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Research paper

Comparative effects of corrosion on electroless-nickel plated A6061 alloys in DOT3 brake fluid

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Abstract

Aluminium alloys used in automobile brake master cylinder pistons wear by corrosion due to contamination and chemical reaction of the contacting brake fluid. The study investigates the corrosion of electroless-nickel (EN) deposition enhanced cast aluminium alloy master cylinder piston surfaces immersed in hydraulic brake oil. Cast specimens were produced from the as-received wrought A6061 alloy scrap by sand casting. EN plated as-received and cast aluminium alloys specimens were immersed fully in brake oil for 1680 hours and corrosion rates were determined every 24 hours. Test samples were characterised using the hardness tester, atomic absorption spectrometer, metallurgical photo-microscope, x-ray diffractometer; and SEM with EDX attachment. Both surfaces corroded in the order of electroless-nickel plated cast aluminium alloy (ENCA) < electroless-nickel plated as-received aluminium alloy (ENAA) at 0.0235 and 0.0251 rates (mg/mm2/y) results which showed improvement in the corrosion resistance with significant influence of electroless-nickel coating in reducing corrosion rates of aluminium alloy in brake oil.

Keywords: *Corrosive Wear; Aluminum Substrate; Hydraulic Brake Fluid; Electro less-Nickel Deposition*

1. Introduction

Aluminium alloys are common in automotive and automobile applications. Many parts, such as the master cylinder and kits are made from this useful material. Diverse reports are available on corrosion of different types of aluminium alloys in various environments and under different conditions [1-2]. For this reason, many materials and methods have been employed to treat the surfaces of different Al alloys against corrosion [3-7]. By the SAE J1703 (DOT 3) and SAE J1704 (DOT 4) standards, inhibitors are added to the base glycol and silicone fluids as formulation additives in brake oils, to protect contacting metals (Al alloys or steel) against corrosion in case of moisture entering the system [8].

Coating technology via plating is one of the versatile techniques employed to control and prevent materials degradation in aggressive environments [9]. Electroless plating is employed in this study and this is because manufacturing industries around the world yearly seek alternatives to cadmium plating, due to the hazardous nature of the latter. One of the most common reasons for the use of EN coatings in functional uses is its excellent corrosion resistance. In the awful corrosive situations faced such as in the drilling and oil wells production, EN has the capability to resist the combined impacts of corrosive chemicals and abrasion [10]. The corrosion resistance test is the most important method in evaluating electroless-nickel (EN) plated samples.

On this basis, the corrosion of Zn-Ni deposits and an appraisal of their prospective as a substitute to cadmium electroplate have been widely investigated using diverse approaches. A study of the corrosion properties of PVD of Zn-Ni coatings was undertaken by Bowden and Matthews [11]. Corrosion behaviours were monitored and compared with cadmium using both electrochemical and more conventional testing methods. The PVD Zn-Ni deposits had the lowest corrosion rate and offered the best barrier protection. However, they were sacrificially inferior to both electrodeposited Zn-Ni and the conventional cadmium. Studies have been performed on EN coatings on Al alloys used in reducing wear [12-17] and corrosion [18-20] of Al alloys and steels in some common aggressive environments. The process is autocatalytic and the most acceptable of all the mechanisms established for the EN deposition given by Agarwala and Agarwala [21]. EN plating is a delicate process that is operated under strict guidelines for the best results, because the quality of the EN deposition is dependent on the working parameters [22-27]. Pari et al., [28] carried out an extensive study on the performance of electroless-nickel plating on aluminium for cylinder liners. The EN plated aluminium alloy was investigated for its wear and strength properties through experimental methods and finite element analysis (FEA). From the result, EN coated aluminium was superior to cast iron and had adequate strength with good tribological properties. It was concluded that electroless-nickel (EN) coated aluminium had a high potential for cylinder liners application. Further, Ali et al, [29] in their work reviewed the application of different materials and coating techniques (including electroless nickel plating) in automotive engines as regarding engine cylinder liner.

The quest to investigate and report research findings on this subject area (automotive engines), the previous reports by the authors have focused on the application, wear and corrosion of Al alloys and EN plating as applicable to automotive engine hydraulic brake system. This study is a continuation of our earlier reports on the assessment of economical and viable production technology, mechanical and tribological properties of cast Al [6]-[7], [30]-[31]. The thrust of the research work is to understand the performance of Al A6061 for automotive and automobile applications. It was established that brake fluid reduced the wear rate, but had corrosive effects on both as-received alloy and cast alloy [7]. The present work compares the effects of corrosive wear on electroless-nickel deposited on both as-received and cast Al alloy immersed in brake oil. Reports are

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available on different coating techniques for aluminium alloy and tests of their corrosion resistance behaviours in diverse aggressive environments and solutions (such as bases, acids, alkalis). There are works on the studies on the corrosion of the wrought and sand cast A6061 alloy in less aggressive organic medium, nonetheless reports have not covered the corrosion of wrought and sand cast A6061 alloy coated with electroless-nickel (EN) in the less aggressive organic media such as DOT3 hydraulic fluid. The importance of this work is to find sustainable enhanced material substitute for the bare Al alloy and steel components immersed in brake fluids of the automobiles. The gravimetric methods were used for assessment and reported while the results of the electrochemical behaviours are expected to be published subsequently.

