FABRICATION AND PERFORMANCE EVALUATION OF ELECTROLESS-NICKEL DEPOSITION LINE FOR METAL ALLOYS AND PLASTIC SUBSTRATES

Supported by tetfund

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Abstract: Cottage metal casting and plastic industries producing diverse automobile and automotive spare parts are springing up at very high rate in the country. Surface finishing defects usually affect and reduce the quality and efficiency of some machine parts produced. The need to improve on the quality of the surface as remedy to wear and corrosion of steel and aluminium alloy used in hydraulic brake cylinder of automobile motivated this work. The design and fabrication of a low cost nickel-electroless line is reported in this paper. The EN process is driven by autocatalysis, the reduction of nickel ion in the hypophosphite bath. The fabrication consists of a pre-treatment line and the EN plating bath. The equipment was tested and found suitable for the coating of moderate size mild steel, cast aluminium alloy and plastic substrates. Electroless-nickel (EN) plating is useful in enhancing uniformity of metal coating on the surface of non-uniform and porous substrates. The machine costs about two hundred and sixty thousand Naira (₦260,000) base on the current Nigeria economy.

Keywords: Aluminium alloy plating, electroless-nickel coating, EN-deposition line, steel plating

Introduction

Local cottage metallurgical and plastic industries are expanding in the country. Primary aluminium is becoming scarce due to very many factors (such as the under development of existing government owned aluminium companies, lack of stable electic power, road, and non existence of aluminium processing plants from bauxite which have influenced the closing down of many aluminium metal fabrication companies (Onwugbolu, 1986; Ajayi, 2011; Ajibola, 2015; Business A.M. June 19, 2018). The only regular source of aluminium is the secondary, through recycling of srap ofvarieties of aluminium alloy products. The largest quantity in circulation goes into the foundry sector of the aluminium working industries for the production of automotive and automobile engine spare parts while the rest are shared by the domestic utencils producers and other wares. Metal castings (aluminium and cast iron) and machined mild steel are usually produced with some anomalies such as surface defects which are not commonly considered at the point of production; but have negative impact on the end usage of the products. Of recent, literatures had reported the results of investigation of the metallurgical characteristics and wear and corrosion behahiours (Ajibola *et al.,* 2014a, 2016, 2018; Ajibola and Oloruntoba, 2015a) of aluminium alloy piston produced by sand casting. There are pores and cracks on the surface which worsen the mechanical properties of the products in service. Active corrosion and high wear rates are experienced in some cases where large numbers of pores are identified. In some instances, these have contributed to the variation in densities, mechanical strength and surface resistance to wear (Ajibola *et al.,* 2014a,c).

Most failures begin at the surface, thus the remedy could be of surface treatments and metallic deposition such as cladding, Parkerizing (Beranger, 1996); hot dipping (Niebel *et al,* 1993); anodising (Pletcher, 1982); electroplating (Schlesinger and Paunovic, 2000; Egunlae and Adewuyi 2008; Oloruntoba 2009); electroless plating (Baudrand *et al.,* 1986); autocatalytic plating (Gabe, 1984) and galvanising (Karlson, 1989; Sullivan and Worsely, 2002).

EN has many advantages over some other coating methods. These include: uniform deposits on complex shapes, less porous film providing better barrier corrosion protection to the substrates, and deposits with zero compressive stress, inherent lubricity and non-galling characteristics, good wetability for oils, low phosphorus, much harder with as-plated micro-hardness of 450-600 VPN which can be increased to 1000-1100 VHN by a suitable heat-treatment (Ramalho and Miranda, 2005; Sahoo and Das, 2011). The process is not electricity control as in case of electroplating whereby the current density and some other factors influence the product. Coating on parts surface can be achieved, no sophisticated jigs or racks requirement**,** with flexibility in plating volume and thickness. The process can plate recesses and blind holes with stable thickness while the chemical replenishment can be monitored automatically since complex filtration method is not required and at the end, different categories of brightness such as matte, semi bright or bright finishes can be obtained (ASM Vol. 5, 1992). Ajibola *et al.* (2015e) reported success in heat treatment of EN plating on mild steel for use in the mineral acid (H_2SO_4) environment.

Different types of EN baths have been developed to provide special properties, depending on the end-use requirement. These include: Aminoborane Baths, Sodium Borohydride Baths, Hydrazine Baths, Nickel-phosphorus Baths; Acid nickel-phosphorus (very low phosphorus, low phosphorus, mid phosphorus, and high phosphorus); and Alkaline nickel-phosphorus which is suitable for plating on plastics, with low phosphorus content deposit; Nickel-boron baths (Balaraju and Seshadri, 1999; Ozimina *et al.*, 2000, Ramalho and Miranda, 2005; Sahoo, 2009); Low-boron-containing baths (Srinivasan *et al.*, 2010; Stallman and Speckhardt, 1981); and the Polyalloy like nickel-cobalt-phosphorus, nickel-iron-phosphorus, nickel-tungsten-phosphorus, nickel-rhenium-phosphorus, nickel-cobalt-phosphorus, nickel-molybdenum-boron, nickel-tungsten-boron among others. Composite coatings enhanced by co-depositing hard particulate matter with the nickel- phosphorus alloy.

The fabrication is based on the readily established scientific theories and principles of engineering design (Stallman and Speckhardt, 1981; Speckhardt, 1992). It considered adequate precisions and factors needed for material selection for efficient perfomance even at low cost of installation.

Electroless nickel solutions are combination of different chemicals, each performing an important specific function

(Anik *et al*., 2008). A typical EN solution contains a source of nickel, a reducing agent to supply electrons for the reduction of nickel; energy (heat source); complexing agents (chelators) to control the free nickel available to the reaction (Mallory and Hadju, 1991; Anik *et al.*, 2008); buffering agents resist the pH changes (Ying *et al.*, 2007); accelerators (exultants) which help to increase the speed of the reaction; inhibitors (stabilizers) that controls reduction and reaction by-products (Cheong, 2005).

