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The influence of Cobalt coating on Corrosion and functional properties of Mild Steel in 3.5% NaCl

K. Mohanam[1], G. Venkatachalam[1], S. Karthikeyan[2], P.A. Jeeva[1]

[1]School of Mechanical and Building Sciences, VIT University, Vellore-632 014, India.

[2]*Surface Engineering Research lab, Centre for Nanobiotechnology, VIT University, Vellore-632 014, India.

*Corresponding author (skarthikeyanphd@yahoo.co.in)

Abstract

The electroless cobalt coatings on mild steel have been studied by weight gain method, corrosion studies by potentiodynamic polarization measurements and hardness by Vickers microhardness tester. The influence of surface roughness has greatly contributed for corrosion and tensile strength of the coatings. SEM and XRD measurements were performed to study the surface morphology of cobalt coatings on mild steel.

Keywords: Electroless cobalt plating, tensile, corrosion, SEM

Introduction

The electroless cobalt coatings are widely used plating process in industries because of their improved corrosion resistance and magnetic properties[1-5]. In particular, defence applications have drawn much attention on cobalt coatings to assess the signals from military armaments owing to its magnetic properties[6-10]. Besides the above, corrosion resistance behaviour is an important parameter for defence materials. Electroless nickel coatings have been generally used as defence coatings. However, the presence of phosphorus in EN induces non-magnetic character and hence EMI shielding is more for EN coatings[11-19]. In recent years, the combined actions of magnetic as well as corrosion resistance behaviour of cobalt have attracted the researchers. The research in this direction is still very scarce and hence the present study.

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Experimental Procedure

Weight gain method

The Mild steel specimen was prepared for the following dimensions: 30 mm x10.60 mm x1.60 mm. They were mechanically polished with fine grit paper, washed with distill water. The bath for electroless plating was prepared as per the chemical composition given in table1. Prior to plating specimen, specimen was immersed in Hydro chloric acid to remove impurities like carbon. Then the process is carried out to protect the surface to be with cobalt coated. Figure 1 shows the schematic diagram of experimental setup. The initial mass of mild steel was weighed using electronic weighing machine. Then the mild steel were subjected to electroless cobalt plating(1 μm). The rate of deposition was calculated using the following formula:

Where,
$$\text{The rate of deposition } (\mu m/h) = \frac{W \times 10^4}{D\,A\,T}$$

W – Weight of the deposit (g)
D – density of the deposit (g/cm^3)
T – plating duration (h)
A – Surface area of the specimen (cm^2)

Micro hardness measurements

Micro hardness measurements for mild steel on cobalt (20 x 50 x 2 mm^3) were measured using Vicker's harness tester as per ASTM with a load of 100 g. A diamond shaped indentation was created on each coated mild steel at eight different locations and the mean of hardness was calculated from the diagonal of indentation on Vicker's scale using the formula.

V.H.N = (1854 x load) / d^2

where d = diagonal of the indenter

Corrosion resistance measurements

The potentiodynamic polarization and impedance studies were performed on mild steel on cobalt coated area of 10 mm^2 exposed surface (test electrode) in 3.5% NaCl, 40 mm^2 of platinum electrode (counter electrode) and saturated calomel as reference electrode in three electrode cell assembly[19].

Potentiodynamic polarization method

A constant quantity of 250 ml of 3.5% NaCl (sea water) solution was taken in a 250 ml beaker. The test electrode, reference electrode and the counter electrode were positioned in the electro chemical workstation (Sinsil Model 604E, USA) and the readings were recorded by shifting the potential ± 300 mV from OCP at a scan rate 10 mV.second-1 for the mild steel.

The corrosion rate factors like E_{corr} and I_{corr}, were recorded. The reduction in E_{corr} and I_{corr} values indicated that the coatings are having good corrosion resistance than those reported earlier.

Tensile strength measurements

This measurement was carried out using tensometer as per ASTM for the tensile test.

Scanning electron microscopic studies (SEM)

The micro structural images of cobalt coated mild steel were studied using SEM analyzer. The coated test electrodes were prepared for size 10 x 10 mm2 and placed firmly on crucible to be examined for SEM images. The SEM images were portrayed by using GEMINI SUPRA 55 model with FESEM and with the magnification range of 25kX.

Results and Discussions

Stress-strain behaviour studies

The Figure 2 shows result of Co coating affects the stress strain behaviour of Mild steel. Till the elastic limit, there is no major difference in the value of yield stress. But a significant difference is visible in the stress strain curve after yield stress. This is due to the high ductility of Co metals. The differences in the stress stain behaviours are insignificant from elastic limit to plastic instability. There is minor change in the values of ultimate stress and failure stress if the mild steel is coated with cobalt. Uncoated mild steel exhibits low percentage of elongation then the coated one.