2. Methodology

2.1. Materials

The as-received wrought A6061 alloy in the form of round bar was use as the starting material for the study. The chemical compositions of aluminium alloy samples (using atomic absorption spectrometer) are shown in Table 1 while the hydraulic brake oil (DOT 3) properties are presented in Table 2.

Table 1: Chemical Composition of 6061 Al Alloy

Samples	Si	Mg	Mn	Cu
As-received	0.38	0.40	0.001	0.01
Cast alloy	0.32	0.29	0.001	0.01
Samples	Fe	Al	Trace	
As-received	0.23	98.87	Balance	
Cast alloy	0.16	98.44	Balance	

Table 2: Chemical Composition of Brake Fluid Medium

Ingredient Name	% wt or % vol
Triethylene Glycol Monobutyl Ethers	5-20
Tetraethylene Glycol Monobutyl Ether	5-20
Polyethylene Glycol	5-20
Diethylene Glycol	5-15
Diethylene Glycol Ethers	<5
Polyalkylene Glycol Ethers	5-20
Polyalkylene Glycols	5-20
Trade Secret Inhibitor Packag	<3
pH	10.0 – 11.5

Source: Manufacturer- Dot Chemicals, Inc. Crosby, Texas [32].

2.2. Production and preparation of sand-cast samples for corrosion tests

The as-received wrought Al alloy was weighed into the melting pot, fired and melted at 750 ± 10 °C using a Taifa model electric furnace under a controlled furnace temperature atmosphere before sand casting. The cast samples were prepared into cylindrical rods with dimension of 100 mm long by 12 mm diameter pistons (Fig. 2 and 3). The surfaces of the aluminium alloy samples were ground and polished with 8 different abrasive paper grits ranging from 50/60 to 1200/2400 µm.

2.3. Deposition of EN on aluminium alloy samples

The EN was deposited on both the as-received Al alloy and cast Al alloy substrates using orthophosphate reduced bath after the surface activation in palladium chloride solution (0.04 g/l). The as-received Al alloy (Fig. 2) was plated using the acid reduced EN plating bath containing sodium hypophosphite (40 g/l), nickel chloride (30 g/l), sodium citrate (25 g/l), ammonium chloride (50 g/l) and PCl_2 (0.02 g/l) [28]. The pH of solution in the bath was regulated to pH 5.0 by adding required quantity of sodium hydroxide (NaOH). The plating was temperature set at 85±5 °C, for an average of 10 minutes.

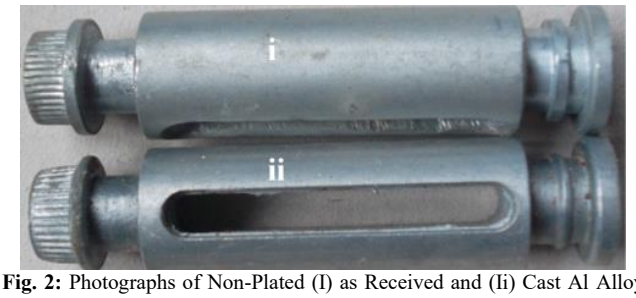


Fig. 2: Photographs of Non-Plated (I) as Received and (Ii) Cast Al Alloy Pistons.

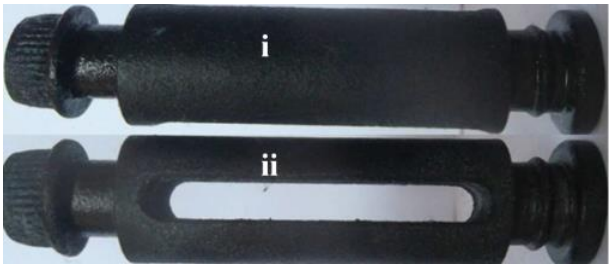


Fig. 3: Photographs of EN-Plated (I) as Received and (Ii) Cast Al Alloy Pistons.

The post EN-plating treatments include rinsing in water, anti-tarnish cleaning in 5 g/l potassium-di-chromate solution and drying in oven. The amount of electroless-nickel deposit on aluminium substrates was determined from the difference between the initial weight (W_i) and the final weight (W_f) before and after immersion into EN plating bath, using an electronic digital weighing machine (model DT-502A, 0.0001 g). The amount of EN deposited per unit area was calculated as the ratio of electroless-nickel film weight deposited to the total surface area of plated sample (Fig. 3).

2.4. Determination of corrosion rates

The chemical properties of hydraulic fluid (brake oil) as supplied by the manufacturer are given in Table 2, while the properties of the EN coatings are presented in Tables 3-4. Since the face of the specimen appeared uniform, the weight loss measurement by full immersion method was employed to assess the corrosion damage and corrosion rates of electroless-nickel plated as-received Al alloy (ENAA) and cast aluminium Al alloy (ENCA) samples in the corrosive brake oil media. The gravimetric technique was adopted in the research. The initial weights (M_1) of the sample were determined immediately after the surface preparation using a very sensitive electric digital weighing machine (DT-502A, 0.0001 g). Samples were fully immersed in plastic vessels containing 25 cm^3 of the test media (brake oil). The electroless-nickel EN plated aluminium alloy samples were regularly examined every day for 70 days. After the expiration of immersion time, the specimens were removed, rinsed in water and dried with cotton wool to remove water and other impurities. The weight loss was determined form the difference between the initial weight (M_1) and final weight (M_2) of the sample before and after immersion in brake oil. The corrosion rate was calculated in mils per year using Equation 1 according to ASTM D 2688–05, G102 [33].

$$\text{Corr} = K\Delta W/\rho At \quad (1)$$

Where K is the corrosion rate constant, ΔW is the weight loss (g), ρ is the density of the material (g/cm^3), A is the total area of exposure (cm^2) and t is the exposure time in hours.

