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RESEARCH

Evaluation of Electroless-Nickel Plated Polypropylene under Thermal Cycling and Mechanical Tests

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A B S T R A C T

The electroless-nickel composite (ENC) consisting of bright metallic electroless-nickel (EN) and dull electroless-nickel-phosphorus (EN-P) were deposited on the polypropylene (PP) substrate from the sodium hypophosphite baths. The ENC plated specimens were subjected to abrasive wear-adhesion test of 1750, 3500, 7000 and 14000 cycles; thermal cycle-adhesion tests, and tensile strength and creep tests. The deposition of ENC influenced the strength and creep strain properties of the PP. The maximum stress σ of 118 (MPa) was obtained from EN-PP specimen at strain ε of 0.1 mm/mm as compared with the PP having stress σ of 36 (MPa) at strain ε of 0.07 mm/mm before failure The surface appearances and microstructures of ENC film on PP substrates were examined under the higher resolution metallurgical microscope with digital camera and microscopic camera. The composition of ENC film was characterized using Scanning Electron Microscopy and Energy Dispersive X-Ray analyses (Jeol JSM-7600F Field Emission) SEM/EDX, The micrographs and spectra lines data generated were used to interpret the results.

1. INTRODUCTION

The word plastic refers to a category of materials such as nylon, polyethylene and poly-tetra-fluoro-ethylene (PTFE) which is a division of the larger group of polymers. When correctly devised and applied, plastic offers light-weight, strong, economic, wear and corrosion resistant products [1]. Just like steel and aluminium [2], plastics have been vastly used for many engineering applications. Plastics are used in coating surfaces of metal alloys against corrosion and friction, and the vice versa. Due to technological advancement in chemical processing techniques, plating on plastics are used in automotive, plumbing, appliance and electronics industries [3,4]. Nonetheless, the plastic materials suffer creeping at high temperature, hence the need to coat the surface with metal.

Ni and Electroless nickel (EN) are known for their extensive wear and corrosion resistant characteristics.

The deposition of several binary, ternary and other poly-alloys coatings for tribological based applications have been studied and reported in the literature. Among these are the Prabhu *et al.,* [5] reports on the development of compositionally modulated multilayer Zn–Ni deposits as replacement for cadmium. Agarwala and Agarwala [6] worked on the electroless alloy/composite coatings. Delaunois *et al.,* [7] reported the studies on autocatalytic electroless nickel–boron plating on light alloys. Anik *et al.,* [8] investigated the effect of coating bath composition on the properties of electroless nickel–boron films. The production and tribological properties of anti-wear Ni–P–Al_2O_3 composite coatings were investigated by Ozimina *et al.,* [9]. Palaniappa and Seshadri [10] studied the friction and wear behaviours of electroless Ni–P and Ni–W–P alloy coatings. Ramalho and Miranda [11] also studied the Friction and wear of electroless NiP and NiP + PTFE coatings. A further study on the friction and wear behaviour of Ni–P coated Si_3N_4 reinforced Al 6061 composites were reported by Ramesh *et al.,* [12].

Further, the corrosion of PVD Zn-Ni coatings was studied by Bowden and Matthews [13]. The need for aluminium alloy plating with a more wear and corrosion resistant electroless Ni/Ni-P for use in brake oil environments has been investigated and reported by Adewuyi *et al.,* [14] and Ajibola *et al.,* [15-18]. Polymers and Elastomers are designed to be protected against the factors that may initiate and accelerate corrosion in plastics. Polypropylene was among the early polymeric materials electroplated on large scale, but with problems including its failure to pass thermal cycling due to: its high coefficient of linear thermal expansion, brittleness after plating and sinking marks caused by the plastic shrinking in the mould. Creep failure of polypropylene material has been reported in literature [19].

In architectural and building designs, a vast number of pure polymer and polymer composite materials are used as electronics packaging and structural components. Many of them are exposed to ultraviolet and solar radiations and weathers (hot and cold) that change intermittently. It is therefore, essential to have pre-consideration for creep behaviour in safeguarding the polymer component against likely failure in future.

Nickel coating is used for engineering, decorative, and electro-forming applications. Nickel plating for engineering purposes uses solutions that deposit pure nickel [20]. Nickel plating baths usually consists of the major baths such as cleaners, pre-dips, etchants neutralizer, pre-activator, activators or catalysts, and eventually the plating bath [6-9, 21]. Also, the microscopic holes left on the surface of the plastic by the etchant provide the bonding sites for the deposited Nickel [3].

Equation (1) represents the reduction reaction that occurs as the plastic is attacked by chrome-based etchants.

$$Cr^{+6} + 3^{e-} = Cr^{+} \quad (1)$$

A pre-activator may be employed for certain resins, after neutralization and water rinsing, Activators or catalysts in most cases contain some noble metal (palladium, platinum or gold) which primary purpose is to provide catalytic sites on the plastic surface. The Pd sites formed the catalytic surface required to deposit the electroless nickel.

The most broadly accepted reaction mechanism and the sequence were established by Agarwala and Agarwala [6] namely; Equations (2) to (5):

$$(H_2PO_2) + H_2O + \frac{catalyst}{heat} = H^+ + (HPO_3)^{-2} + 2H_{abs} \quad (2)$$

$$Ni_2 + 2H_{abs} = Ni + 2H^+ \quad (3)$$

$$(H_2PO_2) + H_{abs} = H_2O_{(l)} = OH^- + P_{(s)} \quad (4)$$

$$(H_2PO_2) + H_2O_{(l)} = H^+ + (HPO_3)^{-2} + H_{2\,(g)} \quad (5)$$

In the company of enough heat energy and a catalyst (catalysed surface), hypophosphite ions are oxidized to orthophosphite.

