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Electrochemical and surface characterization of mild steel with corrosion resistant zirconia network fabricated by aqueous sol-gel technique

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ABSTRACT

Zirconia (ZrO_2) coating was developed on mild steel surface through an aqueous sol-gel route followed by heat treatment. The coating quality was optimized by varying dipping time, curing time, and drying temperature. ZrO_2 coating was competent to prevent a substantial corrosion loss in 0.5 M–2 M hydrochloric acid with more than 90% efficiency. The morphology of coated surface has revealed the formation of a fine ZrO_2 network on the metal surface at optimum conditions. This network is found to be effective to control steel deterioration in hydrochloric acid and the same appeared to be either cracked or irregular for less efficient formulations.

1. Introduction

Zirconia is a promising ceramic material with interesting physical and chemical properties such as high strength, high fracture toughness, abrasion resistance, corrosion resistance, high-temperature resistance, excellent wear resistance, hardness, and chemical resistance [1–5]. It is a wide bandgap p-type semiconducting material of great technological relevance. The material is efficient for oxygen ion transport and reasonably it is one among the best oxidation-resistant barrier materials. Zirconia has been used in catalysis and high-temperature energy conversion systems owing to its high ion exchange capacity, redox properties, and stability. It has been enrolled for future nanoelectronics devices and is frequently used in metal oxide semiconductor devices, dental ceramics, solid oxide fuel cells, and gas sensors. The thermal expansion coefficient of zirconia is very close to carbon steel and zirconia-based ceramic coatings are essentially used in industries for preserving metallic components and machinery [1,5–14].

Industrial sectors employ acid solutions especially hydrochloric acid solutions for pickling, chemical, and electrochemical etching of carbon steel alloys and other construction metals [15–17]. Owing to its good mechanical properties and low cost, mild steel is massively used in industries such as automotive, military, commercial machines, marine, oil, and chemical industries [18–21]. However, the industries have to compromise a substantial economy to tackle corrosion loss of metallic components. Chromate and arsenate treatment were used in the early times were banned since they were identified as carcinogenic. Nowadays, the use of corrosion-resistant coatings and corrosion inhibitors has been widely employed to address the problem [22]. The inhibitor class employs synthetic and natural organic hetero-compounds capable of making a passivation layer on the metal surface which can resist the passage of aggressive ions to the metal surface. Sol-gel-derived nano coatings can be easily deposited on the metal surface to make uniform surface coatings which can provide excellent oxidation resistance. These coatings are effective substituents for the metal surface pre-treatment methods used in the early times which has large adverse environmental and health impact.

In the present study, we have developed sol-gel derived zirconia coating on mild steel surface. Electrochemical corrosion studies were conducted to analyze the corrosion protection efficiency of the coatings. The dipping time in sol-gel, curing time, and the temperature was optimized for the best effective coating characteristics.

2. Materials and methods

Zirconium nitrate, $Zr(NO_3)_4$, was obtained from BDH chemicals (99%) ammonium hydroxide (98%) and ethanol (99%) were purchased from Merk. Triethanolamine (TEA) with 99% purity was provided by Indian drugs & Pharmaceutical Ltd. All chemicals were used without further purification. The mild steel coupons (2 × 1.8 cm^2) of composition 98.75% of iron by weight, with trace amount of other elements: ≈1% manganese, 0.2% carbon, 0.03% phosphorus, and ≈0.02% sulphur.

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