Micro hardness measurements

The hardness of the electroless deposited cobalt coatings determined by Vicker's hardness tester is presented in Table 2. The hardness values increased to 2 or 3 times by Co coating due to the precipitation of inter metallic phases (Co_3P_2) appeared in XRD data. The increased hardness is claimed for precipitation hardening mechanism through the formation of Co_3P_2.

Corrosion resistance studies

Potentiodynamic polarization studies

The corrosion resistance experiments were performed for hard coatings on Mild steel has been done by employing current-voltage measurements using polarization studies. The coated surface was exposed to sea water medium for 5 hours and OCP was noted. The shift of Potential to more positive direction by coating indicated the corrosion resistance of the surface. Also I_{corr} has reduced by coatings shown in figure 3. The results are given in table 3.

Scanning Electron Microscopic studies

The formation of layered structures indicates the Co_3P_2 phase on mild steel. The aggregation of Co-P is clearly evident that through the back ground of cotton like layers. The presence of micro cracks are indicating that cobalt is a soft metal which has deposited on steel are shown in figure 4.

The figure 5 indicates corrosion of mild steel in sea water medium through the severe attack of sea water mild steel particularly at the corners than the rest of the metal. The presence of deep pits, dendrites and scratches confirmed the attack of Cl- on mild steel.

X-Ray Diffraction Analysis

X-ray diffraction patterns, as shown in Figure 6, trace the properties of crystalline and amorphous peaks on coated hardened and coated without hardened. These patterns gradually change from sharp to very broad peaks with increasing phosphorus content as the structural composition slowly changes from crystalline to amorphous. Spectra show sharp peaks around 14°, 17°, 25°, 45°, 65°, 78° corresponding to nickel and very few diffuse diffraction peaks at (110), (220), (100), (111) planes of varying phases of cobalt phosphate.

Surface roughness

Mild steel is made of fine refined surface oriented atomic species. The incorporation of Co decreased the roughness which is evident from Ra values are given in table 4 Cobalt coated on mild steel and table 5 mild steel.

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Conclusion

- An engineering coating based on Co and Mild steel was successfully developed. There is a little influence in values of field stress and ultimate tensile stress due to cobalt coating on mild steel.
- XRD studies revealed that the formation Co_3P phase.
- The coating exhibited higher hardness than Mild steel both plated as well as heat treated condition at 400^0C.
- The enhancement of hardness due to the precipitation hardening effect by forming Co_3P Phase.
- The Co_3P coatings offered better corrosion resistance in sea water medium than Mild steel alloy this was confirmed by potentiodynamic polarization studies.
- Cobalt phosphorus coating have significantly reduced the tensile stress of Co alloy validating that the incorporation of Co_3P in Iron matrix.

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Table 1 The bath used for metallization of mild steel had the following chemicals:

Sl.No	chemical composition	weight
1.	Cobalt Sulphate-0.12M	33g/L
2.	Sodium acetate-0.6M	50g/L
3.	Sodium Hypo phosphate-0.32M	28g/L
4.	pH	4.8
5.	Temperature	700C

Table 2.Micro hardness measurement

S.No	Material	Vickers Hardness Number Load:100g [V.H.N]
1	Mild steel	180
2	Cobalt coating	390
3	Heat treated surface	812

Table 3. Corrosion results

			Tafel slopes	
Nature of substrate	Ecorr (mv)	Icorr (µA.cm-2)	ba	bc
Uncoated	-412mv	1.82X10-4	60	66
Coated	-310mv	5.8x10-5	52	63