Oloruntoba [20], Ajibola and Oloruntoba [22], and Ajibola et al., [23] have deposited Ni and Cu on steels by electroplating. In some other reports, Ajibola et al., had deposited Ni and Ni-P on cast Al alloys and steels [24-26]. Both authors had emphasised the compositions [27-30] and states of the surfaces [31-32] of the substrates as significant factors that control the morphology of Ni deposit and their resistance to wear and corrosion.

Of recent, reports are obtained on the use of different plastics as coatings or reinforcement of metal substrates and the vice versa. Aleksandrova [33] studied the influence of

operating temperature on the electrophysical characteristics of polymer based electro-luminescent structures, for which intention a thin film of light-emitting semiconductor polyphenylenevinylene derivative is deposited between two indium-tin oxide (ITO) electrodes. The viscosity and adhesion characteristics of NBR/SMR L blend based pressure-sensitive adhesive were studied by Poh et al., [34] using toluene, coumarone-indene resin, and polyethylene terephthalate as tackifier, solvent, and coating substrate. In all instances, the coated specimen always demonstrates the highest adhesion values which is connected with the higher volume of adhesive in the system.

The peel strength, loop tack, and shear strength of cross-linked epoxyl-natural rubber (ENR 25)/ethylene-propylene-diene rubber (EPDR) blend adhesives were investigated by Poh and Teh [35] using coumarone-indene resin, toluene, and benzoyl peroxide as the tackifier, solvent, and cross-linking agent, respectively. Results show that the adhesion properties increase with increasing coating thickness and testing rate. Jain et al., [36] examined the effect of optimum concentration of zinc dust and mica containing iron oxide (MIO) as pigments for these surface tolerant coating systems. The result shows that using the two additives enhanced the corrosion resistance several times more as compared to commercially available coating systems.

In the present study, electroless nickel EN film was deposited on the polypropylene (PP) substrate. The mechanical strength, abrasive wear and thermal properties of the coated plastics were studied. The film properties were further characterised by SEM analysis.

2. MATERIALS AND METHODS

2.1 EN plating on polypropylene (PP) Substrates

A sample of 600 mm long x 600 mm wide x 3 mm thick polypropylene (PP) board was procured from the plastics retail store in Ado-Ekiti, Nigeria. The pre-treatment and cleaning chemical [16] and the EN plating chemicals (Table 1) were procured from the chemical stores. The plating line used for the experiment has been described by Ajibola et al., [16] while some additional Activation components were incorporated from the design after Kuzmik, [3].

2.2 Procedures

Two sets of Polypropylene (PP) specimens were cut to 45 mm x 30 mm x 3 mm size (for the wear and thermal cycling tests) and 45 mm x 5 mm x 3 mm size (for the strength and creep tests) respectively (Figs. 1a & 1b). The sample was thoroughly cleaned in series of standard acid, alkaline and salts solutions as recommended for plastic materials. After the cleaning, the surface was etched and neutralised with acid and alkaline before it is Pd strike in $PdCl_2$ solution at 70 ^oC prior to immersing into the EN plating bath for 5 mins. The procedure used to plate EN on plastics includes the steps in Fig. 2.

Table 1. Electroless nickel plating chemicals.

Bath	Media	Conc (g/l)	Temp (^oC)	Time (min)
EN Plating	Nickel Chloride Sodium Hypophosphite Sodium citrate Ammonium chloride $PdCl_2$	30 40 25 50 0.02	80	5
pH regulators	NaOH or NH_4OH	Add to level		

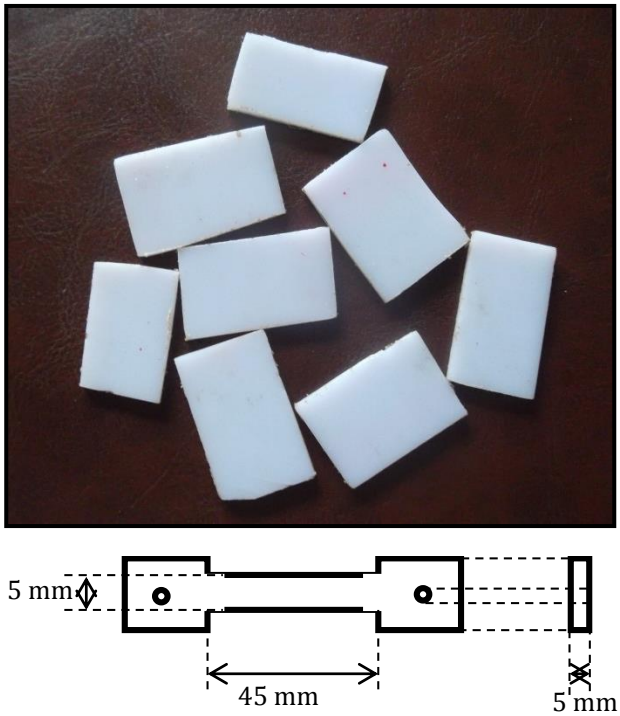


Fig. 1. Polypropylene specimens used for the experiment.

Pre-treatment (Emulsifying)
Rinsing
Etching
Rinsing
Neutralizing
Rinsing
Pre-activation
Rinsing
Activation
Rinsing
Acceleration
Rinsing
Activation
Rinsing
Electroless-nickel plating

Fig. 2. The procedure used to plate EN on plastics.