2.5. Microstructural evaluation of the coating

The effect of corrosion on the appearance, colour and roughness of electroless-nickel plated substrates surfaces were examined using high resolution microscopic camera (Samsung ST65/HD5X-14.2 model), while the chemical characterisation of EN film was

assessed by using a JEOL JSM-7600F field emission scanning electron microscope equipped with energy dispersive x-ray (EDX) facilities. The results are presented in the SEM-EDX micrographs and data tables.

3. Results and discussions

The integrity of EN film for wear and corrosion protection applications is solely dependent on many factors such as the metallurgical qualities of the film [34-40]. The film quality is assessed by the chemistry (composition), mechanical strength, film continuity, the tenacity, adhesion, porosity and some other physical parameters such as the topography of the surface roughness. Fig. 4 and 5 show the SEM-EDX electron images of electroless-nickel plating on Al-alloy. The SEM-EDX reveals two distinct portions: black deposits of electroless-nickel-phosphorus rich (Ni-P) plating (Fig. 4) and the white electroless-nickel rich (Ni) deposition areas (Fig. 5).

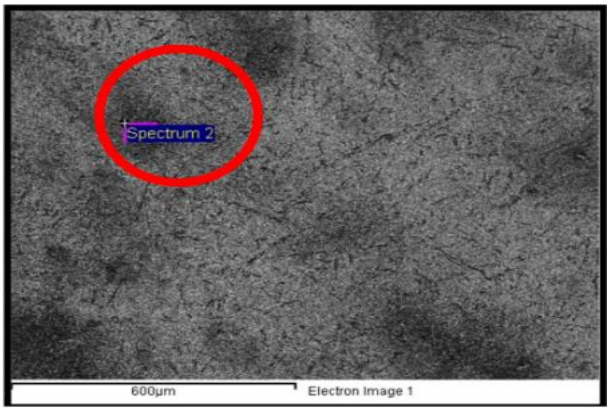


Fig. 4: Showing SEM-EDX Image of Electroless-Nickel-Phosphorus Rich (Ni-P) Plating on Al-Alloy.

Table 3: Composition of Electroless-Nickel-Phosphorus Rich (Ni-P) Plating on Al-Alloy

Element	C	O	Na	Al
Weight %	11.65	23.28	3.28	39.57
Atomic %	21.27	31.92	3.13	32.18
Element	Si	P	Ni	
Weight %	7.66	0.80	17.86	
Atomic %	5.98	0.58	6.67	

A closer SEM-EDX observation (Fig. 4, Table 3) of the black deposition shows the SEM electron image for EN plating contains high amount of % P and % Ni, showing the richness of the film in electroless-nickel-phosphorus (Ni-P).

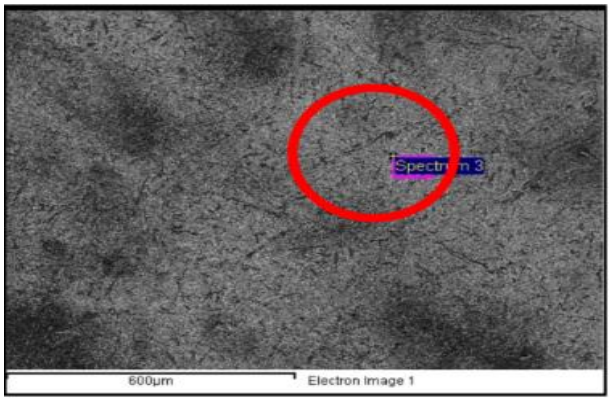


Fig. 5: Showing SEM Image of Electroless-Nickel Rich Film on Al-Alloy.

Table 4: Composition of Electroless-Nickel Rich (Ni) Plating On Al-Alloy

Element	C	O	Na	Al	Si	P	Ni
Weight %	8.16	7.79	1.81	9.63	4.26	1.96	67.51
Atomic %	23.08	16.53	2.68	12.11	5.15	2.15	39.04

Under a similar SEM-EDX observation of the white deposition in Fig. 5, it is shown that the EN plating contains large quantities of % Ni and % P as revealed in the EDX data (Table 4). This shows that the EN film is more of metallic Ni deposition than the Ni-P film as obtained in Fig. 4, even though the % Ni and % P results in the present study are lower as compared with the 91.5%Ni and 8.5%P reported by Panja and Sahoo [38] from the EN plating on mild steel (AISI 1040) at pH = 4.5.

3.1. Integrity of the coating on al alloy substrates

The EN is usually hard and silver coloured coating comprising of nickel alloyed with between 4~14 %P when deposited at a temperature of 85~90 °C [28]. It has the hard chrome like appearance of an electroplated coating. Since the technique is purely a chemical process, the film is distributed uniformly all over the part, including internal crevices, pores and external corners (Fig. 6). In this work, the deposition belongs to the low phosphorous class, which is characteristically hard, good corrosion protection in alkaline environments, with lowest impact on fatigue and the best for high temperature applications [15-18, 21, 38].

