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## **STUDY ON THE PERFORMANCE OF ELECTROLESS NICKEL COATING ON ALUMINIUM FOR CYLINDER LINERS**

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### **ABSTRACT**

Cylinder components contribute to around 30% of total friction in an engine. The most important requirements for the satisfactory service life of the cylinder component in an engine are higher life, higher temperature resistance and higher mechanical properties. Most of the parts inside the cylinder should undergo surface treatment. The choice of the process depends on the functional efficiency and cost. Generally cast iron is used for cylinder components which exhibit outstanding wear characteristics, high strength properties even at high temperatures, but the disadvantages are high weight and excess fuel consumption. Aluminium alloys replace them as they are light weight but the wear resistance against the piston and piston ring is poor. Hence there is a need to investigate methods to improve the performance of Aluminium alloys to enable the practical applications. One such method is Electroless Nickel (EN) coating on Aluminium. EN coated Aluminium was investigated for its tribological properties through experimental methods and strength through Finite Element Analysis. The investigation shows that EN coated Aluminium has superior tribological properties when compared with Cast Iron and it has adequate strength. It is concluded that EN coated Aluminium has a high potential to be used as cylinder liners.

### **INTRODUCTION**

Electroless Nickel (EN) coating first developed by Brenner and Riddell (1) has received attention as a hard coating for industrial applications (2) due to its high hardness, uniform thickness as well as excellent corrosion and wear resistance. EN coating is an autocatalytic deposition of a Nickel–Phosphorus alloy from an aqueous solution onto a substrate without the application of electric current and this property gives it an extra advantage over the conventional electroplating processes that depend on an external source of direct current in order to reduce nickel ions in the electrolyte to nickel metal on the substrate.

It improves the mechanical and tribological properties of coatings (3, 4). The alloys with different percentage of phosphorus, ranging from 2% (low phosphorus) to up to 14% (high phosphorus) are possible (5). EN coating has several advantages when compared with electroplating. It is free from flux-density and power supply issues. It provides an even deposit regardless of work piece geometry. With the proper pre-plate catalyst, it can deposit on non-conductive materials such as plastics also.

### **EXPERIMENTAL PROCEDURE**

#### Test Material

Aluminium specimens of 10 mm diameter x 30 mm length are used as the substrate material for the deposition of EN coating. The chemical composition of the material was analyzed using a direct reading vacuum spectrometer and is given in Table 1.

Table 1: Substrate material composition

Constituent	Si	Mg	P	Ni	Cu	Al
%	8.49	4.77	0.41	0.25	0.06	Balance

### Surface Preparation

The specimens are cleaned by a series of cleaning chemicals such as bases and acids to have good adhesion. Each chemical pre-treatment is followed by water rinsing to remove the chemical that adheres to the surface. Degreasing removes oil from surface and acid cleaning removes scaling. Activation is done with a weak acid etch, or nickel strike. After the coating process, coated material is finished with an anti-oxidation or anti-tarnish chemical (trisodium phosphate, chromate etc) and pure water rinsing to prevent unwanted stains.

### Electroless Nickel Bath

Table 2 indicates the electroless bath composition and operating conditions used for the deposition of EN coating. EN deposition is carried out using nickel chloride as the source of nickel, sodium hypophosphite as the reducing agent and sodium citrate as the stabilizer. The pH value of the bath was maintained at a fixed value by adding required quantity of liquor ammonia. The cleaned samples are activated in palladium chloride at 85°C and placed in the bath for deposition. After the deposition, the samples are washed in distilled water.

Table 2: Electroless bath composition and operating conditions (6).

Constituent	Quantity g/L	Parameter	Condition
Nickel Chloride	30	Bath Temperature	85°C
Sodium Hypophosphite	40	pH	10-12
Sodium Citrate	25	Duration	10 min
Ammonium Chloride	50		
Surfactant	0 -0.12		

### Microstructure

Metallographic preparation was done as per ASTM E 407 standards (7). Etching was done with 10% sodium hydroxide at room temperature for 3 seconds. The microstructure of EN coated Aluminium specimen was photographed using Clemex image analyzer.