Two EN solutions were prepared separately the acidic range (pH = 5.0) and the alkaline range (pH = 11.5). The effects of variation of time, pH and temperature were examined on the quantity and qualities (morphologies like appearance, adhesion) of EN deposition on polypropylene (PP) substrates. The EN plated sample was removed from the EN tank; rinsed in water and immersed in the anti-tarnish chemical at 50 to 65 °C. The EN plated sample is dried in the oven and kept in the desiccators before the final weight W_f is determined using a digital weighing machine. The amount (ΔW) of EN deposit on polypropylene (PP) plastic substrate is determined using electronic digital weighing machine (model DT-502A, 0.0001 g). It is the difference between the initial weight, W_i (before immersion) and the final weight, W_f (after plating). The difference is mathematically expressed as in (6):

$$\Delta W = W_f - W_i \quad (6)$$

The amount of EN deposited per unit area plastic substrate was calculated from the amount deposited: as the ratio of the EN film weight deposited to the total surface area of the plated polypropylene (PP) plastic sample. The EN film thickness was measured to 0.001 mm using a light digital external micrometer screw gauge (MIT 325-Series 293). The amount of electroless nickel deposit per area and average thickness obtained are presented in Table 2.

2.3 Thermal cycle-adhesion tests

EN plated PP samples were subjected to thermal cycles tests. The PP specimen is initially placed inside an air-circulating oven (fan) at 80 °C for 60 mins [3]. The specimen is then taken out and held at room temperature (27 ±2 °C) for 15 min. After, the specimen is positioned under cryogenic condition (in a cold chamber of a refrigerator) at -25 to -10 °C range for 60 mins [3]. This process is repeated for 9, 12, 15 and 18 cycles. In each case, the surface of the plated plastic was subjected to soft abrasive grinding from which the cumulative weight loss was measured. The results of the thermal cycle - adhesion test and the EDX data are presented in Tables 3 and 4.

2.4 Abrasive wear-adhesion test

EN plated samples were subjected to abrasive wear/adhesion test using an orbital palm sander (Hitachi SV12SG) with P150 and P600 (μm) grits of emery paper attachments. The wear test was conducted under 1.1 kg mechanical loading of wear cycle of 14,000 orb/min for 7.5, 15, 30, and 60 sec (1750, 3500, 7000 and 14000 cycles respectively). The wear loss was determined from the weight differences measured before and after wear tests. The results are reported in Tables 5 and 6.

2.5 Strength test

Samples were subjected to tensile strength test using a mini tensometer. The tensile test was conducted under 5 kg mechanical loading. The elongation in the length of specimen was used calculate the strain. The stress (σ) was obtained from the ratio of the applied load (P) and the cross sectional area (A) of the specimen using equation (7) as presented in the Fig. 12.

$$\sigma = \frac{P}{A} \quad (7)$$

where σ =Stress, P = Load, A = cross sectional area.

2.6 Creep test

The polypropylene (PP) and EN-plated polypropylene (ENPP) composite specimens were used for creep test experiments. The test specimens were cut and shaped to gauge-length of 45 mm and 3 mm thickness standard size. The test specimens were mounted on the testing machine while predetermined mechanical load was applied and controlled at the varying temperatures and regular time intervals. The effect of the loading on the specimen was taken as function of the extension in gauge length of

the test specimens. The equation (8) was used to calculate the specific strain at the regular time intervals as presented in the Fig. 13.

$$\varepsilon = \frac{(L_f - L_i)}{L_i} \quad (8)$$

where ε = Strain, L_f = final length, L_i = initial length.

2.7 Characterisation and Micro-structural study of EN plated PP samples

The surface appearances of EN plated polypropylene (PP) samples were examined the under high-resolution microscopic camera (Samsung ST65/HD5X-14.2 model). The electroless nickel plated PP samples were characterised by Scanning Electron Microscopy and Energy Dispersive X-Ray analyses (Jeol JSM-7600F Field Emission SEM/EDX). The micrographs, SEM images and EDX spectra data generated were used to interpret the results.

3. RESULTS AND DISCUSSION

3.1 The EN film morphologies

In the present study, EN film was satisfactorily deposited on the PP substrate at pH range of 5.0 to 5.5 (acid bath) and at pH range of 10.0 to 11.5 (alkaline bath); whereas the effects of the PP activation in Palladium-based etchants was predominantly dependent on the cycles of surface pre-cleaning treatment performed prior to EN plating using sodium hypophosphite reduced bath as described in Table 1 and Fig. 2. The reduction reaction that occurs as the plastic is attacked by Pd based solution can be represented as in the Equation 9.

$$Pd^{+2} + 2^{e-} = Pd^{+} \quad (9)$$

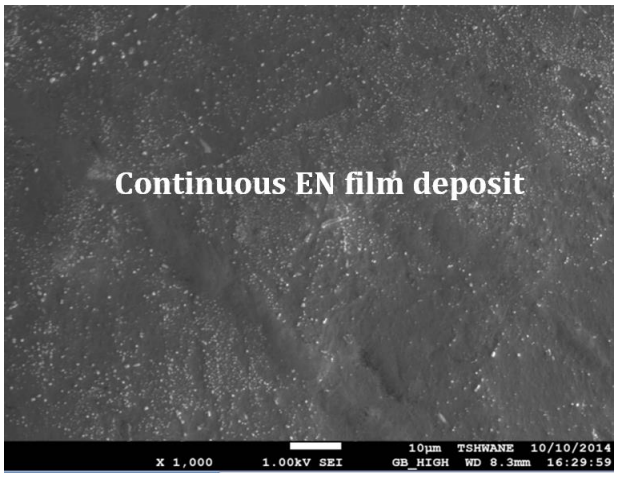
The reaction is further accelerated by Pd in the two step activation and in the EN plating bath (Table 1). The EN deposition per area and average thickness of the EN film obtained from the acid and alkaline baths are shown in Table 2. The acid bath produced a denser EN film (0.02725 g/mm) than that of the alkaline bath (0.02654 g/mm).

