high stiffness, excels at room temperature and tough at high temperature, high wear resistance, low thermal expansion coefficient [2],[3].

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Research has been done by making brake drum for composite material (Al-Si) + SiC/15% that prevented by nickel (Ni) and chrome (Cr), at this stage Corrosion Penetration Rate (CPR) obtained only 0.009 mm/yr when test to 0.1 M HCl solution for 6 hours. CPR= 0.009 mm/yr, which mean that the value is very small because coating Cr-Ni serves to protect against corrosion attacks [4].

Another research for Ford laser (1997) exhaust pipe was coated with decorative and thick chrome (Cr) when corrosion test in the solution of HCl 22.2%, the result of CPR has exceeded the allowable standard rate (allowable standard is 0.5 mm/yr) [5].

Investigate the wear and corrosion behaviour of tungsten carbide ten wt.% nickel (WC-10Ni) and tungsten carbide 12 wt.% w cobalt (WC-12Co) coating deposited onto medium carbon steel (Cast steel BS 3100 GR A3) blade. The result with high volume fraction and hardness, WC-12Co shows higher wear resistance compared to WC-10Ni. However, the value of the corrosion rate for both coating has a slight difference due to better corrosion resistance of Ni binder itself [6]. As for the recycled aluminium chip (AA6061), it can be concluded that the sintered temperature at 552°C was the best result of sintered sample to obtain better physical and mechanical [7].

Research about composite material with matrix pure copper UNS C19000 was reinforced with FeAl, Fe3Al and CuNiAl intermetallic powders, were added externally to pure copper (Cu) by mechanical alloying and thermal consolidation to obtain intermetallic particles reinforced composites (CuFeAl, CuFe3Al and Cu(CuNiAl)) and the result is CuFeAl and CuFe3Al MMCs have the higher corrosion resistance along better electrical and mechanical properties [8].

As we know that aluminium alloy with SiC* reinforcement is common used as the primary material in the manufacture of aerospace and automotive industry. Due to its excellent properties. However, the application in the shipbuilding material is still limited. Therefore, the study of the use of this material in the shipbuilding area is needed. Focusing on the anti-corrosion properties, the purpose of this research is to conduct corrosion test on Material EN AC-43100 (AlSi10Mg (b)) + SiC* to investigate the material resistance when it is exposed to corrosion attack.

2. Methodology

The composition of the sample consisted of: (Sample) AC-43 100 (AlSi10Mg (b)), (Sample 2) AC-43100 (AlSi10Mg(b))95% + 5% SiC*, (Sample 3) AC-43100 o (AlSi10Mg(b))90% + 10% SiC*, and (Sample 4) AC-43100 (AlSi10Mg(b))85% + 15% SiC*. Corrosion test samples prepared in the form of cubes with dimensions (1x1x1) cm3 for wet corrosion test, effect of time and effect of pH solution.

2.1 Effect of Time in Wet Corrosion Test

Corrosion wet in which the sample cubes were dipped in a solution of HCl acid, NaOH, and NaCl, with concentrations of 0.1 Molar for 6 hours. Every interval 2 hours, samples were removed and cleaned by immersion in a mixed solution of HCl (1000 mL), 50 grams SnCl2 and 20 grams Sb2O3 for 15 minutes. After that, samples were washed again with 70% alcohol and dried, then sample weight (m) was measured by digital weight balance. The weight loss of the sample was calculated using this equation below:

$$W = m_0 - m \tag{1}$$

Where m_0 is the initial sample weight before doing the corrosion test.

2.2 Effect of pH solution in Wet Corrosion Test

Samples were dipped for 2 hours in pH = 1, 3, 5, 7, 9, 11, 13 solutions. The pH condition was made from diluting HCl, NaCl and NaOH solution in water. For pH 1, 3, 5 were from 0.1 M; 0.001M and 0.00001 M HCl respectively. pH 7 was obtained from diluting 5.85 gram NaCl in 1000 mL of water. Meanwhile, pH 9, 11, and 13 were made from 40 grams of NaOH. After 2 hours, samples were removed and cleaned, similar to the treatment done in previous test explained above.