The integrity of the EN plating under the brake fluid environment could be traced to some characteristics as identified in the study. These include the high coverage of EN into the tiny pores and corners on the Al alloy substrates. Fig. 6 shows the SEM image of electroless Ni-P deposit inside the hidden holes and micro-pores (Fig. 6a). In some other instance multiple layers of EN film deposited on the Al alloy surface (Fig. 6b). This offers added advantage on the protective ability and the functionality of the deposition even in more hash environment applications.

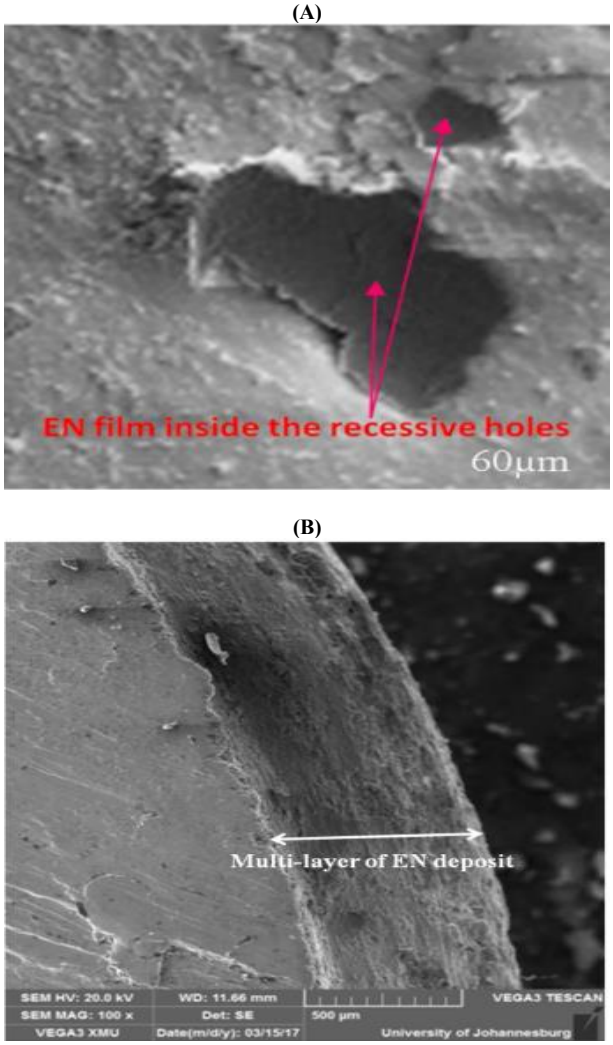


Fig. 6: Micrographs Showing EN Deposit (A) Inside the Recessive Hole and Multiple Layers (B) On Al Alloy.

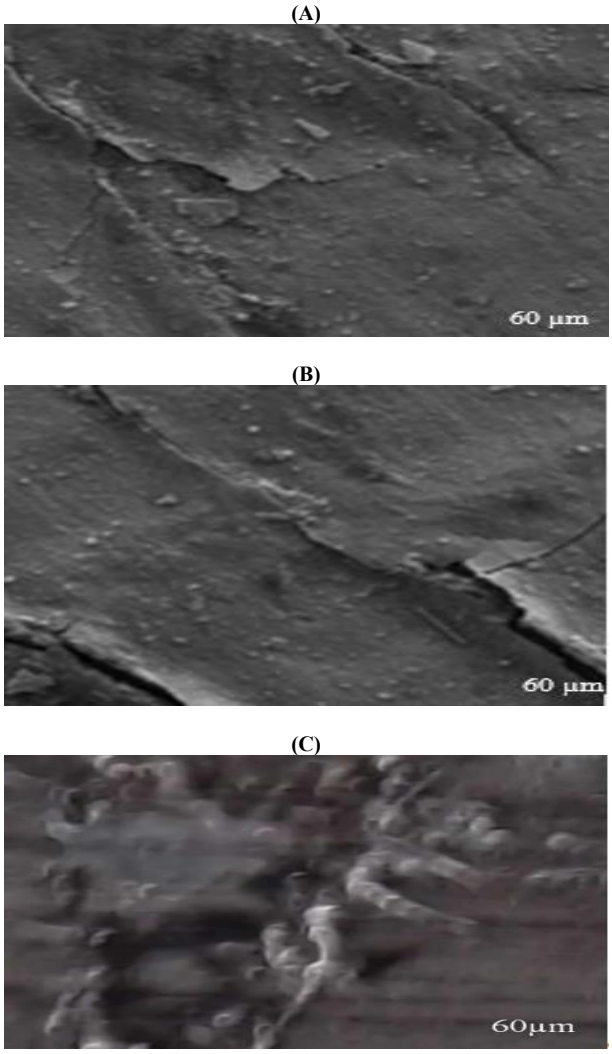


Fig. 7: Micrographs Showing (A) Flakes, (B) Cracks and (C) Peeling of Ni-P Film on Al-Alloy Substrate.