Agarwala and Agarwala, (2003) offered the most extensively acknowledged mechanism and sequences for the chemical reactions that occur in hypophosphite reduced electroless-nickel plating solutions; Equations (1) to (4) (Ajibola, 2015):

$$(H_2PO_2) + (H_2O)\frac{\text{catalyst}}{\square EAT} = H^+ + HPO_3 + 2H_{abs} \quad (1)$$

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

$$(H_2PO_2)^- + 2H_{abs} = H_2O + OH^- + P \quad (3)$$

$$(H_2PO_2)^- + H_2O = H^+ + HPO_3{}^{2-} + H_2 \quad (4)$$

In the presence of sufficient energy and a catalytic surface, hypophosphite ions are oxidized to orthophosphite.

On this foundation, a moderately economic size of EN plating line was designed and fabricated for a small scale industrial use and school laboratories in performing research experiments (Ajibola *et al.,* 2014b, 2015b,c; Ajibola 2016). The pursuit to investigate and report research results on automobile engines subject area, the previous research activities reported by the authors focused on the functions, tribology and corrosion of aluminium alloys, and EN plating as applicable to automobile hydraulic brake cylinder system. The motivation for this project is that it is part of a research work of which some reports are already in public domain (Ajibola *et al*., 2014b, 2015b,c; Ajibola 2016).

Materials and Methods

Design considerations

In this work, the following factors that were put to consideration in the design and fabrication of the EN plating line: the design concepts and theories, design simplicity, exploring the prospect of locally obtainable materials required for the construction, material properties, local price of materials, ease of construction, operation and repair and servicing requirement of the machine; and the ease of material flow for repeated and continuity of materials.

The design drawings and purchase of material components for the design were carried out after detailed assessment of the fundamental design and materials selection standards such as the principle and theories of electroless plating design, availability and cost of local raw materials, design essentials, material properties and easy access of parts. Some other design parameters include: materials, sizes and shapes of tanks (Table 1), weight measurement for plating line components (Table 2), energy and power requirement for the heating up of baths to 85ºC (Table 3), and pumping and filtering design (Table 4).

Table 1: Materials, sizes and shapes of tanks

Parameters	Hot water bath (Tank A)	EN Plating bath (Tank B)	EN-Replenishing Tank (Tank C)	Surfactant bath (Tank D)	Hot water bath (Tank E)
Material	Aluminium tank	Stainless Steel tank	Plastic vessel	Plastic vessel	Aluminium tank
Shape	Cylindrical	Cylindrical	Cuboid	Cuboid	Cylindrical
Mass (kg)	1.0	0.5	0.3	0.2	0.55
Height(m)	0.13	0.16	0.205	0.1	0.13
Diameter (m)	0.27	0.165	-	-	0.18
Thickness (m)	0.002	0.005	0.001	0.001	0.002
Length (m)	-	-	0.155	0.145	-
Breadth (m)	-	-	0.155	0.14	-

Table 2: Weight measurement for plating line components

Components	Units	Capacity
Empty Aluminium tank (A)	kg	1.0
Empty electroless-nickel EN plating bath (Tank B)	kg	0.5
Empty replenishing tank (Tank C)	kg	0.3
Aluminium tank (A) with water	kg	5.3
Water in tank A	kg	5.0
Total mass of 5 litres of EN plating solution in circulation	kg	5.73
Mass of 2 litres of EN plating solution in tank B (stainless steel)	kg	2.29
Mass of Tank B with EN plating solution	kg	2.79
EN solution in replenishing tank (Tank C)	kg	3.43
Mass of Tank C with EN plating solution	kg	3.73
Mass of in surfactant bath (Tank D)	kg	0.20
Mass of surfactant bath (Tank D) with 1 litre of water	kg	1.20
Volume of cylindrical aluminium tank	**m^3**	**0.0075**
Volume EN plating tank	**m^3**	**0.0034**

Table 3: Energy and power requirement for the heating up of baths to 85ºC

Components	Units	Capacity
Electric hot plate power rating	W	1220
Heat generated by electric hot plate,	kJ	3600
Heat gained by Tank A,	kJ	81.64
Heat gained by water bath inside Tank A	kJ	113.24
Heat gained by Tank B	kJ	22.27
Heat gained by Plastic Support	kJ	356.4
Heat generated Electric Heater in cleaning baths	kJ	1500

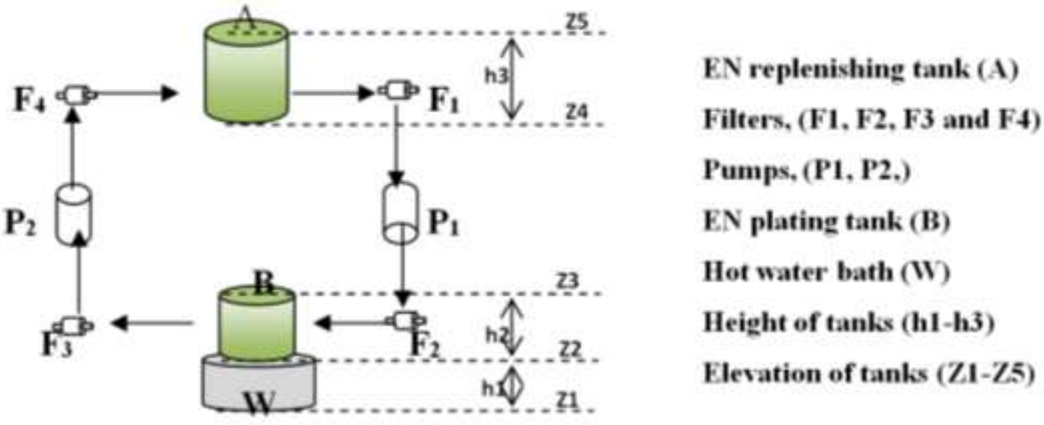

Fig. 1: Pumps and filters layout

Design criteria and calculations

EN plating line design parameters and calculations

The specimen used for the EN plating experiment is made of round shape cast aluminium alloy coins.