The method used to measure the corrosion rate was Weight Loss Method.. This method was used as a measurement of the Corrosion Penetration Rate (CPR) which is expressed in mile per year (mpy) or millimeter per year (mm /yr). Where the material density (D), testing time (T) and weight are a parameter which to is known during the testing process, the CPR can be calculated by the equation:

$$CPR = \frac{KW}{ADT} \tag{2}$$

CPR is Corrosion Penetration Rate (mpy) or reduction in the thickness of the material per time unit. Unit: mile per year (mpy) or millimeter per year (mm/yr). W is weight loss during testing (mg) = mo – m, m is weight after corroded, mois weight before corroded. K is constant depends on unit used, when K = 534 the mpy will be used. When K = 87.6, mm/yr will be used. D is density (gr/cm3), T is time (hours), A = surface area (cm2) (same units other such as CPR wear mpy). When the value of CPR was less than 20 mpy (0.5 mm/yr), the value/coefficient was still acceptable.

3.0 Results and Discussion

3.1 Effect of Time in Wet Corrosion Test

The result for CPR data obtained from the effect of time in wet corrosion test when dipped in solution of 0.1 M HCl, 0.1 M NaCl and 0.1, NaOH, shown in Figure 1, 2, and 3 respectively.

In all figures, the materials (AC-43100 (AlSi10Mg (b)) and composite materials (AC-43100 (AlSi10Mg (b)) + SiC*) in the solution of HCl have the highest CPR compared to the solution of NaOH and NaCl. Actually, in principle, AC 43100 (aluminium casting) is a type of metal where the protective layer of Al_2O_3 will be formed on the surface in oxidation environments. Oxidation environment is the environment which can remove or reduce the electron while the rate of oxidation increases. The protective Al_2O_3 layer is very good because it can make the current density (current per area) approaches the zero value. However, when the AC-43100 was dipped in solution of HCl, it will be easily eroded, since HCl had no oxygen. HCl in the absence of oxygen will lead to a reaction at the cathode side of the galvanic cell, allowing the formation of a galvanic cell pairing in the microstructure of these samples have led to very easily affected, so the corrosion rate when the samples were stored in HCl became very fast. The fastest corrosion rate values during dipped for 6 hours of the sample without addition of SiC* is 0.98 mm/yr. This value of the CPR was dangerous because it exceeds the maximum allowable CPR (0.5 mm/yr). When the AC-43 100 is reinforced with SiC*, the corrosion rate of the samples become slower. The addition of SiC*, the majority (15%) of the four samples reached a value of CPR of 0.19 mm/year for 6 hours' weeks. The addition of SiC* was very effective for the corrosion that occurs in the material to prevent AC-43100 [9].