Table 2. Electroless nickel deposition per area and average thickness.

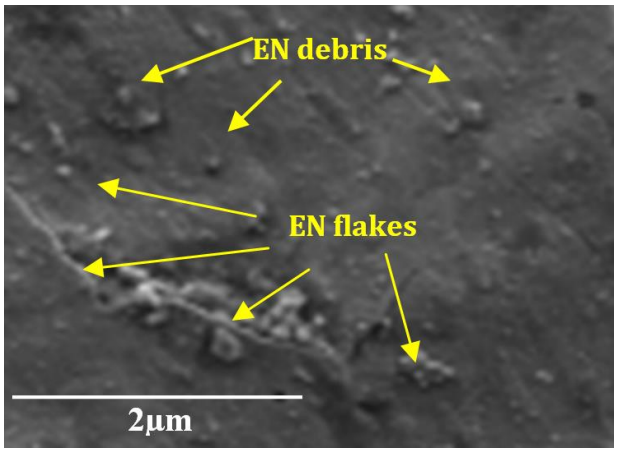
Baths	pH	Temp (°C)	Time (min)	Film Wt (gmm^{-2})	Ave. thick. (mm)
Acid	5.0	80	5	0.000327	0.012
Alkaline	11.5	80	5	0.000345	0.013

The physical properties such as the continuity, roughness, brightness, porosity, reflectance and lustre of the various EN depositions obtained are reported as photo macrographs and SEM images and EDX spectra data.

The enlargement of 10 µm size SEM image in Fig. 3a shows the continuity electroless Ni film. The Ni film demonstrated high magnetic attraction to the stainless steel plating vessel. Figure 3b shows the amplified 2 µm size SEM electron image of EN flakes on $PdCl_2$ activated polypropylene (PP) plastic substrate, for the purpose of clarity and emphasis.



a)



b)

Fig. 3. SEM image showing (a) the continuity electroless EN film and (b) EN flakes on $PdCl_2$ activated PP substrate (x1000)

The photo-macrograph showing adhesion at the interface of bright metallic EN deposition on $PdCl_2$ activated polypropylene (PP) plastic is illustrated in Fig. 4. The Figure shows the presence of some micro pores on $PdCl_2$ activated bright metallic EN deposition on polypropylene

(PP) plastic substrate. The bases for occurrence of these micro-pores have been explained [3].

Fig. 4. Photomacrograph showing adhesion at interface of bright metallic electroless Ni deposition on $PdCl_2$ activated PP plastic (x50).

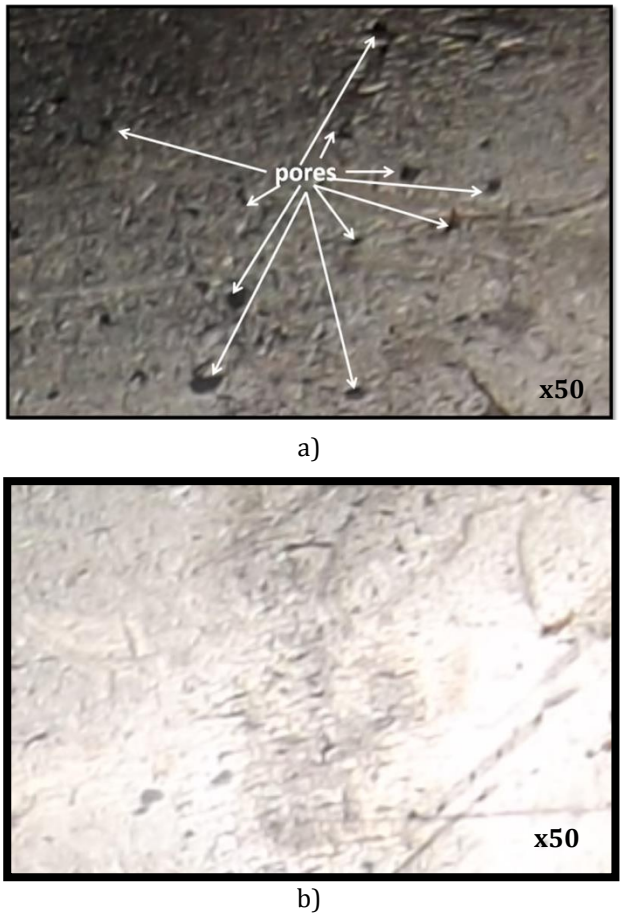


Fig. 5. Showing (a) dull, rough and porous metallic electroless Ni-P deposition with pores and (b) bright metallic EN deposition with high reflection on $PdCl_2$ activated PP substrates (x50).

Figure 5a displays low density, dull, rough and porous metallic EN deposition with micro pores while in Fig. 5b, the macrograph shows bright metallic EN deposition with high reflection. Table 3 presents the results of the effect of thermal cycling on the EN film on the polypropylene (PP) surface and the images of the outlooks are shown in Figs. 6-9.

Table 3. Results of thermal cycle -adhesion test.

Thermal cycle	Cum. Wt loss (g)	Wt loss/cycle (g/cycle)	Observation	Result/ Remark
9	0.0013	0.000144	Film is tenacious	Good adhesion
12	0.0017	0.000142	Blisters formed, peeling begins	Loss of adhesion
15	0.0023	0.000153	Blisters formed, cracking observed	Failure begins
18	0.0029	0.000161	Cracks expand	Film failure

Figure 6 shows the contours and roughness on 100 μm size SEM photomicrograph for the electroless Ni-P deposit. It shows the cracks and outlook of electroless Ni-P deposit on $PdCl_2$ activated polypropylene (PP) plastic substrate surface.