On the other hand, some areas were characterised as weak due to discontinuity of EN (Ni-P rich) film in Fig. 7(a) and peeling of the EN (Ni-P rich) film due to film cracks and poor adhesion of the film to the Al alloy surface (Fig. 7b, c). Unlike metal coating such as cadmium or zinc, protection by EN coating is not a sacrificial type. Electroless Nickel (Ni-P rich) is a barrier coating that prevents a corrosive media from attacking a susceptible substrate. EN serves only as a barrier between the metal substrate and the corrosive environment. Thus, the corrosion protection resistance is wholly dependent on the integrity of the coating; film adhesion and tenacity, film continuity, film being free from cracks and porosity, and with very minute residual compressive stress. The micrographs in Fig. 7 (a-c) show some plating weaknesses in form (a) flakes, (b) cracks and (c) peeling of Ni-P film on Al-alloy substrate. These will promote the penetration of fluid to the substrate-EN interface and thereby allow corrosion especially when the fluid contains fewer amounts of inhibitors as required.

3.2. Corrosion of EN plated al alloys in brake oil

The macrographs in Fig. 8 show corrosion of electroless-nickel (Ni rich) plated as-received Al alloy (ENAA) before (Fig. 8a) and after 70 days (Fig. 8b) of immersion in the fluid. It shows the layer of corrosion product deposited on the electroless-nickel plated as-received Al alloy specimen surface. The white patches represent the areas of active corrosion; the observation of changes in colouration in shows effect of corrosion at the interface of the electroless-nickel layer and the as-received Al alloy substrate in brake oil. The examination of the surface under microscopic camera revealed some tiny pores on the surface. The most affected areas had poor adhesion of the electroless-nickel film to base Al alloy substrate, which allowed the access of the brake fluid to the Al alloy substrate surface and corrosion occurred.

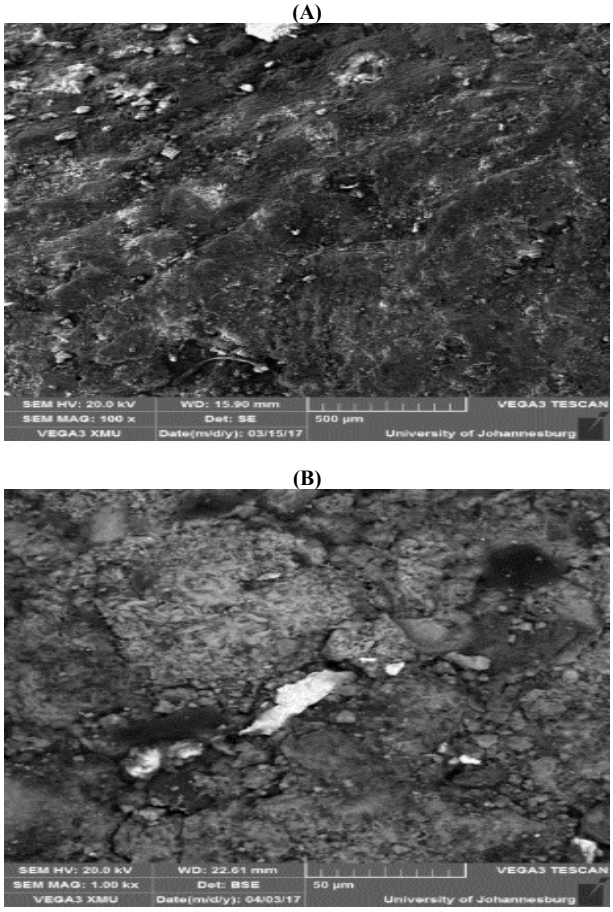


Fig. 8: Macrophotographs of EN Plated as-Received Al Alloy (ENAA) in Oil (A) before And (B) after 70 Days.

Fig. 9 and 10 illustrate SEM images showing the corrosion product and the affected areas on the EN plated on the as-received Al alloy surface.

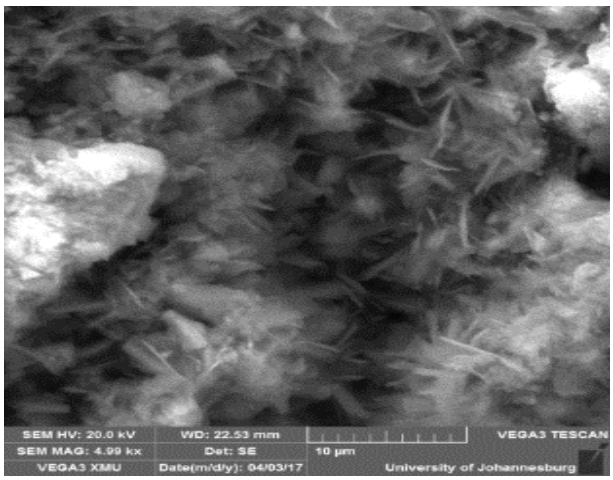


Fig. 9: SEM Image of Corrosion Product on EN Plated as-Received Al-Alloy Surface.

Table 5: Composition of Corrosion Product on EN Plated as-Received Al-Alloy by EDX

Element	C	O	Al	Si	P	Ni
Weight %	29.78	70.22	-	-	-	-
Atomic %	36.10	63.90	-	-	-	-

Fig. 9 is the SEM-EDX electron image for surface of EN-plated Al alloy affected by corrosion. Table 5 shows the composition of the

corrosion product on EN plated as-received Al-alloy substrate. The corrosion product is Ni depleted.