The cross sectional area of a circular specimen is given by

$$A_s = \pi r^2 \qquad (5)$$

Where: π = 3.142, r = radius of specimen

Total surface area of specimen is given by

$$A_T = 2\pi\left(\frac{d}{2}\right)^2 + 2\pi\left(\frac{d}{2}\right)\pi h_s = 2\pi r^2 + \pi r h_s \qquad (6)$$

Where: π = 3.142, d = diameter of specimen, r = radius of specimen, h_s = height of specimen,

The volume of a cylindrical shape coin specimen is given by $V_s = \pi r^2 h_s$ where π = 3.142, r = radius of specimen, h_s = height of specimen.

For a cylindrical EN plating bath; Volume of bath,

$$V_b > (V_T + V_r) \qquad (7)$$

Where: V_T = total volume of specimen in plating tank; V_r= volume of EN plating reagents in mm^3

Volume of EN plating tank,

$$V_b = \pi R^2 H_p > (V_T + V_r) \quad mm \qquad (8)$$

Where: π = 3.142, R = radius of EN plating tank, H_p = height of EN plating tank

The 2D views of the EN plating line set up are shown in Fig. 2. The parameters obtained are listed in Tables 1 and 2.

Pumps and filters layout design parameters for EN plating line

The pumping and the filtering systems are essential components in running an efficient EN plating line. The plating solution has to be very clean and maintained at constant flow and temperature range. The presence of dirt and solid precipitate of any kind resulting from chemical reactions occurring in the electroless-nickel tank has negative influence on the electroless-nickel deposition process; hence, provisions are made for quick and continuous removal of all unwanted extraneous particles from the electroless-nickel plating process by filtration process. In the present work, ultra-fine solid particle precipitates and dirt in the electroless-nickel plating solution tank are filtered using four 30 µm aperture plastic filters which are mounted at the inlet and outlet ends of the two pumps (P_1 and P_2) as shown in Fig. 1. The first pump, P_1 draws electroless-nickel solution from the electroless-nickel replenishing tank C into the electroless-nickel plating tank B through two filters F_1 and F_2; while the second pump, P_2 draws electroless-nickel solution from the tank B into the tank C through two other filters F_3 and F_4. By this arrangement, a clean EN solution is continuously recycled while the required range of bath temperature (85 ±5°C) is maintained in the process.

Variation of pressure and velocity in fluid flow

A fluid in motion moves in such a manner that mass is conserved, thus, the mass conservation put restrictions on the velocity field; considering the steady flow of fluid through a system such that the inlet and outlet flows do not vary with time. Applying the law of mass conservation, since there is no flow through the side walls of the bath, fluid mass comes in over A_1 goes out of A_2, (steady flow i.e., no mass accumulation). Therefore,

$$\rho A_1 V_1 = \rho A_2 V_2 \qquad (9)$$

When EN solution flows from tank A to tank B (and/or vice versa), the energy equations for sections 1, 2, 3 and 4 are as follows,

$$\frac{V_1^2}{2} + \frac{P_1}{\rho} + Z_1 = \frac{V_2^2}{2} + \frac{P_2}{\rho} + Z_2 = \frac{V_3^2}{2} + \frac{P_3}{\rho} + Z_3 = \frac{V_4^2}{2} + \frac{P_4}{\rho} + Z_4 \quad (10)$$

Where: p is pressure, ρ is density, v is the velocity, and z is the elevation

Bernoulli equation states:

$$p + \frac{1}{2}\rho V^2 + \rho \square g = constant \qquad (11)$$

Where: p is pressure, ρ is density, v is the velocity, h is the elevation and g is acceleration due to gravity

Calculations were based on the fundamental principles of heat and mass transfer, fluid flow theories using established equations from the literatures such as:

Fluid flow – Bernoulli's equation

For an incompressible fluid, the Bernoulli equation is expressed in terms of total head or energy head *H in* (12):

$$H = z + \frac{p}{\rho g} + \frac{v^2}{2g} \qquad (12)$$

For an irrotational flow, the flow velocity can be described as the gradient ∇φ of a velocity potential φ. In that case, and for a constant density ρ, the momentum equations of the Euler equations can be integrated to (13) [wiki/Bernoulli's_principle];

$$\frac{\partial \varphi}{\partial t} + \frac{1}{2}v^2 + \frac{p}{\rho} + gz = f(t) \qquad (13)$$

which is a Bernoulli equation that is valid also for unsteady-or time dependent-flows.

Flow rate equation

$$Q = VA \qquad (14)$$

$$Q = V_1 A_1 = V_2 A_2 \qquad (15)$$

For a round pipe,

$$A = \pi \frac{D^2}{4} \qquad (16)$$

Heat calculation and material balance

Electric power $W = IV$ (17)

Electric heater Q_H = water bath Q_W = EN plating bath Q_B + EN replenish bath Q_A (18)

According to Joule's law,

$Q = McT$ (19)

Heat Q_W = Heat Q_B + heat Q_A (20)

$Q_{Heater} = Q_{Water\ bat\square} = Q_{ENplating\ bat\square} + Q_{EN\ repl\ bat\square}$ (21)

The energy and power requirement for heating up and chemical recycling are listed in Table 3.

Also, power $P = Q/t$ (22)

$Q = mc\Delta T$ (23)

For an electrical energy input

$Q = ivt$ (24)

For equations 17 – 24; Q = heat, M = mass, c = heat capacity, T = temperature, t = time, I = current, v = voltage, P = W = power

Diffusion

Flux magnitude for conduction through a plate in series with heat transfer through a fluid boundary layer (analagous to either 1st-order chemical reaction or mass transfer through a fluid boundary layer):

$$|q_x| = \frac{|T_{fl} - T_i|}{\frac{1}{h} + \frac{L}{k}} \quad (25)$$

(T_{fl} is the fluid temperature, analagous to the concentration in equilibrium with the fluid in diffusion; T_1 is the temperature on the side opposite the fluid.)