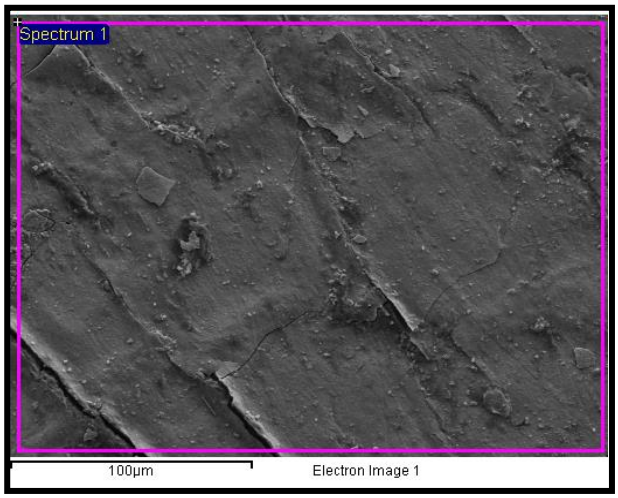
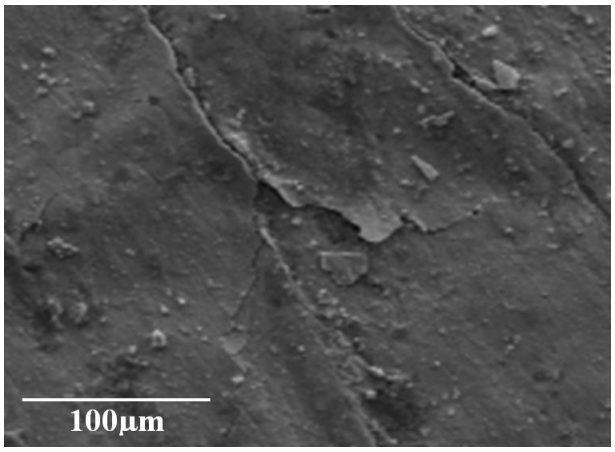
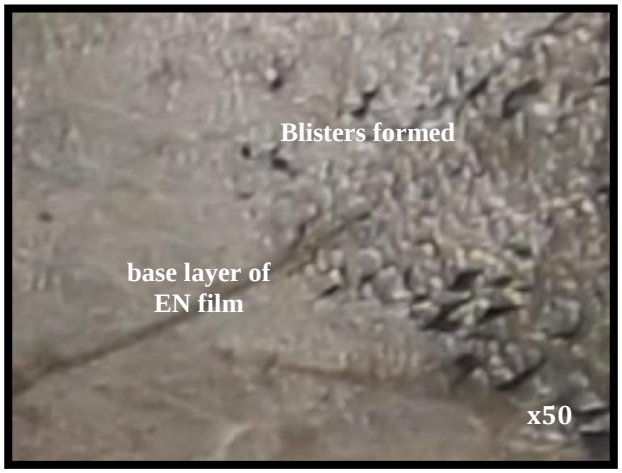


Fig. 6. SEM image showing the topography of electroless Ni-P film morphology (cracks and roughness) on PP surface (x1000).

The additional examination of on $PdCl_2$ activated polypropylene (PP) plastic substrate surface morphology in Fig. 7a shows that the SEM image revealed discontinuity electroless Ni-P film on the substrate. It is the magnification of 100 μm size SEM image, showing the chips of electroless Ni-P film. The flakes were formed as a result of poor Ni adhesion in some site [3].



a) (x1000)



b) (x50)

Fig. 7. Images showing (a) film discontinuous flaky electroless Ni-P film and (b) the multiple EN layers (base layer of EN film and Blisters formed) on PP plastic substrate after 15 thermal cycles.

Table 4. Composition of base layer of electroless Ni-P deposit on PP surface.

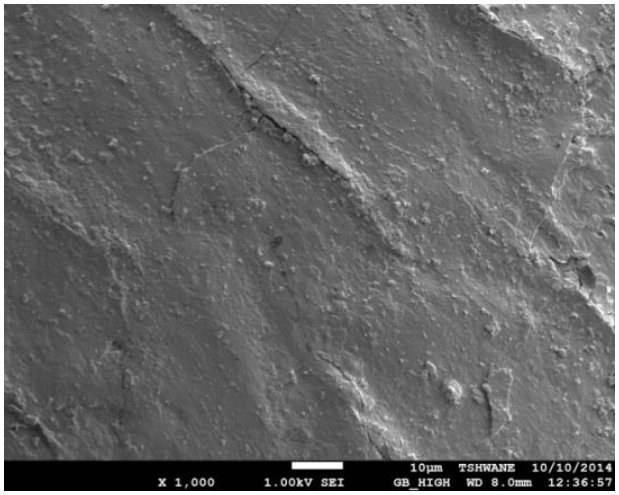
Element	C	O	Na	P	Ni
Weight %	7.60	7.87	1.06	3.98	79.49
Atomic %	23.90	18.51	1.74	4.84	51.01

Photomacrograph (Fig. 7b) revealed the multiple EN layers (base layer of EN film and Blisters formed) deposited on the PP substrate. The Figure shows that multiple layers of EN were deposited on the PP plastic within the 5 minutes of immersion (plating) period. This enhances the properties of the EN deposition in terms of wear and corrosion resistance. The assessment of metallic Ni film offered better film continuity than the Ni-P rich deposition on $PdCl_2$ activated polypropylene (PP) plastic substrate as in Fig. 7b. The deposition of metallic Ni with good EN film continuity and tenacity will make it to be useful in electrical and electronic applications.