### Surface Roughness

The surface roughness of the specimen was measured using Taylor Hobson surface roughness tester for an evaluation length of 10 mm with measuring speed of 0.3 mm/s.

### Microhardness

The microhardness of the surface layers of the Cast Iron, Aluminium and EN coated Aluminium specimens were measured using a ZWICK 3232 model micro hardness tester. The hardness tests were performed under an indentation load of 100g for 15s.

### Wear and Friction

Pin-on-disc tests were carried out to examine the wear and friction properties. The tests were operated under dry lubricated conditions in air with a relative humidity of 80± 5% and an

ambient temperature of 25°C. The pin of 10 mm diameter (specimen) was loaded with a normal force of 30N against the disc with a sliding velocity of 0.5 m/s.

### Line Scan Analysis

The specimens were characterized using a scanning electron microscope with energy dispersive analysis of x-ray. The line scanning was carried out to identify the concentration and distribution of the elements Nickel and Phosphorus.

### Coupled Field Analysis of Cylinder Liner

The finite element analysis of the EN coated Aluminium cylinder liner was done using ANSYS software (8). To make the analysis simple the following assumptions were made:

- i. The EN coated Aluminium is a homogeneous and isotropic material
- ii. The effects of other neighbouring areas are neglected.

The stepwise procedure for the analysis is as follows:

1. Coupled Field Analysis: To find out the stress distribution across the substrate and coating, thermal analysis is coupled with the structural analysis.
2. Element Type: The element which best suits this analysis is a brick element SOLID 45 (8 nodes) which is used for the 3-D modeling of the structures. The element is defined by eight nodes having three degrees of freedom at each translation in the nodal x, y and z directions. The element has plasticity, creep, swelling, stress stiffening, large deflection and large strain capabilities.
3. Material Type: The material property data such as thermal and structural constraints for Cast Iron, Aluminium and EN coated Aluminium are shown in the Table 3.

Table 3 Properties of different material used for the FEA

Material	Elasticity Modulus E, GPa	Thermal Conductivity k, cal/s cm °C	Poisson's Ratio $\nu$
Cast Iron	100	0.13	0.23
Aluminium	67.5	0.53	0.34
Nickel	200	0.31	0.22

4. Modeling: A three-dimensional model of the cylinder liner was created using various tools like hollow cylinder, create area and extrude. For EN coated Aluminium, the coated material is glued to the aluminium material using Boolean operation. Standard cylinder liner dimensions are used for generating the model in the software.

5. Meshing: The model was meshed into a fine mesh of brick type eight noded solid elements. The cylindrical element is meshed using sweep mesh option to have better meshing for accurate results. The sweep mesh of EN coated Aluminium is shown in Figure 1.

6. Boundary Conditions: The cylindrical cross section on both sides of the liner are fixed i.e. on the outer end  $dx = dy = dz = 0$

7. Loading Conditions for the analysis are shown in Figure 2.

- i. The inner surface of the cylinder is assumed as 100 °C in all cases

- ii. Temperature on the outer surface is varied in accordance with the thermal conductivity of the respective material.
- iii. The pressure distribution on the inner surface is assumed to be constant for all cases.