Thermal diffusivity

14 – 15 had defined and given different correlation among factors of thermal conductivity, diffusion and diffusibility, temperature, heat capacities, density (area, volume, mass) and time

In heat transfer analysis, thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure (26). It measures the rate of transfer of heat of a material from the hot side to the cold side (Lide, 2009).

$$\propto = \frac{k}{\rho c_p} \quad (26)$$

Where: ρ = density (kg/m³), *k* = thermal conductivity (W/(m·K)), c_p = specific heat capacity (J/(kg·K)),

Knowing also that thermal diffusivity is the ratio of the time derivative of temperature to its curvature (27) (wiki/Thermal_diffusivity)

$$\frac{\partial \varphi}{\partial t} = \propto \nabla^2 T \quad (27)$$

For pure aluminium = 9.7×10^{-5} (m²/s), Aluminium 6061-T6 Alloy = 6.4×10^{-5}(m²/s), PVC (Polyvinyl Chloride) 8×10^{-8} (m²/s), PP (Polypropylene) (at 25°C) = 0.096×10^{-6}(m²/s), Water (at 25°C) = 0.143×10^{-6} (m²/s).

Table 4: Pumps and filters specifications

Parameter	Units	Spec.
height of filters above the ground level	cm	30
height of replenishing tank above the ground level	cm	45
height of pump above the ground level	cm	5
height of plating tank above the ground level	cm	10
volumetric capacity of filters	ml	50
Diameter of discharge orifice of filter	mm	5
Cross-sectional area of discharge of filter	mm²	19.6375
Diameter of discharge orifice of pump	mm	5
Cross-sectional area of discharge of pump	mm²	19.6375

Speci. = Specifications

Design drawings

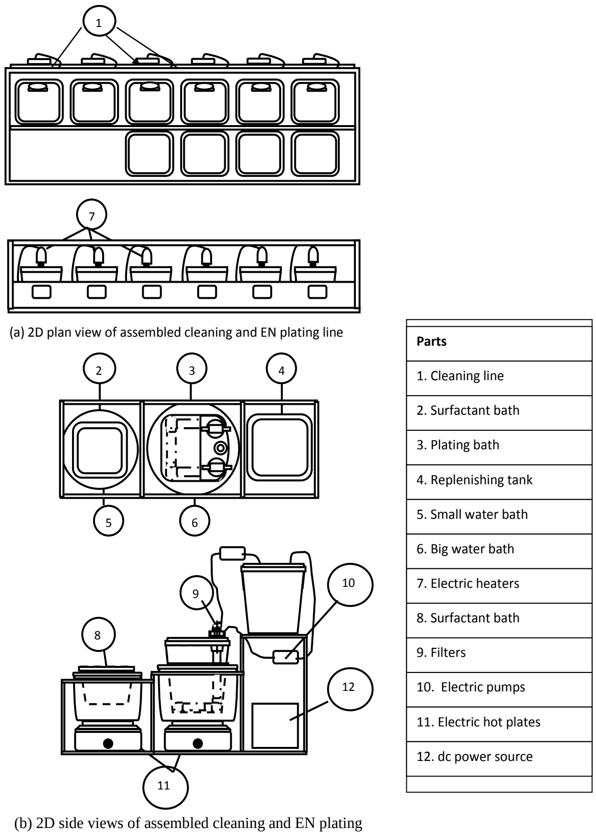

Fig. 2: Schematic drawing of plan and side views of assembled cleaning and electroless plating line

Results and Discussion

The evalution of the design and fabrication pivoted on the already established scientific theories and principles are considered to be adequate in precisions for efficient perfomance at low cost of installation and running of laboratory experiments as evident in some of the works where the equipment has been utilised as reported in various literature by Ajibola *et al.*, (2014b); Ajibola *et al.* (2015b); Ajibola *et al.* (2015c); Ajibola *et al.* (2015e); Ajibola (2016); Ajibola and Olubambi (2018).

Assembling, fabrication and evaluation of EN plating line

The arrangements and pictorial views of the components and assembly of the pre-treatment and plating line are shown in Fig. 2 and Plates 1 – 2. The pictorial views of the cleaning line is shown in Plate 1, while Plate 2 illustrates (a) the pictorial front view of activation bath, EN plating bath and replenishing tank; (b) Pictorial view of complete assembly of EN plating bath.

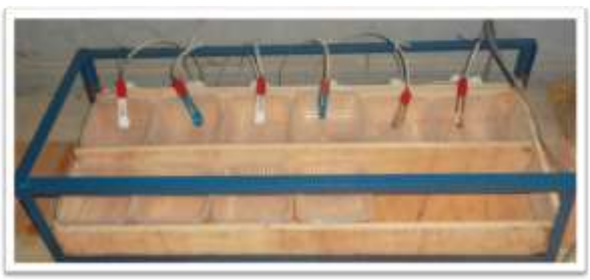

Plate 1: Pictorial plan view of the cleaning line (Ajibola *et al.*, 2015c)

Plate 2: (a) Pictorial front views of activation bath, EN plating bath, replenishing tank (Ajibola *et al*., 2014b; Ajibola *et al*., 2015c) and (b) complete assembly of EN plating Bath (Ajibola *et al*., 2014b, 2015c)

Each of the components was selected based on merit of their materials engineering properties and the conditions of their applications. The characteristic of each component used in the fabrication are illustrated in the Material Selection table (Table 10).

The standing frame was made of the steel angle bar. It was cut and arranged to get the require shape according to the design drawings (Fig. 2). The steel bars were firmly joined together by electric arc welding. The wooden rack made from plywood materials was cut to specification; smoothen with electric plane and later smoothened with sand paper to close the pores. The parts of the wooden rack were joined together by nails. The rack was fixed to the frame using screws, bolt and nuts. The metal steel frame was coated with acrylic base paint to prevent rusting. PVC pipes were joined using resinous glue.