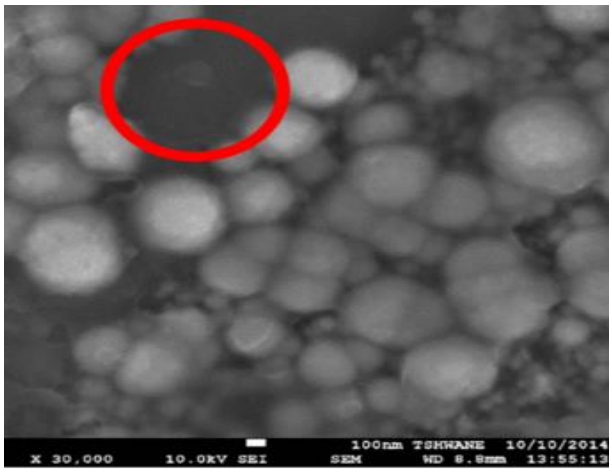


Fig. 10: SEM Image Showing Corrosion Affected Area of EN Plated as-Received Al-Alloy.

Table 6: Composition of Corrosion-Affected Area of EN Plated as-Received Al-Alloy by EDX

Element	C	O	Al	Si
Weight %	3.97	18.06	9.42	2.25
Atomic %	8.36	28.53	13.95	2.02
Element	P	Cl	Ni	Zn
Weight %	0.63	0.27	18.28	0.79
Atomic %	0.51	0.19	7.87	0.30

Fig. 10 shows SEM electron image of corrosion affected EN plating on zincate activated as-received Al-alloy surface. The study of SEM image matched with the EDX chemical characterisation (Table 6) revealed that the selected black portion consists of P and Ni. It also contains traces of Cl and Zn resulting from the $PdCl_2$ and zincate solutions as revealed in the EDX data.

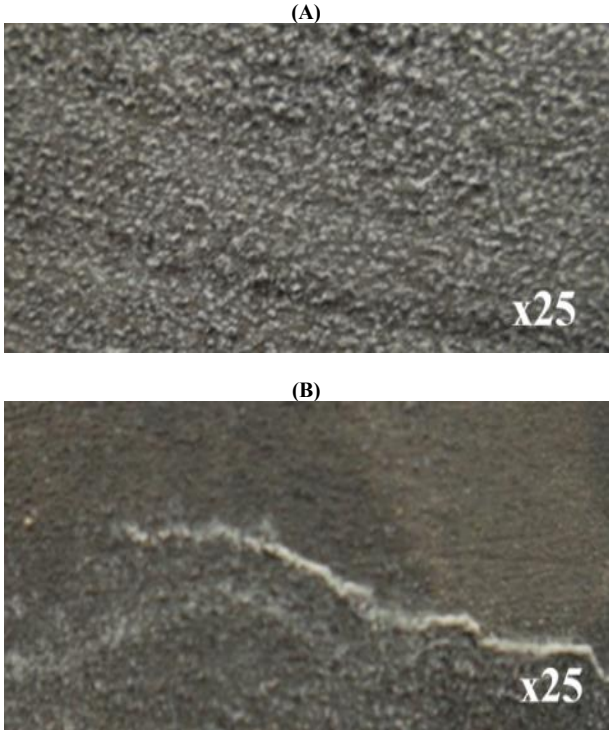


Fig. 11: Macrophotographs of Corrosion of EN Plated Cast Al Alloy in Oil (A) before and (B) after 70 Days Immersion in Brake Oil.

Fig. 11 (a) shows the surface of the ENCA before immersion in the brake oil and (b) shows the effect of brake oil on the electroless-nickel coat. The whitish portions show the little electroless-nickel corrosion affected areas compared to the surfaces of ENAA in oil. The image in Fig. 11(b) was obtained after 70 days with layer of corrosion product deposited on the ENCA surface. The white patches represent the areas of active corrosion; the colouration in (b) shows the affected areas are at the interface of the EN film and cast Al alloy substrate.

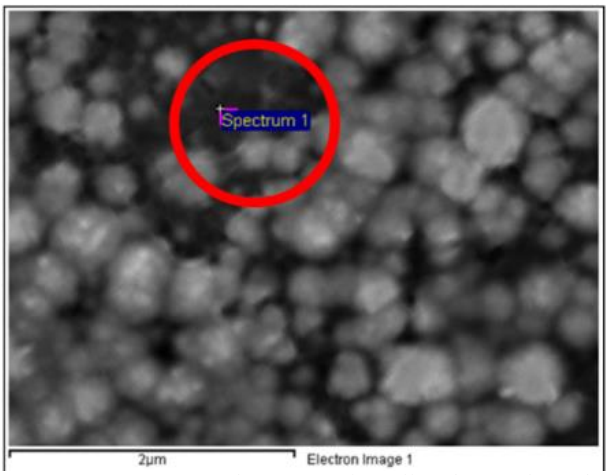


Fig. 12: SEM-EDX Image of Less Corrosion Affected Area of EN Plated Cast Al-Alloy Surface.