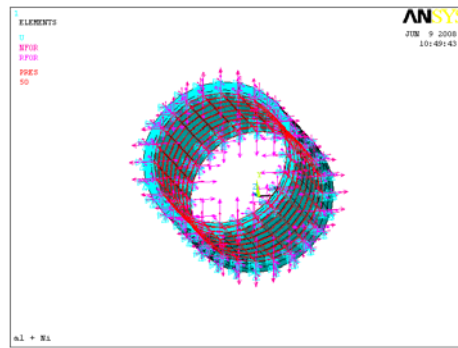
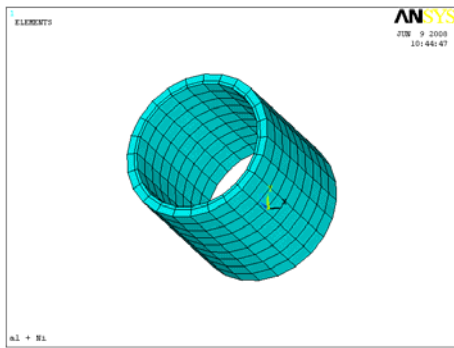
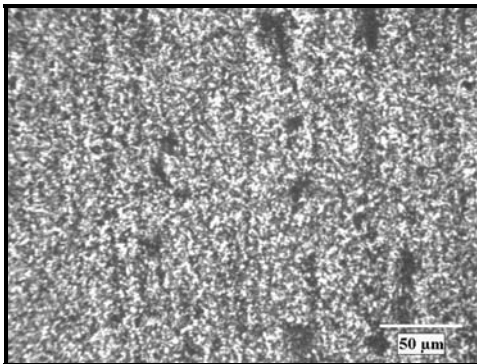


Figure 1: EN coated Aluminium sweep mesh      Figure 2: Loading conditions for EN coated Aluminium

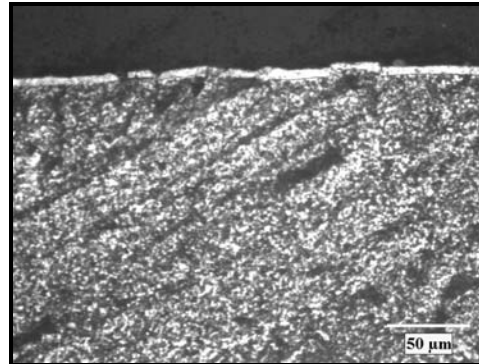
## RESULTS AND DISCUSSION

### Microstructure

Samples were prepared using standard metallographic procedures and etched in 10 % sodium hydroxide solution to reveal the microstructure. Figure 3(a) shows the microstructure of Aluminium specimen. Figure 3(b) shows a typical microstructure of EN coated Aluminium specimen consisting a surface layer of Nickel-Phosphorus alloy and the base metal.



(a) Aluminium



(b) EN coated Aluminium

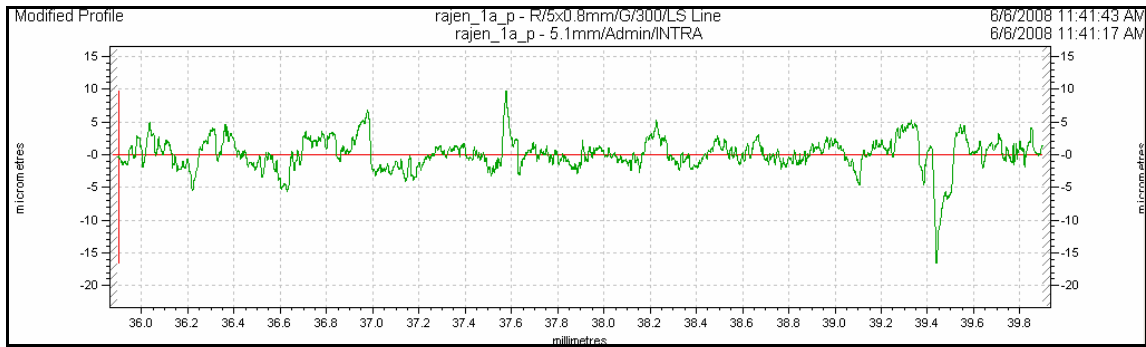
Figure 3: Optical micrograph: Etchant used: 10 % NaOH Mag: 200 X