All electrical fittings such as the hot plate, electric heaters, sockets and dc power supply were connected and well insulated to avoid electric current leakage and shock. The dc pumps were also connected using transparent delivery hose, the pumps were fixed to the rack using metal screws. Each of the component such as plating bath, water baths, replenishing tank and surfactant bath were positioned with the most possible firmness (Plates 1 – 2). Each of the plating bath and the surfactant bath were provided with temperature control device to regulate the operating temperatures.

Evaluation of heat transfer to baths

The trends of heat transfer from the water bath to the plating solution and surfactant bath are shown in Fig. 3. The trends of the bath temperatures change with respect to increasing heating time were studied with the aid of the experimental data generated from the experiment. The trends of heat transfer from the hot plate through the water bath (tank A) to the plating solution (tank B) using stainless steel and plastic tank are compared. Heat could not be adequately transferred through the plastic material intended for plating bath at the appropriate rate to attain the required temperature of 85°C. The maximum plating bath temperature of 79°C was attained after the 60 min of heating the water bath to boiling (100°C). The prolong heating of the water bath for about 70 min could only yield an additional increase in temperature, less than 5°C at which point the water bath is boiling and there was distortion in shape of the plastic container. Hence, stainless steel, a more heat conducting material with higher chemical resistance to EN solution was used for the replacement of plastic vessel previously used for the experiment. As reported in the literature, stainless steel has been found as very useful construction material for EN plating. To this effect, the stainless steel EN plating tank and pumps has to be stricken with 30% nitric acid (HNO_3) solution for passivation before and after use (ASM Vol. 5).

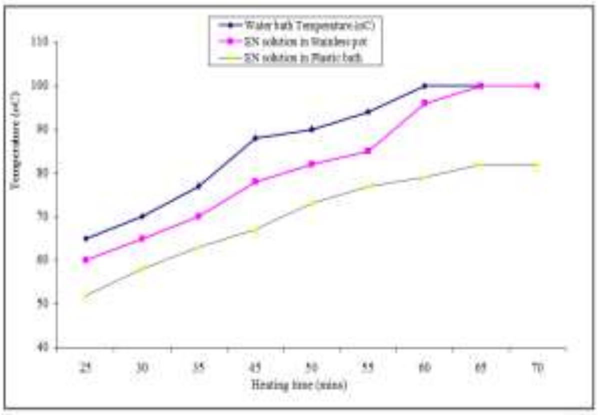

Fig. 3: Trend of heat transfer from water bath to plating solution

The designed process flow sheet to run the Electroless-Ni plating process plating line is shown in Fig. 4. It illustrates the materials movement from the start to end. Also, the plating chemicals, the mixing ratios and operating conditions are presented in Table 5.

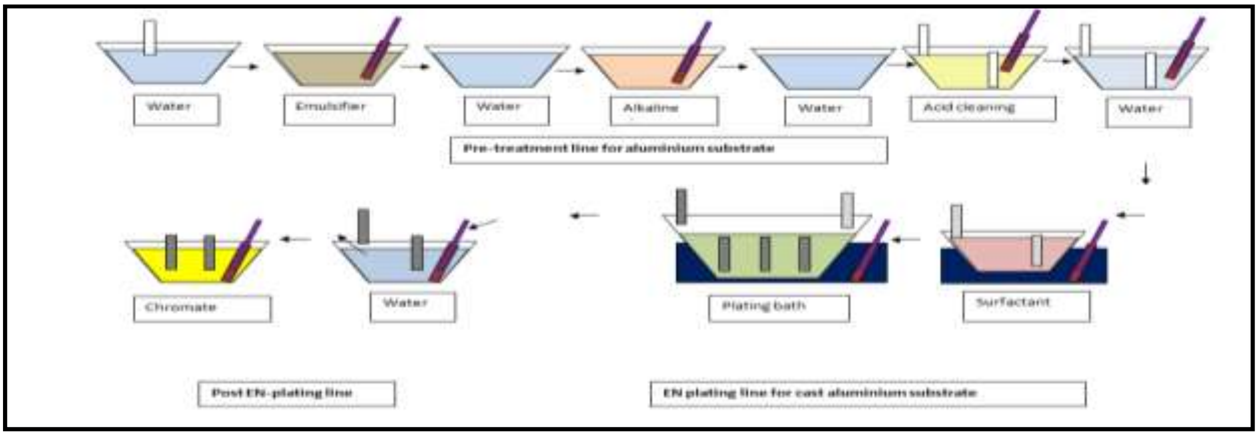

Figure 4: Flow sheet of Electroless-Ni plating process

Table 5: Plating chemicals and mixing ratios

Bath	Media	Concentration (g/l or ml/l)	Working Temperature (ºC)	Time (min)
Rinsing	Water	-	25-30	5
Emulsifying	Emulsifying solution	15 ml, 15 g	60-65	5
Alkaline cleaning	Sodium hydroxide	0.4 g	60-70	5
Acid cleaning	Hydrochloric acid	5 ml	60-70	5
Surfactant	PCl_2	0.0 ~ 0.12 g	85-95	2
Plating (option I)- Alkaline bath	Nickel Chloride	24 g	85-95	2 - 10
	Sodium Hypophosphite	18 g		
	Sodium citrate	12 g		
	Ammonium hydroxide solution PCl_2	60 g		
	pH	0.02 g		
	(Oloruntoba 2009).	9.0~11.5		
Plating (option II)- Acid bath	Nickel Chloride	30 g	85-95	2 - 10
	Sodium Hypophosphite	40 g		
	Sodium citrate	25 g		
	Ammonium chloride	50 g		
	PCl_2	0.02 g		
	pH	5.0~5.5		
	(Pari*et al*. 2008)			
Post plating	anti-tarnish chemical: potassium-di-chromate solution	5 g	50-65	3
Zincate bath	Zinc oxide	5 g		1
	Sodium hydroxide	50 g		
	Potassium sodium tartrate Sodium	10 g		
	nitrate	0.2 g		
	Ferric chloride	1 g		