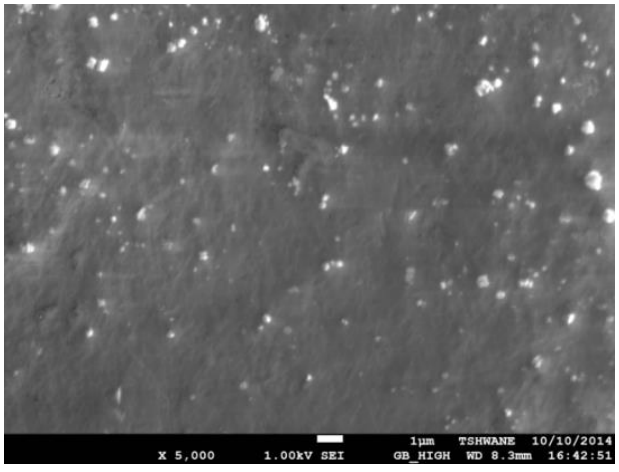
The EDX spectrum processing data (Table 4) presents the chemical composition of the EN film. The result indicates that the EN deposition is rich in metallic Ni, which consists of 79.48 % Ni and 3.98 % P deposit and, in addition, 1.06 % Na (weight) from the solution.

3.2 Effect of thermal cycling

The results (Table 3) show that with the increase in the thermal cycle, there was corresponding increase in the cumulative weight loss resulting from the application of abrasive wear. Nonetheless, the weight loss per thermal cycle is reduced showing an advantage for the plating. It has been reported (24) that heat treatment enhances the mechanical properties (hardness, strength, wear resistance) of electroless Ni film especially when it contains Ni-P component.



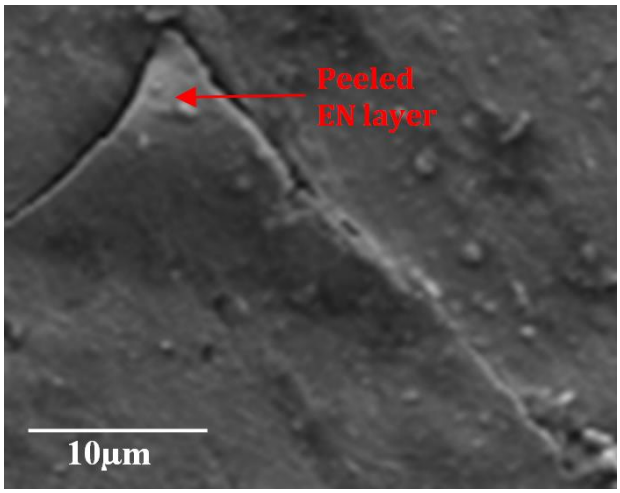
a)



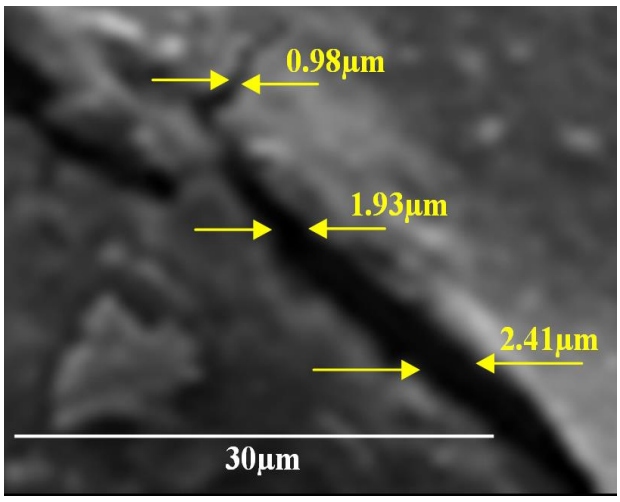
b)

Fig. 8. SEM images showing (a) blisters of EN deposition on PP substrate after thermal cycling (x1000) and (b) the base layer of electroless Ni-P deposit on PP surface (x5000).

Figure 8a presents the enlarged SEM image showing the formation of blisters of EN deposition on polypropylene (PP) plastic substrate after 15 thermal cycles. Blistering is an indication of failure in adhesion that gradually lead to the peeling of the film as a result of thermal fluctuations. The enlargement of 10 μm size SEM image of the base layer of electroless Ni-P deposit on $PdCl_2$ activated polypropylene (PP) plastic substrate surface is shown in Fig. 8b. From the figure, film break was observed on the nickel deposit. The fractures were only visible under the microscope, and become more spectacular under SEM image examination.



a)



b)

Fig. 9. SEM images showing (a) peeling electroless Ni-P deposit and (b) cracks on electroless Ni-P film on PP surface after thermal cycles (x1000).

The enlargement of 10 μm size SEM image of the multiple layers of electroless Ni-P deposit on $PdCl_2$ activated polypropylene (PP) plastic substrate surface reveals the details of the deposition (Fig. 9a). The SEM image shows many fragments, which also form different levels of the multilayer of Ni deposit. Figure 9b presents the magnification of 30 μm size SEM photomicrographs showing cracks on electroless Ni-P film. The crack digitally measured about 0.98~2.41 μm width size range. The cracks that are seen on the EN surface is an indication of an advance level of film failure.

3.3 Effect of abrasive wear cycle

Table 5 presents the results of the on the adhesion EN film on the polypropylene (PP) surface.

