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Application of nanotechnology in metal protection Against metal corrosion

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Abstract
The paper explores the latest advancements in the uses of Nanomaterial in Metal protection against metal corrosion. Nanotechnology offers innovative solutions by using the unique properties such as thermal conductivity, electrical conductivity, meting point, catalytic activity, light absorption, physical properties, chemical properties, magnetic properties, mechanical properties etc. The Properties are useful for controlling the metal corrosion, including enhanced rating, large surface area, improve barriers qualities and superior mechanical stability.
The discussion encompassed Nanocoating, Nanocomposite and inhibitors examine their role in corrosion prevention across industries. Metal corrosion presents the most significant challenges across factories and industries, causing safety risks and economical losses.
The experimental results indicates that nanomaterials are not only enhance corrosive resistance but also improve sustainability and cost efficiencies, paving the way for future development.

Keywords: Nanotechnology, metal corrosion, anticorrosion coatings, Nanomaterials, graphene oxide, titanium dioxide, corrosion inhibitors, smart coatings, self-healing materiel, environmental protection

1. Introduction
The materials composed of a set of the particulars of which at least one dimension is less then approximately 100nm providing unique Physical, Chemical, Magnetic, Optical etc properties that exist at the nanoscale are commonly called nanomaterials. Nanomaterials are different from microscopic atoms, Molecules and Macroscopic bodies in terms of their physical, Chemical, Mechanical, Magnetic, Optical etc properties [1]. Nanomaterials and system essentially depend on number of dimensions which lie within the nanometer range. Due to the reduction in the spatial dimension or confinement of particles or quasi particulars in a particular crystallographic direction within the structure, a significant change takes place in their properties.
The high surface to volume ratio is responsible exceptional properties of nanomaterials. The physical properties like as optical absorption and melting point vary significantly with change in size at nanoscale. Nanomaterials have higher catalytic activity towards the chemical reaction due to increasing ratio to corner and edge site to surface atoms [2]. Nanomaterial are used for protecting it from corrosion like barrier protection, Self-healing, Corrosion resistance, Improving adhesion, Increased hardness and Wear resistance, Superior mechanical properties, Thermal stability, Elemental conductivity, Reducing environmental impact, Self cleaning and Anti-Fouling capabilities etc.

2. Literature & Review
2.1 Types of Corrosion Protection
a) Passive Protection
Shield a Metallic component from the influence of corrosive media is referred as passive protection. Which is defend as the method of shielding a metallic body from corrosive components by producing a physical barrier by using a coating of suitable material like protective paints, metallic, organic and inorganic coatings for producing a barrier between the metal and environments. For passive corrosion protection wax, oils and greases are also used which penetrate small cracks and pores in the metal component for preventing direct contact with air and moisture.
The type of protection changes neither the general ability of the package contents to corrode

nor the aggressiveness the corrosive agent and its is called passive corrosion protection.

b) Active Corrosion Protection

It is referred as the method of protecting a metallic component from corrosion by releasing a soluble inhibitor to fix scratches and defects likes as cathodic protection, hot-dip galvanizing protection, powder coating, duplex coating etc. Active corrosion protection is based on multi-functional micro and nanocontainers.

A nanosized volume filled by an active material confided with porous core is refers as nanocontainers. In active protection the nanomaterials like ZnO (Zinc Oxide) released inhibitors [3]. The nano - encapsulated inhibitors repair micro cracks in-coating, prolonging metal durability [4].

2.2 Mechanism of Corrosion Protection by Using Nanotechnology

The corrosion is electron chemical in nature, occurring or exposing electrolytes on a Metal surface.

The chemical reaction for reaction in iron as represented.

$$4Fe\ (s) + 3O_2\ (g) + xH_2O = 2Fe_2O_3 \cdot xH_2O$$

It is a chemical change. Which occurred on reacting iron (Fe) with Oxygen (O_2) and Water (H_2O) and forms hydrated iron oxide, known as rust.

The main mechanism of corrosion protection by nanotechnology is that the technology can protect against corrosion by altering the interface between the metals and electrolytes by creating a thin film of nanocomposite on the metal surface. The film i.e. the coating prevents corrosion by reducing anodic and cathodic reaction. Coating of nanomaterials improves barrier qualities and corrosion resistance by increasing surface coverage and adherence. The coating can prevent corrosion successfully due to their high surface area to volume ratio and small size, due to this, they allow to permeate surface defects [5, 6]. The nanosized materials i.e. nanomaterials absorbs into metal surface efficiently and create a barrier. Which removes the corrosive substances [7]. Due to a larger surface area to volume ratio, the coating of nanomaterials make more contact with the metal substrate and have a better adsorption capacity [8, 9].

2.3 Types of Nanomaterials in corrosion control

a) Graphene Oxide (Go)

It is compound made by carbon by hydrogen and oxygen in various ratios. Which is created by reacting graphite with strong acids and oxidizers to remove extra metals. It is a nanomaterial that has been known for more then 150 years [10]. They are used in many applications. It is an two - dimensional materials and part of carbon allotropes. The material was discovered by Andre Geim's team in 2004 at the University of Manchester in England [11]. It has unique properties that make it more effective in application.

It is applied as anti corrosive coatings due to their high conductivity and barrier effect [12].

b) Titanium Dioxide (TiO_2)

The nano crystalline titanium dioxide or microcrystalline titanium dioxide or ultrafine titanium dioxide particles with diameter less than 100nm are refers as titanium dioxide nanoparticles. The particles have ability to blocks ultraviolet radiation. Hence these are used in sunscreen. They have ultraviolet stability and self cleaning characteristics [13].