### Surface Roughness

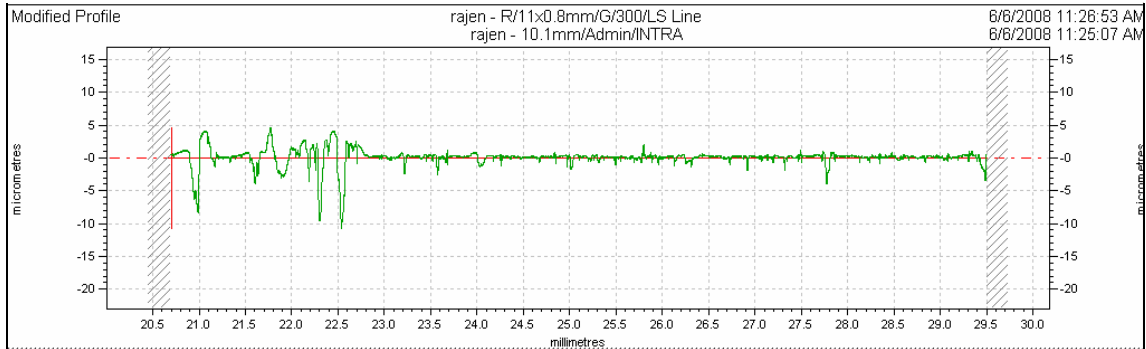
The surface roughness ( $R_a$ ) values of the Aluminium and EN coated Aluminium specimens were found to be  $1.6995 \mu\text{m}$  ( $Rz_{Al} = 12.64444 \mu\text{m}$ ) and  $0.6460 \mu\text{m}$  ( $Rz_{EN Al} = 6.0091 \mu\text{m}$ ) respectively. The roughness profile is shown in the Figure 4(a-b).

### Microhardness

Surface hardness of the EN coated Aluminium specimen is 480-500  $Hv_{0.1}$  (9) whereas the surface hardness of Aluminium specimen is 80- 90  $Hv_{0.1}$  as seen in Figure 5(a). It is clearly seen that EN coated Aluminium specimen has attained a high hardness when compared with the base Aluminium specimen.



(a) Aluminium

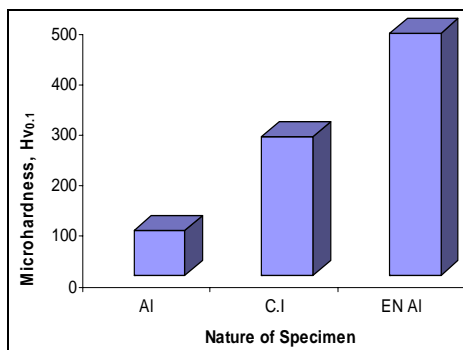


(b) EN coated Aluminium

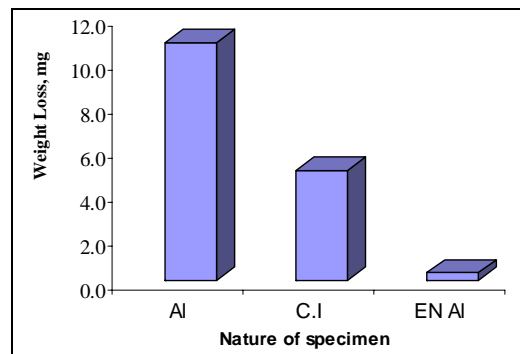
Figure 4: Surface roughness profile

### Wear and Friction

The wear test was conducted on a pin on disc wear testing machine at a load of 30 N with sliding distance of 1000 m. The wear of EN coated Aluminium specimen was found to be significantly less than Aluminium and also Cast Iron specimens as shown in Figure 5(b).