Table.4. Surface roughness result for cobalt coated mild steel

Sl.No	Ra(µm)
1	0.3737
2	1.1497
3	0.3322
Average	0.6185

Table.5. Surface roughness result for uncoated mild steel

Sl.No	Ra(µm)
1	1.6502
2	1.6570
3	1.4297
Average	1.5790

Legends for figure

1. Experimental apparatus of autocatalytic cobalt deposition.

2. Stress strain curve for steel with and without coated Experimental.

3. Cobalt coated Mild steel & Mild steel.

4. SEM image of Cobalt coated Mild steel.

5. SEM image of Uncoated Mild steel.

6. XRD Patterns of electroless Cobalt coated mildsteel with and without hardening.

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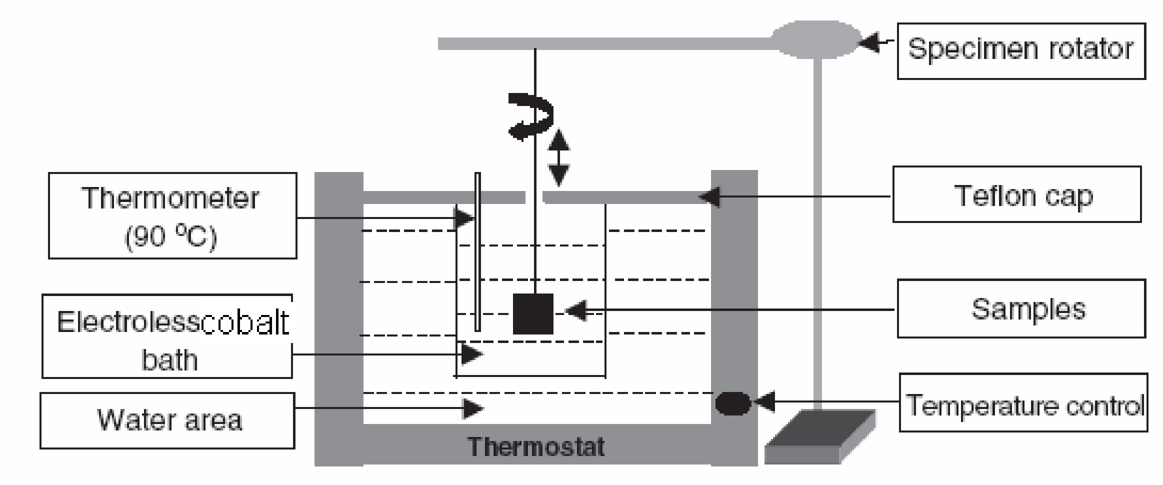