It is applicable in photo catalytic degradation of corrosive agents.

c) Zinc Oxide (ZnO)

Zinc oxide is white powder, insoluble in water and an inorganic compound. Which is occurred as rare mineral zincite. The minerals contains manganese with other types of impurities in yellowish red [14]. It is an amphoteric oxide approximately insoluble in water however dissolves in most acids [15].

$$\longrightarrow \backslash Zn + 2HCl\ ZnCl_2 + H_2O$$

Its key properties in corrosion inhibition [16].

As Sacrificial Anode Coatings.

d) Silica Nano Particles

The nano particles made from silicon dioxide (SiO_2). Which is a common and abundant mineral found in sand and rock is refers as silica nanoparticles. The nanoparticles with high surface area and chemical stability are used to different catalysis application. It has high meting point and chemical attack resistance make useful in different industries. It has water repellency characteristics. Hence it is used as hydrophobic coatings [17].

2.4 Application of Nanotechnology in metal corrosion protection

- **a) Nanocoatings:** Coating of nanomaterial on a metal surface i.e. nano coatings are applied to prevent contact with corrosive environments, like grapheme - based coating on a metal surface resists to oxygen and moisture [18].
- **b) Corrosion Inhibitors:** The nanonmaterial particles are incorporated into paints as corrosion inhibitors and released protective ions.
  Example: Nano particles of cerium oxide [19].
- **c) Environmental Applications:** Nano technology - based nanonmaterial coatings reduce the requirement for toxic heavy metals in traditional corrosion protection [20].
- **d) Smart Coatings:** The coatings can sense their environment and respond to it. They are made us of nanomaterial particles like ceramics and metals with the various benefits like corrosion protection, scratch resistance, where proofing, strain sensing etc. The coatings embedded with nano capsules and release inhibitors only when corrosion is detected [21].

3. Methodology

Data was collected from various sources, including

* Peer reviewed Journals, examples- corrosion Engineering's review, surface coat Technology, industrial, Environmental solutions, Material science, Corrosion Science etc. The comparative performance of traditional and nanomaterial a coating was analyzed by using statistical tools for determining corrosion rate reduction.

4. Experimental

The present Studies focus on a critical review on nanotechnology based on corrosion protection strategies. The experimental frame work in outline to demonstrate are practically evaluated for corrosion resistance. For this we take following steps.

4.1 Substrate Preparation
The specimens of mile steel were mechanically polished by using silicon carbide abrasive papers followed by ultrasonic cleaning in ethanol and distilled water.

4.2 Nanocoating Deposition
In nanocoating deposition following techniques were uses-

a) Physical Vapour Deposition (PVD)
b) Chemical Vapour Deposition (CVD)
c) Sol-gel Coating
d) Electrophoretic Deposition

4.3 Electrochemical Corrosion Testing
Electrochemical corrosion testing measurement where conducted in 3.5 wt% NaCl solution at room temperature by using three dimensional electro cell configuration

a) Tafel polarization test - the test were performed to determine corrosion potential (E_{corr}) and corrosion current density (I_{corr})
b) Electrochemical Impedance Spectroscopy (EIS) - It was carried out over a frequency range 10^5 to 10^{-2} Hz to analyze coating resistance and charge transfer behavior.

5. Results and Discussion
5.1 Enhanced corrosion resistance
The grapheme enhanced epoxy coatings exhibited about 75% reduction in corrosion rate in comparison of Traditional epoxy coatings.

The salt spray tests confirmed the strapping resistance to rust formation under high humidity conditions.

Titanium dioxide Nano particles (TiO_2)

The coating Titanium dioxide Nanoparticles provide superior resistance to pitting corrosion in marine field and reduced the pitting depth about 50%.

Silica Nano Particles

The coating of silica nanoparticles increased hydrophobicity and reduces water contact. It is effectively limiting moisture penetration.

5.2 Improved Self Healing Properties
Nanocapsules contained corrosion inhibitors in smart coatings and released inhibitors upon micro crack formation. The smart coatings restored the barrier properties after damage about 85%.

5.3 Cost Analysis
The nanomaterial coatings are effective regarding corrosion protection, but these are more expensive than traditional coatings about 50%.

5.4 Environmental Impact
The coatings of Nanomaterials are less toxic and more ecofriendly in-comparison of traditional coatings.

6. Conclusion
Nanotechnology provides the transformative solutions for metal protection through advance nonocoatings.

Nonmaterials like graphene oxide (Go), Titanium dioxide (TiO_2) and silica significantly enhanced corrosion resistance and durability. The smart coating provides long term protection by addressing micro cracks and other defects.

However it is challenge regarding cost efficiency, scalability and standardization.

7. Scope and Feature Perspectives
Nanotechnology presents immense potential for advancing corrosion protection strategies due to its ability to industrial materials at atomic and molecular scales. There are following scopes may be.

7.1 Future Research Scope
- Development of Self healing nanocoatings.
- Exploration of green and biobased nanomaterials.
- Optimization of multilayer and hybrid nanocoatings.
- Integration of Smart nonocoating with sensing capability for real time corrosion monitoring.

7.2 Industrial and Technological Scopes
- Large Scale application of nanocoating in marine, aerospace, oil & gas and infra structure sectors.
- Improvement in coating durability under extreme environments such as high temperature, acidic and saline conditions.
- Development of Cost effective and scalable deposition techniques for commercial implementation.

7.3 Academic and Scientific Scopes
- Standardization of testing photo cells for nanocoatting.
- Advanced modeling and simulations of nanometal interface behavior.

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