Table 5. Abrasive wear/adhesion test using P600 grit.

Time (sec)	Wear (cycle)	Wear loss (g)	Thickness loss (mm)	Wear rate (g/sec)	Observation & Remark
7.5	1750	0.0014	0.001	1.9E-4	Tenacious film, Good adhesion
15.0	3500	0.0017	0.001	1.1E-4	
30.0	7000	0.0021	0.004	7.0E-5	
60.0	14000	0.0032	0.009	5.3E-5	

Table 6. Composition of 100 μm size electroless Ni-P deposit on PP surface.

Element	C	O	Na	Si
Weight %	13.19	13.44	1.15	0.33
Atomic %	33.22	25.41	1.51	0.36
Element	**P**	**Cl**	**Ca**	**Ni**
Weight %	4.43	0.55	0.34	66.57
Atomic %	4.33	0.47	0.24	34.46

The impact of the orbiting wear abrasive on the surface outlook of the EN film is illustrated in Figs. 10 and 11 (a) and (b). With the very few micrometre thickness layer of EN deposition on the PP substrate, the P600 abrasive grits gave very shallow cut while the P150 grits gave deep cut through a small portion of the plating as illustrated in the SEM image Fig. 11 (a) and (b) respectively. The EDX spectrum processing data (Table 6) shows that the marked area consists of 1.15 % Na, 0.33 % Si, and 4.43 % P, 0.55 % Cl, 0.33 % Ca and 66.57 % Ni. The SEM image shows the base layer of electroless Ni-P deposit on $PdCl_2$ activated polypropylene plastic (PP) substrate surface. The film is tenacious and fairly adheres to the plastic substrate, even though the wear loss increases with the cycle quantitatively. The loss rate reduced with time (Table 5) might be due to the removal of the

overlaid debris and exposure to the hard tenacious Ni/EN-P layer.

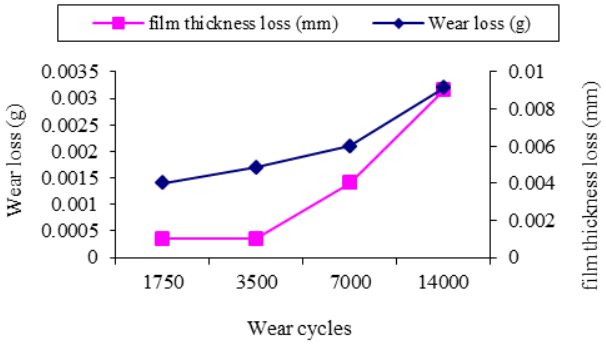
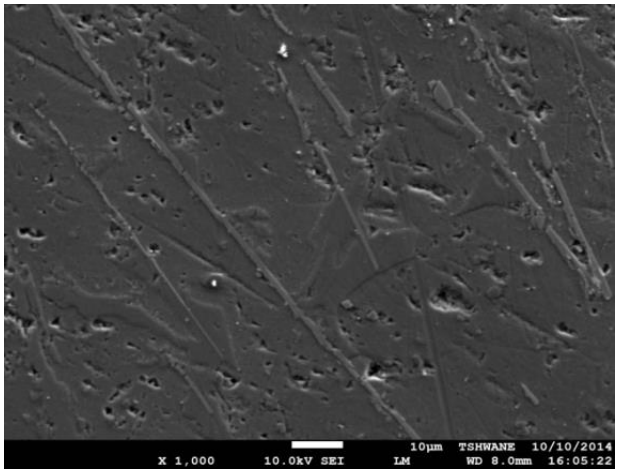
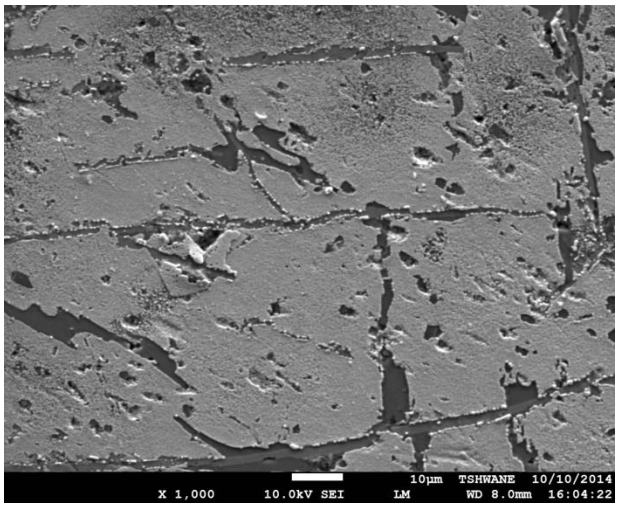


Fig. 10. Wear loss and film thickness loss due to abrasive wear test using P600 grit.



a)



b)

Fig. 11. SEM images of surface outlook of the EN film subjected to orbiting wear cycle (x1000).

Investigating the nature and mechanism of damages done to the EN film on the PP surface under the wear and thermal cycles are still of interest to the authors.

3.4 Tensile strength and creep behaviours

The tensile strength and the creep behaviours of the EN-PP and PP are compared in the Figs. 12 and 13 respectively. In Fig. 12, the result is presented as a plot of the stress versus strain of the EN plated PP and the as-received PP. The maximum σ = 118 (MPa) was obtained from ENPP specimen at ε = 0.1 mm/mm as compared with the PP having σ = 36 (MPa) at ε = 0.07 mm/mm before failure. This testifies to the fact that the EN-PP tends to behave like a composite material, the EN film layer has increased the mechanical strength and reduced the creep values of the PP material [37,38].

