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# Experimental study on the microstructural and anti-corrosion behaviour of Co-deposition Ni–Co–$SiO_2$ composite coating on mild steel

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ABSTRACT

Mild steel is commonly used in the construction of Pipeline. The major problem of this Pipeline is corrosion. Effort is make my researchers to combat this problem. In this work Co-deposition of Ni-Co-$SiO_2$ composite coating on mild steel was reported with the view to reduce this problem. The $SiO_2$ was varies from 5 to 25wt% in the deposition. The microstructure, hardness values and potentiodynamic polarization in simulated sea water were determined. The results show that XRD pattern of the NiCo deposited mild steel revealed the presence hard phases of NiO, $Co_5Ni$, $Co_2Ni_3$, $NiCo_5$ while that of Ni-Co-$SiO_2$ deposited mild steel revealed the presence harder phases of $NiOSiO_2$, $CoNi_7Si_2$, $Co_5Ni_2Si_3$. The NiCo-25$SiO_2$ deposited sample has smaller particle size than Ni-10Co coating. Coating thickness of 110.7 μm was obtained for Ni-10Co coating, while coating thickness of 135.7, 157.7, 165.0 μm were obtained at Ni-10Co-x$SiO_2$(x = 10, 15, 25wt%). 99.90% corrosion resistance was achieved at Ni-Co-25$SiO_2$. This improvement in corrosion resistance after composites coating could be attributed to the hard and fine structure obtained after coating.

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## 1. Introduction

Electrodeposition of zinc is a widely used industrial process to coat on steel materials to enhance its service life. Zinc, being more active than iron, protects sacrificially by forming white rust. Zinc has been the most widely used electrodeposited metal for protecting steel from corrosion because of economic usage and cost [1]. Its corrosion resistance, however, is limited. During the last two decades, efforts to improve the corrosion stability of pure zinc coatings have been directed towards alloying it with more noble metals such as nickel, cobalt, iron, and cadmium [2,3]. As a result, alloys such as Zn-Ni, Zn-Co, Zn-Fe, and Zn-Cd find wild spread use in industries as replacement for direct electroplating of zinc [4].

Recently, much effort has been devoted to fabricating Ni-Co composite coatings You et al. [5] studied electrodeposition of Ni-Co alloys from a deep eutectic solvent. The effects of saccharin and cobalt concentration in electrolytic solution on microhardness of nanocrystalline Ni-Co alloys was reported by Li et al. [6]. Yuxinet al [7] reported on Ni-Co-$TiO_2$nano-composite coatings on mild steel by adding transparent $TiO_2$sol (0–50 mL/L) into the Ni-Co plating solution. It was found that after adding an optimum sol concentration into the plating bath, a good dispersion of $TiO_2$ nanoparticles can be achieved in the Ni-Co coating matrix, resulting in a significant improvement in coating mechanical properties.

Tolumoye et al. [8] reported on composite electrodeposits of Zn-Ni/$SiO_2$ produced electrolytically using direct current. The linear polarisation resistance of coatings containing $SiO_2$ tends to increase with increasing particle content up to 5.5wt% $SiO_2$ and then decreases. Popoola et al. [9] reported on Surface characterization, mechanical properties and corrosion behaviour of ternary based Zn-ZnO-$SiO_2$ composite coating. The results showed that average hardness value of 142.5 and 251.2HV and corrosion rate of 0.13088 and 0.00122 mm/yr were obtained for the 0 and 16wt% $SiO_2$ in Zn-ZnO.

Eliaz et al. [10] reported on Zn–Ni, Zn–Co and Zn–Ni–Co coatings on mild steel from an acidic chloride bath containing p-aminobenzenesulphonic acid (SA) and gelatin. The effect of gelatin was more pronounced than that of SA. The Faradaic efficiency was higher than 90%. As the current density was increased or the bath

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temperature was decreased, the concentration of the nobler metal in the coating increased. Tamilselvi et al. [11]reported on the development of nano $SiO_2$ incorporated nano zinc phosphate coatings on mild steel at low temperature for better corrosion protection. The results showed that, the nano $SiO_2$ in the phosphating solution changed the initial potential of the interface between mild steel substrate and phosphating solution and reduce the activation energy of the phosphating process, increase the nucleation sites and yielded zinc phosphate coatings of higher coating weight, greater surface coverage and enhanced corrosion resistance. Better corrosion resistance was observed for coatings derived from phosphating bath containing 1.5 g/L nano $SiO_2$. The new formulation reported in the present study was free from Ni or Mn salts and had very low concentration of sodium nitrite (0.4 g/L) as accelerator.