Figure 1

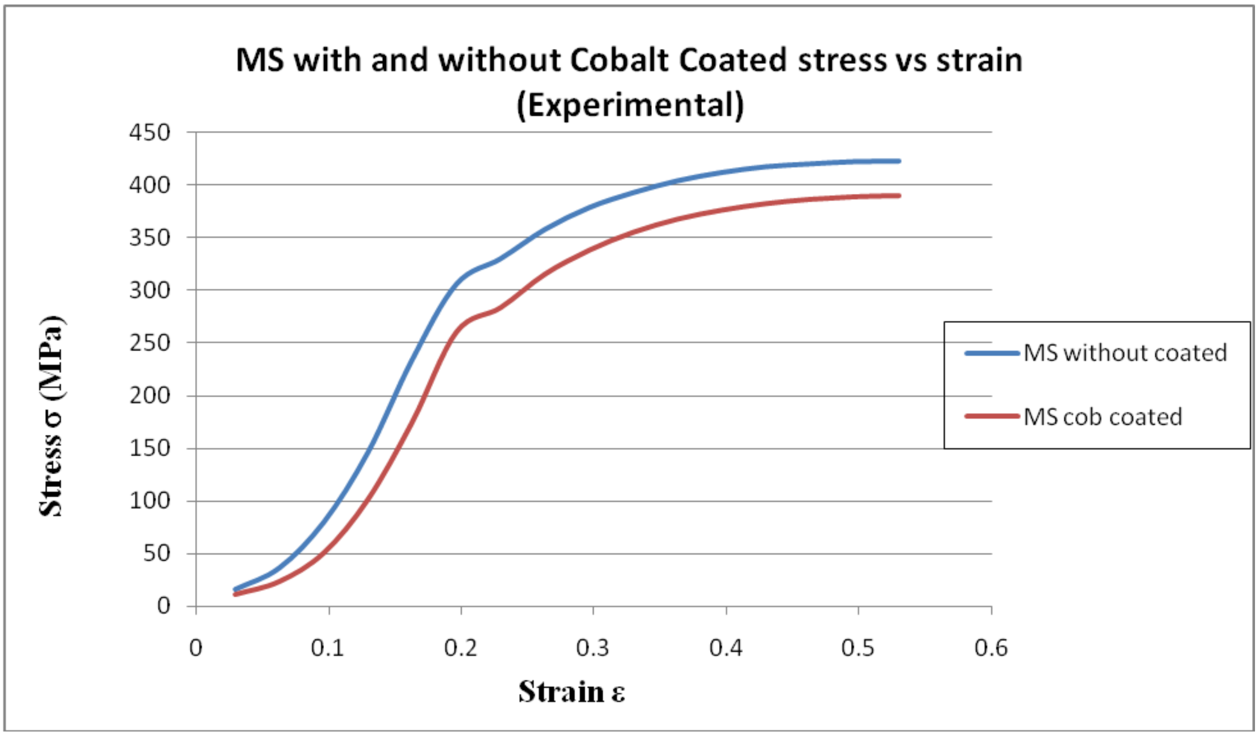

Figure 2

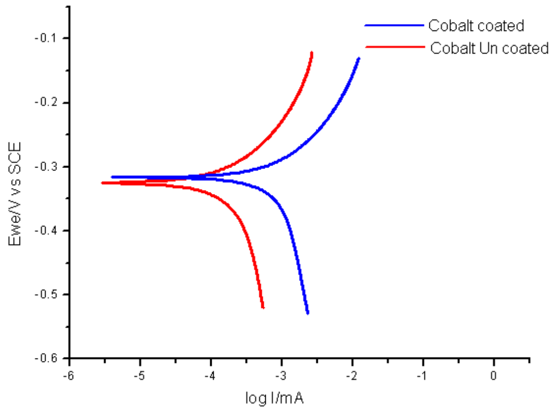

Figure 3

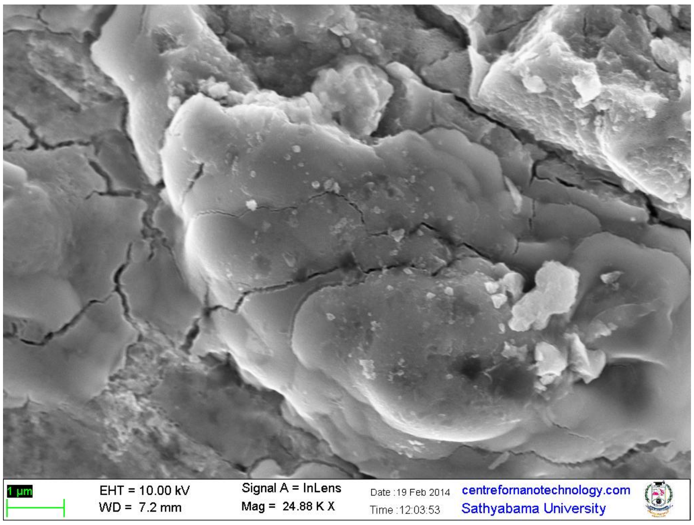

Figure 4

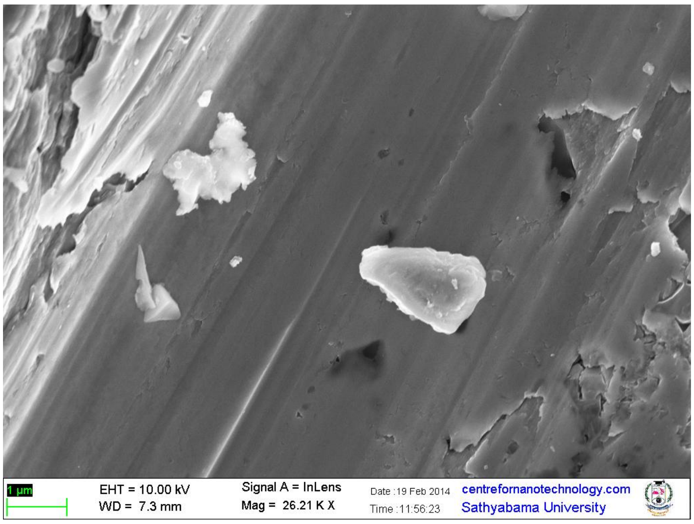

Figure 5

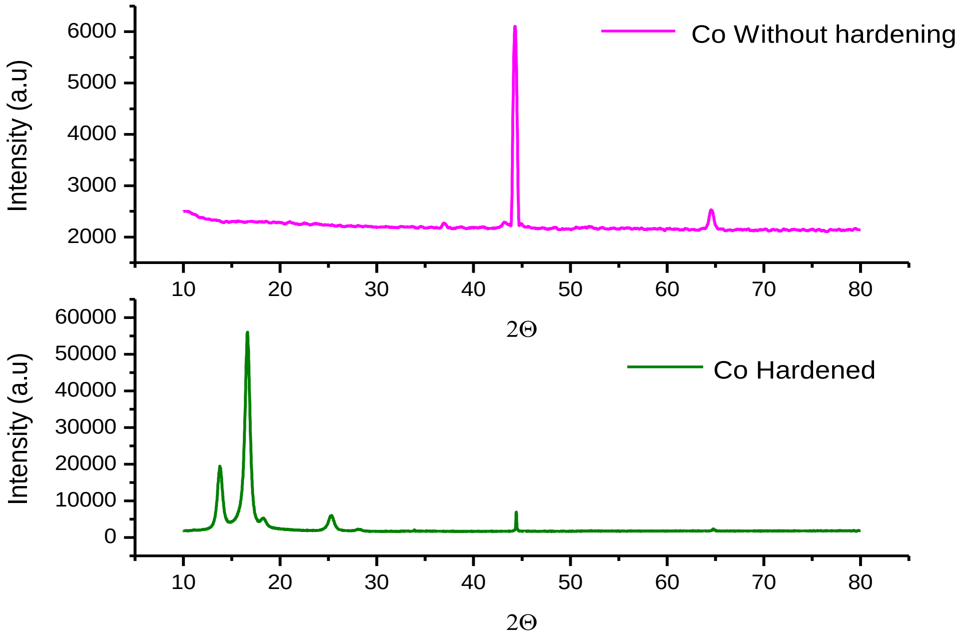

Figure 6