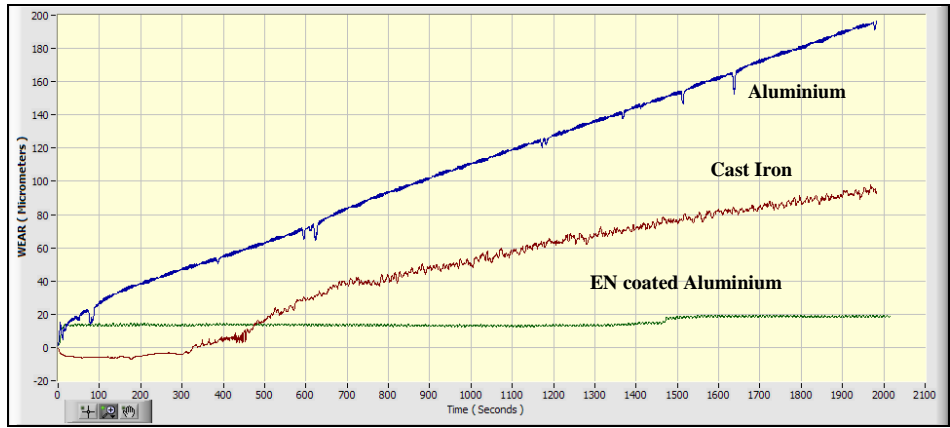
(a) Surface hardness



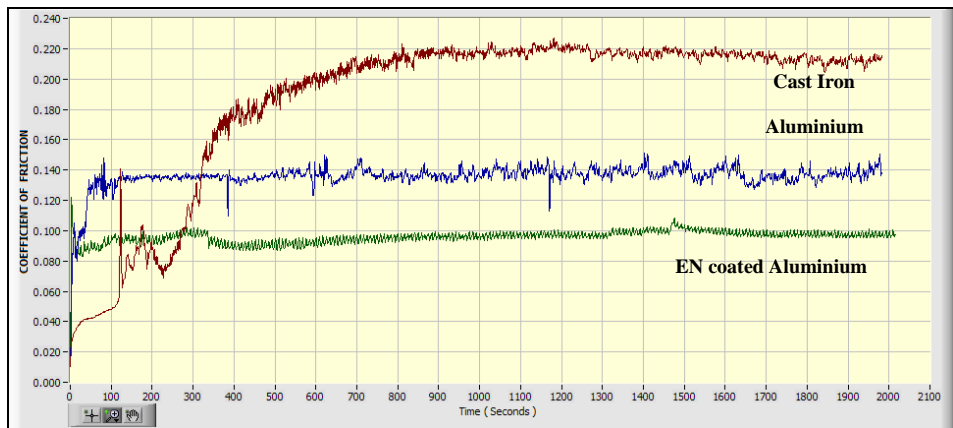
(b) Wear

Figure 5: Comparison of properties - Aluminium, Cast Iron and EN coated Aluminium

The results of the pin-on-disc wear test at room temperature are summarised in the Figure 6(a). The coefficient of friction values for EN coated Aluminium was found to be lower than Cast Iron and Aluminium as shown in Figure 6(b).



(a) wear

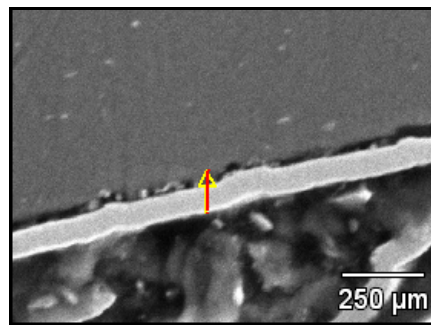


(b) Coefficient of friction

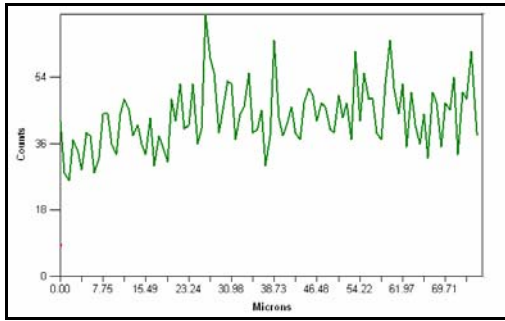
Figure 6: Comparison - Cast Iron, Aluminium and EN coated Aluminium

### Line Scan Analysis

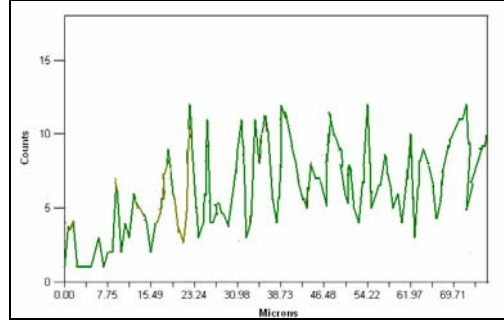
Figure 7(a) shows the SEM photograph of EN coated Aluminium. The line-scan analysis was performed across the coated specimen to a certain distance and the elemental spectra of Nickel and Phosphorus are shown in Figure 7(b-c). The results of the line scan reveal that Nickel is present in large percentage and Phosphorus is in small amount 5-7%.