Development of a multilayer-modified coating that enhanced the surface characteristics of mild steel against chemical and mechanical deterioration with a ternary Zn-Ni-$Al_2O_3$ composition induced with monoethylanine and triethylanine as surfactant using electrolytic chemical deposition was successfully done by Fayomi et al. [12]. The deposition of admixed Zn-Ni-$Al_2O_3$ ternary composite particles in the presence of bath-additive surfactant on to the substrate was impressively enhanced. There exist an improvement in the structural modification and better interfacial adhesion of coatings on the substrate upon addition of triethylanine and monoethylanine as surfactants during the deposition process along with the electro-deposition variables considered. The corrosion resistance improvement of the coated surface was observed. Ghaziof and Gao [13] reported on Zn-Ni-$Al_2O_3$ nanocomposite coatings on mild steel using a novel sol enhanced electroplating method. They found out, that Zn-Ni-$Al_2O_3$ nanocomposite coatings produced more uniform and compact deposits, with fine grained microstructure when compared to Zn-Ni coatings. The corrosion resistance of Zn-Ni coatings improved significantly by incorporation of alumina nanoparticles into the coatings. In order to increases research in this novel area of co-deposition of mild steel pipeline, this present work study look at the development of a multilayer-modified coating that will enhance the surface characteristics of mild steel against chemical and mechanical deterioration with a ternary Ni-Co-$SiO_2$ composites surfactant using electrolytic chemical deposition.

## 2. Materials and method

### 2.1. Materials

Mild steel of dimension 200 mm × 200 mm was used for the substrate. Table 1 shows the chemical composition of mild steel used. Pure nickel anode, nickel chloride, potassium chloride, boric acid, thiourea, 2 dimethylaminoethanol, cobalt and silicon dioxide, cobalt and silicon oxide powders were sourced from Sunc International Limited and TLS Technik.

### 2.2. Method

Sectioning of the mild steel was done using automatic struers high precision cut-off machine. The mild steel was sectioned in plates of dimensions of 20 mm by 20 mm.After sectioning the steel plates, they were ground and polished with grit paper and diamond paste. The degreasing of the polished samples was done using ethanol. The composition and condition of the electro-bath to produce Ni-Co and Ni-Co-$SiO_2$ composites coating is shown in Tables 2 and 3.

**Table 1**
Chemical composition of mild steel.

| Element | C | Mn | Si | P | S | Al | Ni | Fe |
|---|---|---|---|---|---|---|---|---|
| Composition | 0.15 | 0.45 | 0.18 | 0.01 | 0.031 | 0.005 | 0.008 | Balance |

The pH of the bath was adjusted to 4.5 by the addition of HCl and NaOH. Before co-deposition, the $SiO_2$ particulates of a mean diameter 55 nm were distributed in the bath electrolyte in the presence of other additives. The deposition setup test was achieved on a set up vessel connected to a laboratory rectifier. The bath was stirred by a magnetic stirrer consistently with about 200 rpm at 40 °C. The morphologies of the composite coatings were observed with the help of atomic force microscope, scanning electron microscope and x-ray diffractometer. The electrochemical studies were performed with Autolab PGSTAT 101 Metrohm potentiostat using a three-electrode cell assembly in a 3.65% NaCl static solution at 40 °C. The developed composite was the working electrode, platinum electrode was used as counter electrode and Ag/AgCl was used as reference electrode. The anodic and cathodic polarization curves were recorded by a constant scan rate of 0.012 V/s which was fixed from ±1.5 mV. From the Tafel corrosion analysis, the corrosion rate, potential and linear polarization resistance was obtained.

## 3. Results and discussion

### 3.1. XRD analysis

The XRD of the mild steel is shown in Fig. 1. From Fig. 1 it can be seen that the XRD spectrum has phases of $Fe_3C$(cementite) and α-Fe(ferrite). It was observed that the steel has α-Fe(ferrite) phase with 100 relative intensity. This supported the analysis of chemical composition of the steel in Table 1. This is par with the XRD pattern of Fayomi et al. [12].

Fig. 2 shows the XRD pattern of the NiCo deposited mild steel. The XRD pattern revealed that hard phases of NiO, $Co_5Ni$, $Co_2Ni_3$ and $NiCo_5$, covered the steel surface after deposition while Fig. 3 shows the Ni-Co-$SiO_2$ deposited mild steel. Fig. 3 revealed the presence of harder phases of $NiOSiO_2$, $CoNi_7Si_2$ and $Co_5Ni_2Si_3$. These phases formed from the Ni-Co-$SiO_2$ deposited sample are harder than that of Ni-Co deposited sample. This is attributed to the presence of $SiO_2$ and Si in Fig. 3 which help to strengthen the materials. Similar observation was obtained in the work of Yuxin Wang et al. [7] of deposition of Ni-Co-$TiO_2$ nano-composite coatings on mild steel.

**Table 2**
Bath Composition of Ni-Co-$SiO_2$ Alloy co-deposition Matrix.

| Composition | Mass concentration/($g \cdot L^{-1}$) |
|---|---|
| Nickel chloride | 100 |
| Potassium chloride | 30 |
| Boric acid | 10 |
| Thiourea | 5 |
| 2 Dimethylaminoethanol | 5 |
| Silicon dioxide | 10–25 |

**Table 3**
Formulated Designed bath composition of Ni-Co-$SiO_2$.

| Sample order | Matrix sample | Time of deposition/min | Current/($A \cdot cm^{-2}$) |
|---|---|---|---|
| 1 | Ni-10Co | 20 | 1.0 |
| 2 | Ni-10Co-10$SiO_2$ | 20 | 1.0 |
| 3 | Ni-10Co-15$SiO_2$ | 20 | 1.0 |
| 4 | Ni-10Co-25$SiO_2$ | 20 | 1.0 |

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