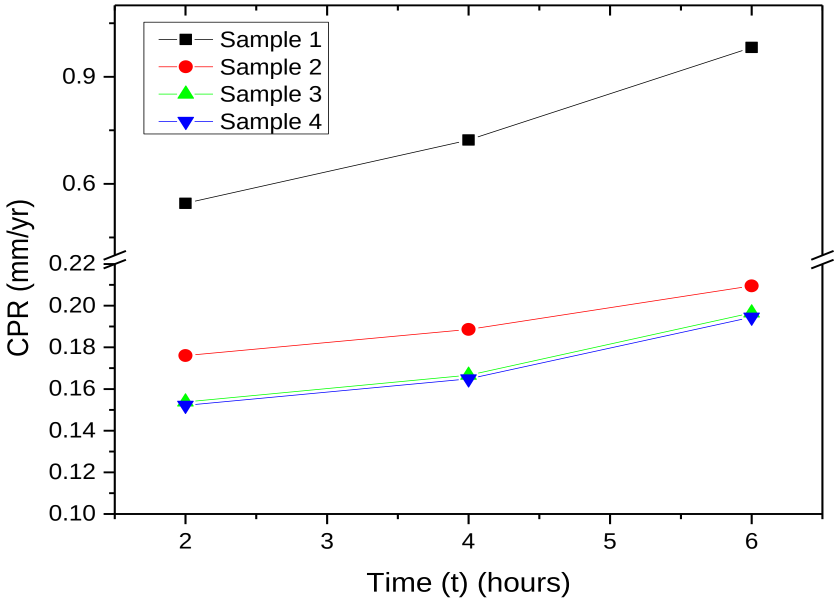

Fig. 1 - Graph of CPR vs dipped time in 0.1 M HCl solution

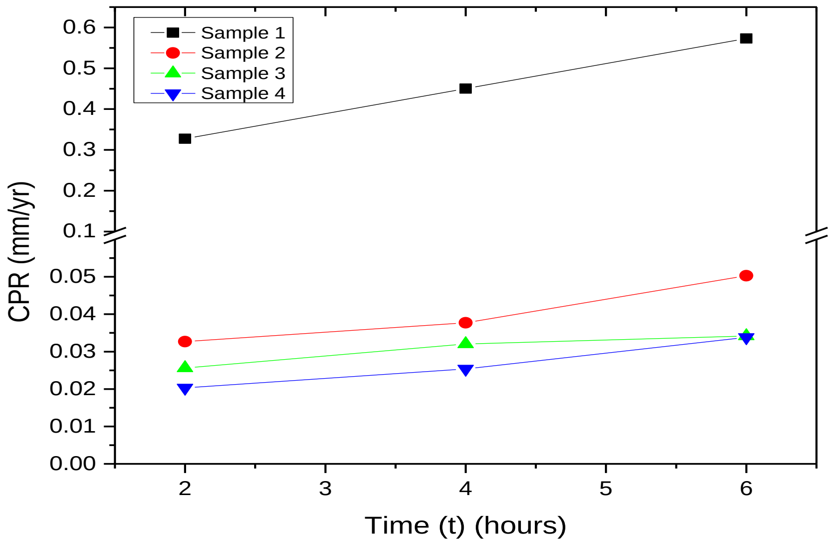

Fig. 2 - Graph of CPR vs dipped time in 0.1 M NaCl solution.

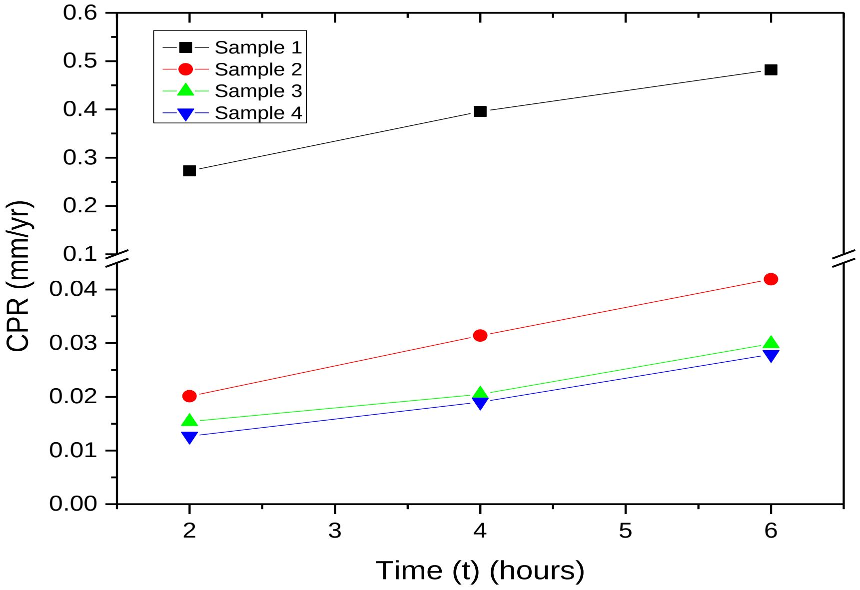

Fig. 3 - Graph of CPR vs dipped time in 0.1 M NaOH.solution

When the composites samples dipped in a solution of NaCl and NaOH, SiC*,the corrosion rate is also reduced. In the NaOH conditions the oxygen reduction reaction will follow this reaction:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (2)$$

Moreover, OH^- ions from the base oxidized to oxygen (O_2), the reaction:

$$4OH^- \rightarrow 2H_2O + O_2 + 4e \quad (3)$$

The formation of oxygen, causing a delay in the process of corrosion in alkaline environments. The corrosion rate values of AC-43100 (AlSi10Mg (b)85%+ 15% SiC*dipped in a solution of NaOH is 0.028 mm/yr, with one-week period of 6 hours.

When the sample is dipped in the solution of NaCl which contains of ions Na$^+$ and Cl$^-$,Cl$^-$ ions tend to react with the oxygen bonding of aluminium, so the process of corrosion takes place more rapidly than in the alkaline environment. The corrosion rate values for the four samples when dipped in a solution of NaCl reach up to 0.034 mm/yr, with one-week period of 6 hours.