Table 7: Composition of Less Corrosion Affected Area of EN Plated Cast Al-Alloy by EDX

Element	C	O	Al	Si
Weight %	3.58.	6.52	9.42	3.04
Atomic %	11.92	16.30	13.95	4.32
Element	P	Cl	Ni	Pd
Weight %	1.76	0.32	73.35	1.43
Atomic %	2.27	0.36	50.35	0.54

The SEM image in Fig. 12 shows the effect of corrosion of EN plated Al-alloy substrate. The EDX chemical characterisation (Table 7) revealed that the black portion consists of combination of Pd and $PdCl_2$ (used as surfactant). Under the SEM observation of the black portions of the EN plating contains Al, Si, P, and Ni with traces of Cl and Pd being deposited from the $PdCl_2$ solutions, as revealed in SEX-EDX chemical characterisation data which shows that the deposition is very rich in Ni and Ni-P combined.

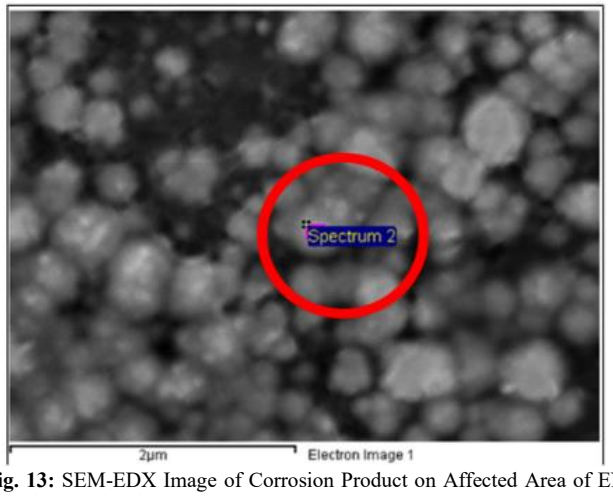


Fig. 13: SEM-EDX Image of Corrosion Product on Affected Area of EN Plated Cast Al-Alloy Surface.

T Able 8: Composition of Corrosion Product on Affected Area of EN Plated Cast Al-Alloy

Elements	C	O	Al	Si	P	Ni
Weight %	40.80	59.20	-	-	-	-
Atomic %	47.86	52.14	-	-	-	-

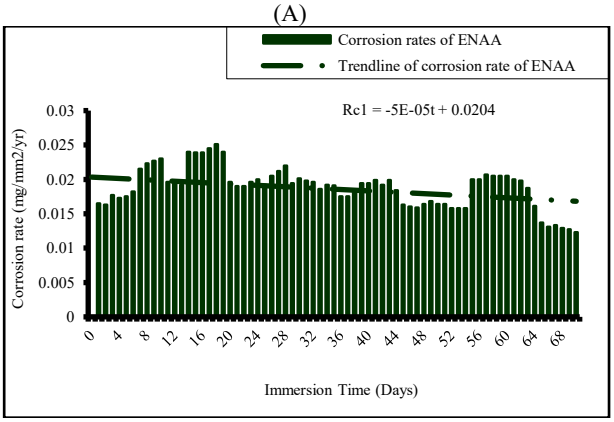
The study of the SEM imagery (Fig. 13) and chemical composition (Table 8) revealed that the white portion contains mainly of C and O. The EDX targeted portion is depleted of the metallic element

such as Ni and Ni-P compared with what is obtained in the white portions. The SEM-EDX data shows that at the target area is deficient of Zn, and that there was possibility of poor adhesion which might have increased the oxidation. Within this target area, high contents (%) of Al and O might signify the presence of Al_2O_3 which significantly hindered the deposition of Zn during zincating.

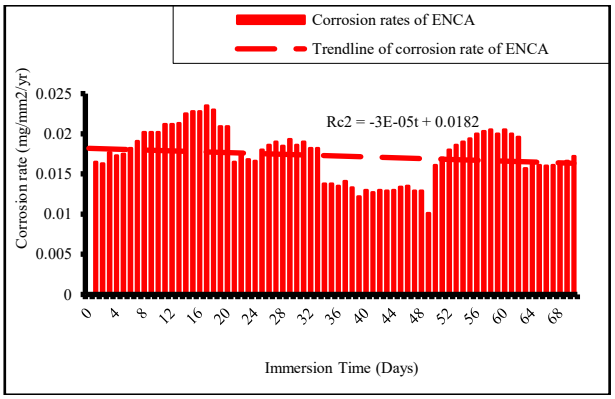
3.3. Corrosion rates of EN plated Al alloy substrates