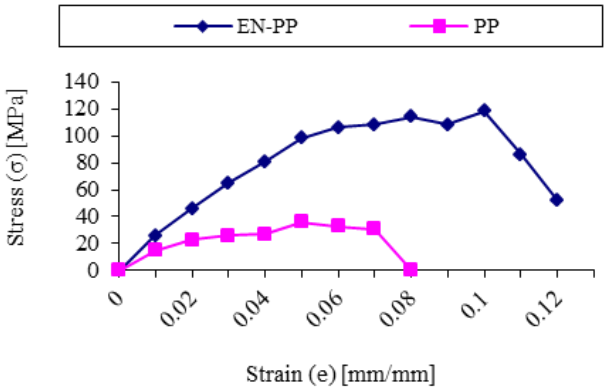


Fig. 12. Strength test of EN-PP and PP.

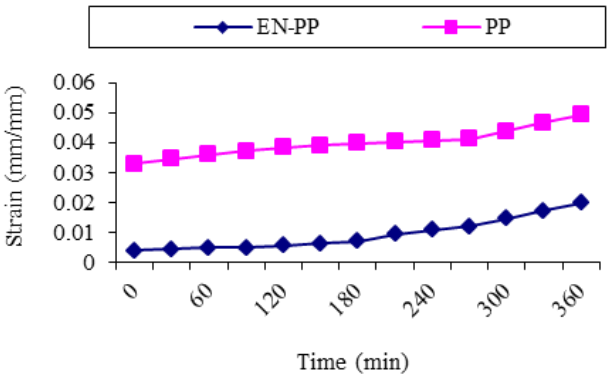


Fig. 13. Creep test of EN-PP and PP under 5 kg load.

Ayoub [39] had reported that uniform, dense mixture of microstructures of amorphous and microcrystalline Ni-P coatings (up to 8.57 wt% P) produce quality and efficient performance in use.

EN-P is well recognized for its uniform thickness, high hardness coupled with excellent corrosion and wear resistant properties, [40,41]. EN-P coating is remarkably accepted chiefly in the electronic industries due to its conductivity and other relative properties [4]. Coatings with

enhanced tribo-mechanical properties are obtained from EN alloyed with different % phosphorus, ranging from 2 % (low phosphorus) to up to 14 % (high phosphorus) [42-44].

The ENPP trend slightly demonstrates the characteristic behaviour and influence of the metallic Ni film under the tensile test rather than that of the plastic (PP). The PP has lower trend of strength values as compared with the electroless-Nickel plated polypropylene (ENPP). In another instance, Fig. 13, relates the creep as the plot of the strain versus time of the EN-PP and the as-received PP. The results show that the strains increased with the time under the applied 5 kg loading and temperature. The EN-PP has lower trend of strain-time values as compared with the PP.

The tribological and wear properties of many materials such as fibre fabrics, epoxy, clay, talc, plastics (polymers), glass and ceramics, metals, alloys and composites have been widely studied and reported in literatures [45].

Reporting investigations on wears can be either comparative or parametric. Comparative techniques are very easy and ordinarily based on references and visual microscopy [46-48]. The Parametric methods use diverse statistics of surface roughness heights, brilliance, and colour quality of their images [49-50]. For the assessment of texture properties, roughness parameters are mostly used base on GOST 25142–82 or advance techniques [51].

Das and Sahoo [52] had reported the characterized abrasive wear nature of EN coating using SEM, EDX and X-ray diffraction analysis. In this study, the SEM images of surface damages on EN film subjected to orbiting wear cycle (Fig. 11) show the combination of abrasion wear, plastic deformation, ploughing and adhesive fracture; and fatigue wear as previously reported by Myshkin and Grigoriev [53]. It is comparatively different from result of abrasive wear test of anodised coating reported by Ovundur et al. [54].

The thermal cycle was limited to 80 ^{o}C to avoid heating the plastic (PP) beyond the EN plating temperature. Both the creep and failures related to creep are critical issues in designing dependable components. The service temperatures for materials subject to creep are usually greater than 40 % of Tm [55].

Zhang et al., [55] worked over a temperature range from -40 to 120 °C. Whereas, Denay et al., [56] had reported the observation of many deformational changes mainly from -20 °C and thus limited the temperature range to -20 ~ 80 °C. In the present instance, working the composite (EN-PP) at 80 ^{o}C will be quite safe under application as much that the service temperature for Ni or EN is greater than 0.4Tm. The coat has much lower coefficient of linear thermal expansion than the substrate and behaves more stably when perfect adhesion and high film tenacity are obtained.

Some possible applications of this composite include the door knob, sliding door for refrigerator and deep freezer, sliding gear in printed circuit board and electronic packaging units. Since PP materials are liable to degradation especially under exposure to heat and UV, the composite will be suitable for long time application for packaging units exposed to the combination of hot (sunlight) and cryogenic weathers.

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are drawn based on the results obtained from the study; Enhanced Electroless-Nickel was deposited on $PdCl_2$ activated polypropylene (PP) plastic substrate in acid solutions at pH = 5.0 and alkaline bath at pH= 11.5 respectively. The acid bath produced ENC containing more quantity of bright metallic electroless-Nickel was deposited on polypropylene (PP) while more amount of dull metallic Ni-P deposit was produced from the alkaline bath. The film is tenacious at long cycles in abrasive wear and thermal cycle tests. The deposition of ENC strongly influenced the strength and creep strain properties of the PP. From the SEM/EDX analyses showing multilayer and high %Ni, the plating will fit for wear resistance and electrical use. These characteristics denote that EN plated PP could be used for such application as required in the plastic plating for electronic industries.

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