Table 6: Chemical composition of aluminium alloy and mild steel samples used for the experiments

Sample 1	**Al**	**Si**	**Mg**	**Fe**	**Mn**	**Cu**	**Zn**	**Cr**	**Ti**
Aluminium	98.44	0.32	0.29	0.16	0.001	0.01	0.001	0.001	0.001
Sample 2		**Si**	**C**	**Fe**	**Mn**	**Cu**	**S**	**P**	
Mild Steel		0.168	0.346	98.45	0.727	0.289	0.013	0.0097	

Evaluation of electroless-nickel plating line

The EN plating line was tested **in** batches **on** materials: aluminium alloy, mild steel and plastic samples. The chemical compositions of aluminium alloy and mild steel substrates used in this experiment are presented in Table 6.

Surface cleaning and electroless-nickel deposition on specimens

The surfaces of the specimens were thoroughly cleaned and pre-treated in various chemical mixtures as listed in Table 5; and were immersed in electroless-nickel plating bath containing either the acid reduced or alkaline reduced electroless-nickel plating solution presented in Tables 5. Thereafter, the electroless-nickel plated sample was dried in oven and kept in the desiccators before the final weight is determined using a digital weight meter.

The amount of electroless-nickel deposit (ΔW) on aluminium substrate was determined from weight difference before (W_i) and after (W_f) plating respectively and expressed as 28:

$$\Delta W = W_f - W_i \qquad (28)$$

The amount deposited per unit area was calculated from the amount deposited as the ratio of electroless-nickel film weight deposited to the total surface area of plated sample (Ajibola *et al*., 2014b, 2015c).

The machine fabricated was used to deposit electroless nickel on the mild steel, aluminium alloy and plastic substrates. The effect of some plating parameters such as time, pH, temperature, and surface polishing grits were examined on the quantity and the morphologies of electroless nickel deposition on the three substrates.

Effect of plating temperature variation on electroless-nickel deposition

Effect of plating temperature variation on the amount and physical appearances of the electroless-nickel deposition on MS, Al and plastic substrates are shown in Fig. 5.

Effect of solution ph on the electroless-nickel deposition

Effect of solution pH (5.0-5.5, 9.0-11.5) on the amount and physical appearances of the electroless-nickel deposition on MS, Al and plastic substrates are in Fig. 6.

Effect of plating time on electroless-nickel deposition

Effect of immersion time variation on the amount and physical appearances of the electroless-nickel deposition on MS, Al and plastic substrates are presented in Fig. 7.

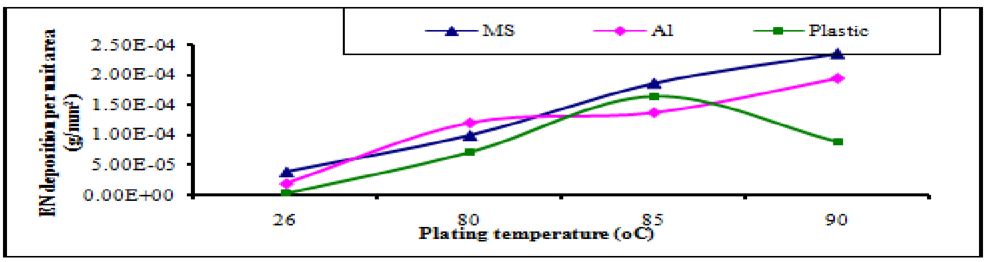

Fig. 5: Variation of plating temperature on Electroless-Nickel deposition per unit area on MS, Al and plastic substrates

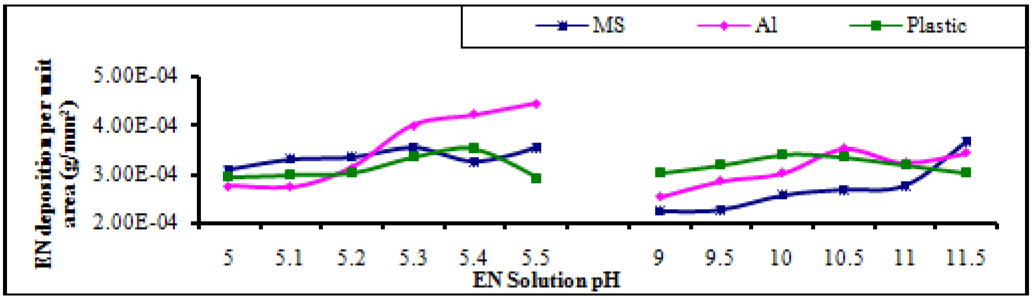

Fig. 6: Plot of solution pH on EN deposition per unit area on MS, Al and plastic substrates in acid and alkaline reduced baths

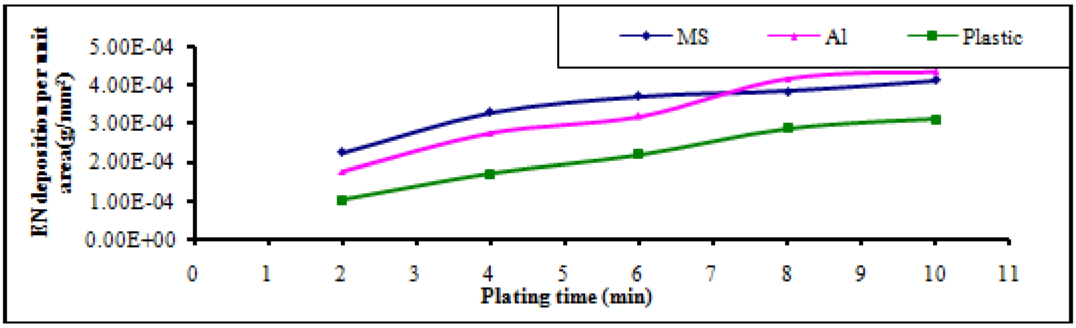

Fig. 7: Variation of plating time on Electroless-Nickel deposition per unit area on MS, Al and plastic substrates