The trends of corrosion rates (mg/mm^2/y) of electroless-nickel plated as-received Al alloy (ENAA) and electroless-nickel plated cast Al alloy substrates (ENCA) in brake oil are illustrated in Fig. 14 (a-c) respectively. Both ENAA and ENCA demonstrated very close ranges of corrosion rates though ENCA tends to corrode at lower rate than ENAA in brake oil. The very close values portrayed the corrosion behaviour of the electroless-nickel film rather than the as-received Al alloy substrate and/or cast Al alloy substrate in oil.
In both cases, the trends of corrosion were characterized by increasing corrosion rates, film passivation or constant corrosion rates, film break, and low corrosion rates in oil. This is of a similar mechanism that holds for the passivation of zinc as suggested by Devanathan and Lakshmanan [39]. In the present study, the features of metal (Ni coating) passivation can be caused by adsorption of corrosion inhibitors (present in brake fluid) to form the strong adsorption bonds with metal surface. Accordingly, thus hindering its oxidation and passing of metal cation into the solution especially when immersed in organic mixture containing corrosion inhibitors like ethers and heterocyclic compounds as hinted by Kuznetsov et al, [40].
From the ENAA corrosion rate curve, the film-break occurred twice between 13-14th and 54-55th day and only once in the ENCA corrosion rate curve at 49th-51st day of immersion in oil.
ENCA corrodes at lower rate and demonstrated increase in corrosion rates at 1-11 days. It was of slightly higher corrosion rate increase within the 11-20th day). The corrosion rate pattern of ENCA became very significant after 21 days. The corrosion rate of ENCA reduces as compared with an earlier report on the bare as-cast Al alloy immersed in same fluid medium in the previous works [6-7].
In the present case, EN film serves as barrier to the corrosive fluid in reaching the as-cast Al alloy-EN interface, thus there is reduction in the ENCA corrosion rate during the immersion period.
Based on the results of the corrosion rate curves in Fig. 14, it will be justified to choose ENCA in preference to ENAA for solving the corrosion problem.

(A)



(B)



(C)

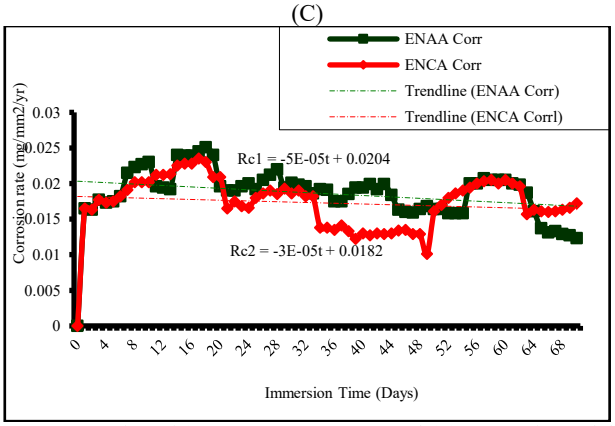


Fig. 14: Corrosion of (A) ENAA, (B) ENCA and (C) Comparison of the Corrosion Rates of ENAA and ENCA in Brake Oil.

The corrosion rate versus immersion time curves are plotted using Ms Excel software and the model equations of the trends of the curves are generated and represented as linear/straight line curves. The trend of the corrosion rates of ENAA and ENCA in brake oil obtained from the curve are presented as mathematical equations as follows:

$$R_{C1} = -5E-05t + 0.0204 \quad (2)$$

$$R_{C2} = -3E-05t + 0.0182 \quad (3)$$

Where $0 \leq t \leq 70$, t = immersion time (days) R_{c1} and R_{c2} are the corrosion rates (mg/mm^2/yr) of the ENAA and ENCA respectively with respect to immersion time in brake oil.
The electroless-nickel plated cast Al alloy specimen has lower corrosion rate than that of the electroless-nickel plated as-received Al alloy sample in the present study; as well as a bare cast Aluminum and non-plated wrought Al alloy exposed to DOT3 brake fluid environment previously reported in the literatures [1-2], [6-7], [13], [41].

4. Conclusion

The application of electroless nickel deposition in reducing the extent of corrosion of cast aluminium alloy for the replacement frequently worn out Al alloy piston used in brake master cylinder have been studied. The following conclusions are drawn from the results obtained. Quality electroless-nickel plating was deposited on the as-received and cast Al alloys.
A functional EN coating corrosion protection is mainly dependent on factors such as the film quality as assessed by the chemistry (composition), film continuity, the tenacity, adhesion, porosity as revealed in the SEM-EDX results. The SEM-EDX reveals the deposits of composite EN coatings in the form of black EN-phosphorus rich (Ni-P) plating and the white EN-nickel rich (Ni) deposition. The integrity of the EN plating in brake fluid environment is dependent on the high coverage of EN into the tiny

pores and corners on the Al alloy substrates as seen in the SEM-EDX images and data. This is reinforced by the multiple layers of EN film deposited on the Al alloy surface adding advantage to the protective ability and functionality of the deposition.
Conversely, some areas were marked as weak due to discontinuity, peeling of the EN (Ni-P rich) film, film cracks and poor adhesion of the EN (Ni-P rich) film to the Al alloy surface. The combination of the SEM-EDX images and chemical composition data revealed that the corrosion products contain mainly of complexes of C and O being depleted of the metallic element such as Ni and Ni-P compared with what is obtained in the substrate.
For the corrosion tests carried out on the two materials, the trend of corrosion rate was obtained as follows; electroless-nickel plated cast Al alloy (ENCA) corrodes at 0.0235 mg/mm^2/yr rates after 17th day; and the highest corrosion rate of electroless-nickel plated as-received Al alloy (ENAA) was obtained as 0.0251 mg/mm^2/yr after 18 days of immersion in oil. This shows a reduced order of corrosion rate as electroless-nickel plated cast Al alloy is lower than that of the electroless-nickel plated as-received Al alloy in DOT3 brake fluid.
Consequently, the deposition of thin film of electroless nickel will go a long way in reducing the corrosion on the intricate surface of the aluminium alloy. This will prop up the service life of the Al alloys used for piston in master cylinder.

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Conflict of Interests

The authors declare that there is no conflict of interests as regarding the publication of this paper.

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