(a). SEM photograph of EN coated Aluminium showing the layer thickness



(b) Nickel

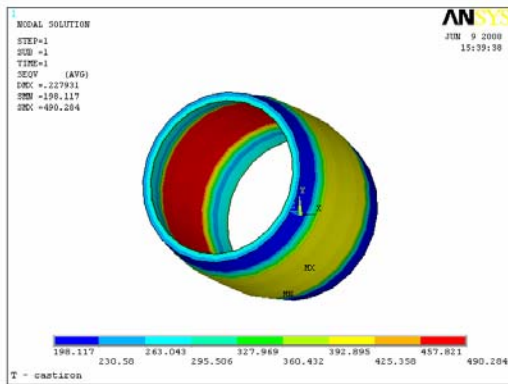


(c) Phosphorus

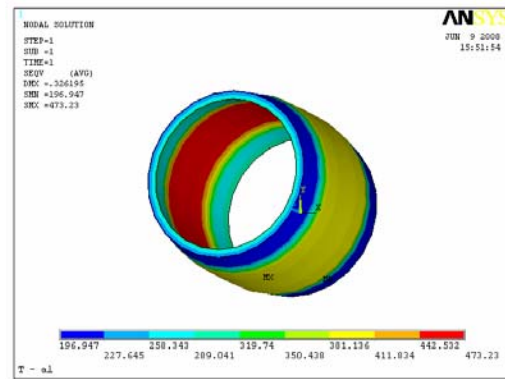
Figure 7: Line Scan Profile of the EN coated Aluminium

### Thermal Stress Distribution on the surface of the Cylinder Liner

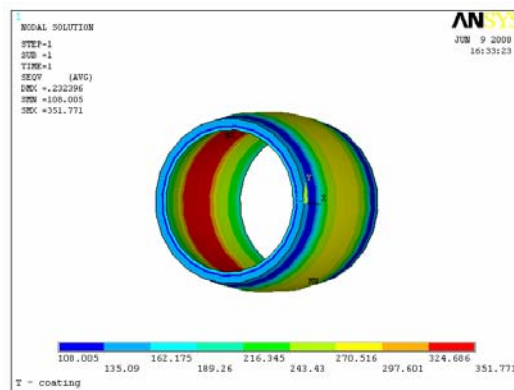
The analysis of the cylinder liner based on the given boundary conditions is carried out using the software and the results are plotted. The thermal stress distribution over the entire surface of the Cast Iron, Aluminium and EN coated Aluminium are obtained from the finite element analysis.



(a) Cast Iron



(b) Aluminium



(c) EN coated Aluminium

Figure 8: Thermal Stress distribution and deflection

Figure 8(a-c) shows the thermal stress distribution over the entire surface of the cylinder liner for various materials. The thermal stress range of EN coated Aluminium is less than the stress values of Cast Iron and Aluminium as evident in Table 4.

Table 4: Thermal stress range and Deflection obtained from FEA

Material	Max Deflection	Stress Range
Cast Iron	0.227931	292.167
Aluminium	0.326195	276.283
EN coated Aluminium	0.232396	243.766

## CONCLUSION

Electroless Nickel coating on Aluminium has following properties:

1. uniform coating thickness
2. high hardness in the range of 480- 500 Hv<sub>0.1</sub>
3. low surface roughness value of 0.646  $\mu\text{m}$ .
4. high wear resistance
5. low coefficient of friction

These properties are significantly better than base Aluminium and also Cast Iron. The primary cause for these improved properties is the presence of Nickel and Phosphorus (5-7%) revealed by line scan analysis.

The stresses obtained by FEA are found to be well below the allowable stress for EN coated Aluminium.

Hence it is concluded that EN coated Aluminium has a high potential to be used as engine liners.

## ACKNOWLEDGEMENT

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