The addition of SiC* reinforcement material to AC-43100 AlSi10Mg(b) may delay the CPR in a solution of HCl, NaCl and NaOH. The lowest corrosion rate occurs on the addition of SiC* optimal composition in AC-43100 (AlSi10Mg (b)85% + 15% SiC*), for dipped times of 2, 4 and 6 hours. The fastest of corrosion penetration rate for six hours to weeks was occurred in solution of HCl, and NaCl. While the slowest has happened in NaOH solution (Figure 4).

The microstructure of samples was observed using the optical microscope (OM). Figure 5 shows the microstructure of AC-43100 (AlSi10Mg(b) in the magnification of 600x, before wet corrosion test. While Figure 6, 7 and 8 show composite materials AC-43100(AlSi10Mg (b)85% + 15% SiC* after corrosion in 0.1 M HCl, 0.1 M NaCl, and 0.1 M NaOH. Corrosion attack only to matrix AC-43100 AlSi10Mg(b) not to reinforcement SiC*. From these figures, corrosion attacks the grain boundaries, can be seen in the presence of white and grows grain boundaries.

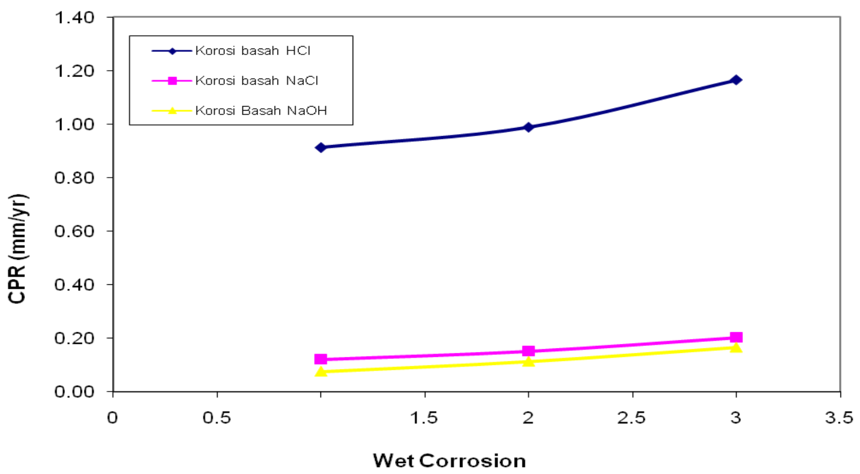

Fig. 4 - Graph of CPR comparison of solution HCl, NaCl and NaOH.

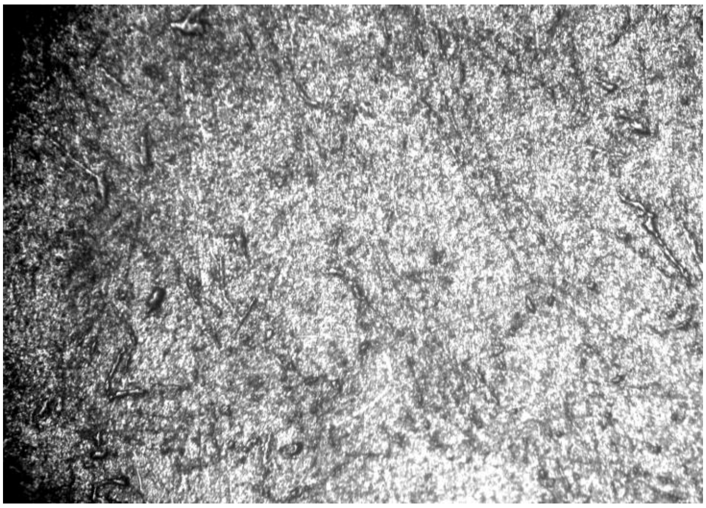

Fig. 5 - MO images AC-43100(AlSi10Mg(b)) before wet corrosion test. (magnification of 100x)