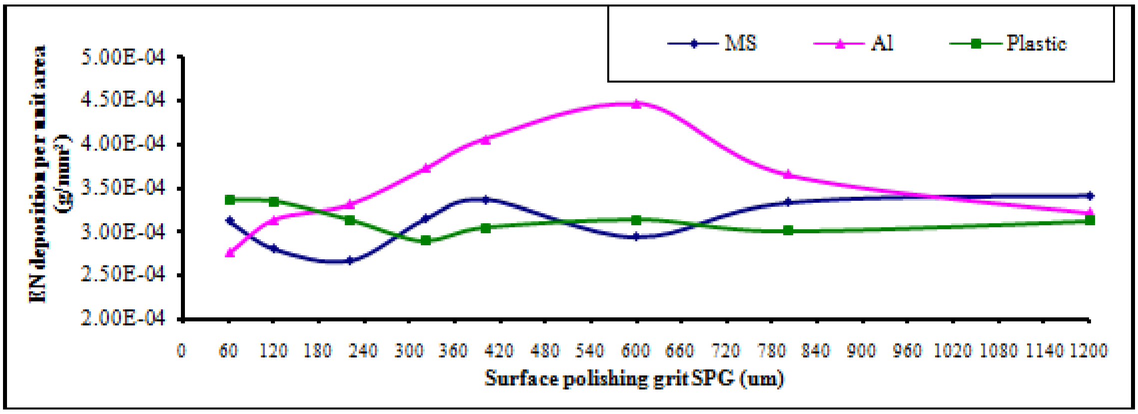

Fig. 8: Variation surface polishing grits on Electroless-Nickel deposition per unit area on MS, Al and plastic substrates (Ajibola *et al*., 2015c)

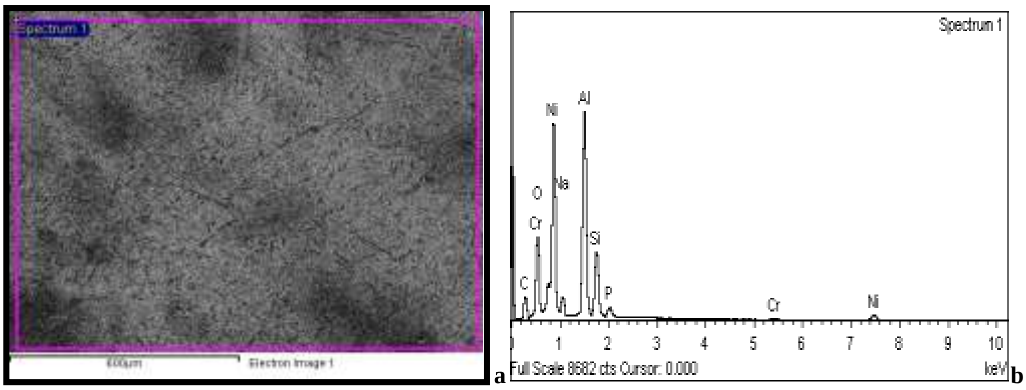

Fig. 9: (a) SEM and (b) EDX Spectra lines for EN plating on chromate activated cast Al-alloy (Ajibola *et al*., 2015b,c)

Table 7: EDX Spectrum data for EN plating on chromate activated cast Al-alloy substrate

Element	C	O	Na	Al	Si	P	Ni	Total
Weight %	9.99	11.71	2.31	20.34	7.70	1.47	48.04	100
Atomic %	23.57	20.74	2.85	21.37	7.77	1.35	23.20	

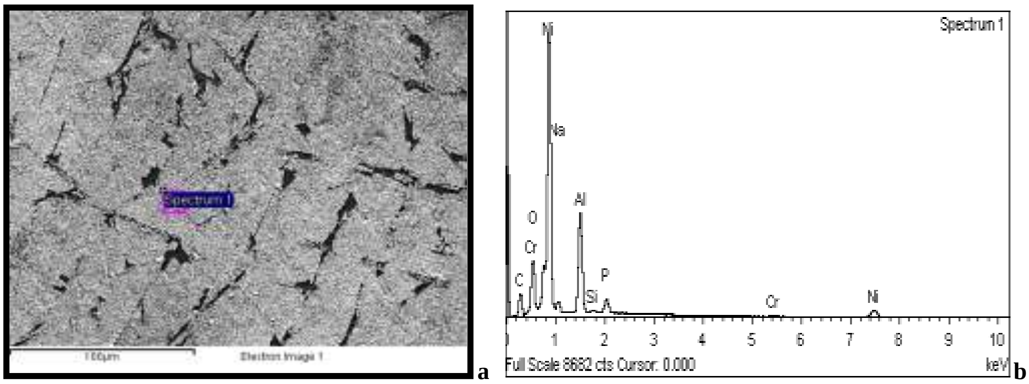

Fig. 10: (a) SEM and (b) EDX Spectra lines of EN plating cast Al-alloy substrate (Ajibola *et al*., 2015b,c)

Table 8: Spectrum processing of EN plating on cast Al-alloy substrate

Element	C	O	Na	Al	Si	P	Ni	Total
Weight %	8.73	7.36	1.65	11.41	0.31	2.31	70.94	100
Atomic %	24.87	15.73	2.45	14.46	0.38	2.55	41.33	

Effect of surface polishing grits on the electroless-nickel deposition

Effect of surface polishing grits (60 ~1200 µm) variation on the amount and physical appearances of the electroless-nickel deposition on MS, Al and plastic substrates in the acid baths are shown in Fig. 8.