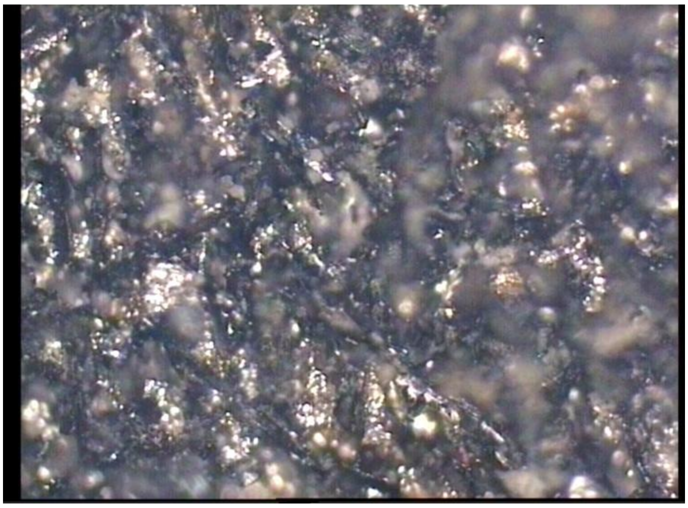

Fig. 6 - MO images composite material AC-43100 AlSi10Mg (b) 85% + 15% SiC*, after corrosion in 0.1 M HCl

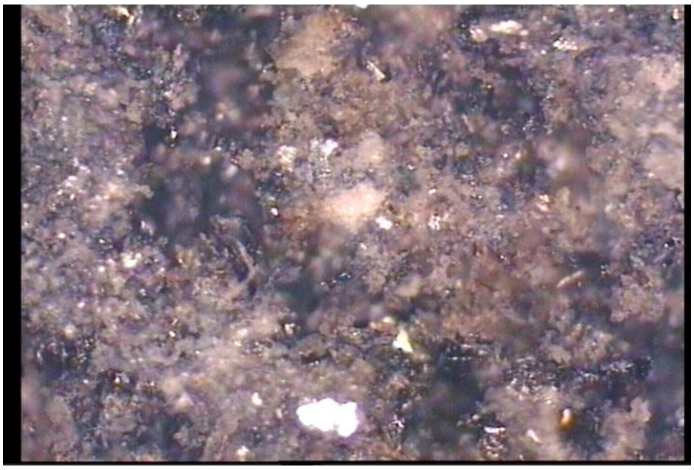

Fig. 7 - MO images composite material AC-43100 (AlSi10Mg (b) 85%+15% SiC*, after corrosion in 0.1 M NaCl

Fig. 8 - MO images composite material AC-43100 (AlSi10Mg (b)85% +15%SiC*, after corrosion in 0.1 M NaCl

3.2 Effect of pH solution in Wet Corrosion Test

The results obtained from pH 1, pH 3, pH 5, pH 7, pH 9, pH 11 and pH 13, show that the highest corrosion penetration rate (CPR) is occurred when the sample is soaked in a solution of pH 1. Because the pH 1 is the solution of a strong acid. Strong acidic water will be fully ionized, so that the concentration of H^+ can be determined. If the acid is dissolved in water, then the acid will release H^+ ions, resulting in $[H^+]$ in the water will rise, while the $[OH^{-]}$ in the water will be reduced. The value of $[H^+]$ and $[OH^-]$, shown in equation (4):

$$[H^+] > 10^{-7}\,\text{mol} \quad [OH^-] < 10^{-7}\,\text{mol} \tag{4}$$

When:-log $[H^+]$ = pH, then

Neutral solution: pH = 7
Acid solution : pH < 7
Base solution : pH > 7

Can be demonstrated by:

——————————— - ———————————
1 7 14
Acid (Neutral) base

The role of pH in corrosive media is to change the cathodic reaction. However, the corrosion rate decrease with the increasing of SiC* reinforcement. Composite material (AC-43100 (AlSi10Mg (b)85% + 15% SiC*), is the smallest value of the corrosion rate when dipped in all solution pH. Figure 9 shows a graph of it dipped in solution of pH 1 to pH 13 concerning dipped time. The microstructures of wet corrosion (dipped in pH 1, pH 7 and pH 13) was observed with MO magnification of 600X shown in Figure 10, 11, and 12. The observed images show that the corrosion in pH 1, seems fairly having sharp attack because of the environmental pH 1 is an acidic environment, which is strong enough to attack the samples. While the environmental pH 7, is not as influential in material, and pH 13, which is alkaline the environment oxygen species, causing a delay in the process of corrosion in the alkaline environment.