SEM and EDX examinations of EN deposit

The quality of depositions derived from the equipment as examined from the SEM and EDS analyses were broadly reported by Ajibola *et al.* (2014b); Ajibola *et al.* (2015b); Ajibola *et al.* (2015c); Ajibola *et al.* (2015e); Ajibola (2016) and; Ajibola and Olubambi (2018).

Based on previous report by Ajibola *et al*. (2014b); Ajibola *et al*. (2015b); Ajibola *et al*. (2015c); Ajibola *et al*. (2015e); Ajibola (2016) and; Ajibola and Olubambi (2018); the functionality (for wear and corrosion) is dependent on the film quality such as chemical composition (black EN (Ni-P) rich plating and the white EN (Ni) rich deposition (Fig. 10), film continuity, the tenacity, adhesion, low porosity, with the high coverage of EN into the tiny pores and corners on the Al alloy as shown in the SEM images and EDX results (Tables 7 – 9). The reinforcement by the multiple EN film layers is an advantage to the protection offered and functionality of the deposition. On the contrary, some discontinuity, peeling of film, cracks and poor adhesion were also noted in some areas. The combination of bright metallic Ni and dull Ni-P film formed complex composite stuctures on the metal alloy substrate surface (Fig. 9). SEM-EDX results revealed EN of low phosphorous class, characterised with lowest impact on fatigue, good hardness, good corrosion resistance in alkaline environments, and for high temperature.

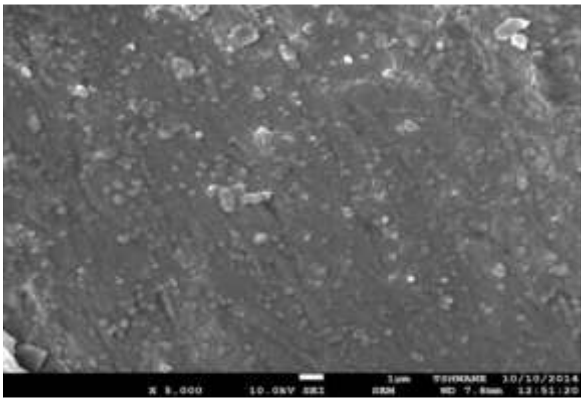

Fig. 11: SEM showing electron image of EN plating plastic substrate (Ajibola, 2016)

Table 9: Spectrum data of EN plating on plastic substrate

Element	C	O	Na	P	Cl	Ni	Total
Weight %	13.19	13.44	1.15	4.43	0.55	67.24	100
Atomic %	33.22	25.41	1.51	4.33	0.47	35.06	

In the case of EN deposition on plastic by Ajibola (2016); SEM macrographs (Fig. 11) showed good adhesion at the interface of bright metallic EN deposition on $PdCl_2$ activated PP plastic surface; nonetheless with the presence of some micro pores on bright metallic EN plating which reasons for the occurrence have been explained. SEM shows the cracks, contours and roughness on the electroless Ni-P deposit.

Table 10: Materials selection for EN plating bath

Components	Selected Materials	Reason for Selection
12.5 mm diameter elbow joint, pipe and T-joint	PVC	Corrosion and heat resistance
Hydraulic pump	12v dc pump	High pressure required and Resistant to Ni solution
Plating bath	Stainless steel	Resistant to EN deposition
Heat Sources	hot plate, boiling ring	Heat source is controllable
Temperature measurement	Thermometer	Ease to read and accuracy
Pre-treatment tanks	Plastic containers	Corrosion and heat resistance
Replenishing bath	Plastic containers	Corrosion and heat resistance

Table 11: Bill of quantity

S/N	Description	Quantity	Rate	Cost price (₦)
1.	12V dc pump	2	4000	8000
2.	12.5 mm PVC elbow joint	10	50	500
3.	12.5 mm PVC T-joint	10	50	500
4.	25 mm Steel angle bar	4	1500	6000
5.	Cartridge Filters	4	500	2000
6.	13 Amp Socket	12	200	2400
7.	2.5 mm x 3 core wire	1m	2500	2500
8.	12.5 mm diameter pipe	0.5m	3000	1500
9.	Plastic vessel (big)	2	1000	2000
10.	Plastic vessel (small)	12	750	9000
11.	Electric Heaters	10	500	5000
12.	Electric hot Plates	2	2000	4000
13.	Aluminium pots	2	2500	5000
14.	Stainless steel pot	2	1000	2000
15.	Super adhesive glue	6	100	600
16.	12.5 mm nail	1 kg	200	200
17.	Mercury Thermometer	2	2400	4800
18.	Silicone glue	2	1000	2000
19.	Wooden glue	1	500	500
20.	Aluminium alloy	10 kg	1700	17000
21.	Plastic materials		2000	2000
22.	Paint and painting		5000	5000
23.	Pre-treatment chemicals			25000
24.	Zincating chemicals			10000
25.	Plating chemicals			88000
26.	Welding and wood work			12500
27.	Casting & machining			12500
28.	Professional consultation			20000
29.	Logistics			5400
	Total			**₦255,900**

Materials selection and cost

All the materials selected and components used for the design of the EN plating line machine are presented in Tables 10. The materials and equipment employed in the design were locally sourced, and the total cost of designing the machine is approximately ₦260,000:00 ($800.00) as listed in Table 11. The machine is cheaper in comparison to similar commercial kind of machines imported from overseas.

Conclusion and Recommendations

A moderately economic size of EN plating line is designed and fabricated for a small scale industrial use. It will assist the cottage cast alluminium alloy industries and school laboratories in performing research experiments. The equipment is suitable for the coating of moderate size mild steels, HDPE and aluminium alloys products characterised by small pores. The plated EN film can be heat treated to acquire high mechanical strength and hardness than ordinary EN coated surface. The machine could be scaled up to suit lager size of work piece and quantity required per hour.

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Conflict of Interest

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

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