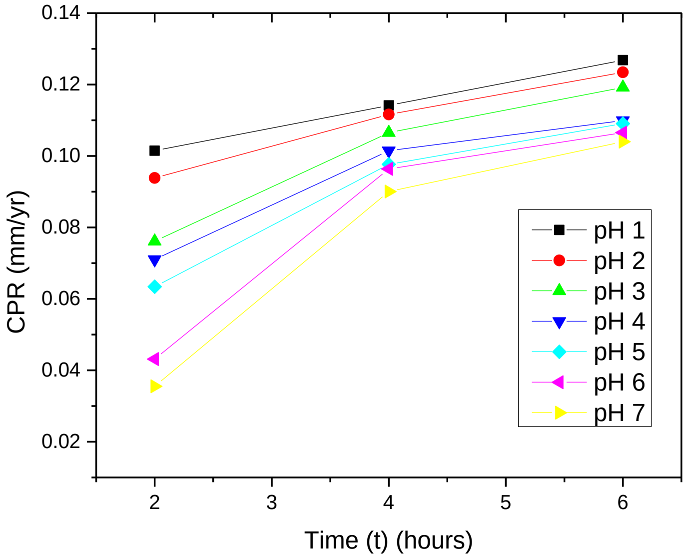

Fig. 9 - CPR sample 4: AC-43100 (AlSi10Mg(b)85%+15% SiC* dipped pH 1 - pH 13 solution vs hours.

The results of CPR obtained for effect of time in wet corrosion test and effect of pH solution in wet corrosion test, when compared to the corrosion resistance of an Al 6092/SiC$_P$ metal matrix composite (MMC) has been evaluated by recording of impedance spectra during immersion in 0.5 N NaCl for at least one week. Significant improvements of the corrosion resistance were only observed for the anodized surface with a dichromate seal [10]. Beside that corrosion behaviour of aluminium-based particulate metal matrix composites (PMMC$_s$) begun with its pitting initiation on the interface of the PMMC$_s$.

Stress corrosion crack, potential dynamic test and immersion test in different salinity like 3.5% NaCl, HCl on aluminium-based PMMC$_s$, this result revealed that corrosion tendency is more in case of SiC, Al_2O_3, B_4C, Fly ash as based PMMC as compared to base alloy, however the opposite trend was reported in the case of TiC and $ZrSiO_{4,}$.The fabrications route like stir cast, powder metallurgical, in situ, squeeze cast also influence the corrosion behaviour [11].

Fig. 10 - MO images composite material AC-43100 AlSi10Mg(b)85%+15%SiC*after corrosion in pH 1

Fig. 11 - MO images composite material AC-43100 AlSi10Mg(b)85% +15%SiC* after corrosion in pH 7

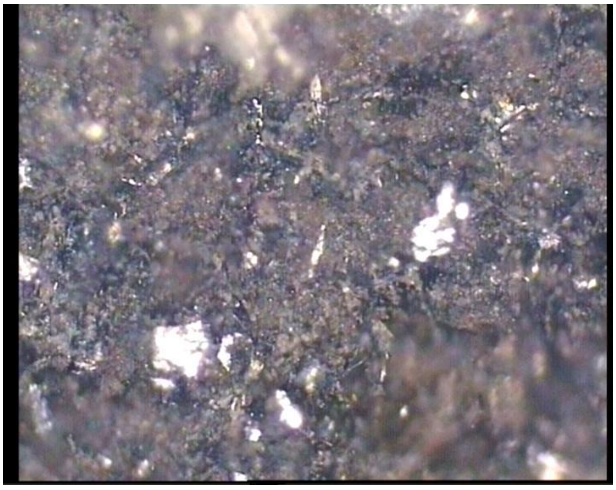

Fig. 12 - MO images composite material AC-43100 AlSi10Mg(b)85%+15%SiC* after corrosion in pH 13

4. Summary

The effect of EN AC-43100 (AlSi10Mg (b)) + SiC* reinforcement with different matrix ratio and in the variation of pH of corrosion measurement have been studied. The highest of CPR occurs when the material is dipped in the solution of HCl. CPR will be reduced when the material is exposed to the SiC* reinforcement. The best matrix combination of aluminium-based composite material achieves at AC-43100 (AlSi10Mg (b)85%+ 15% SiC* with smaller CPR compared to others.

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