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A Review on coating of steel with nanocomposite for industrial applications

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Abstract

The current review goal to provide a thorough understanding of the nanocomposite coating of steel for industrial applications. Based on findings from recent research, we will go into detail here about the several coating materials, deposition methods, and the challenges associated with creating the best coating for steel. The two primary categories in which this article has been prepared are. In the first part, anti-corrosion coating, ceramic film, chemical vapour deposition, carbon nanotube, graphene has been presented with latest research. The second part focuses on industrial application of the current research including aerospace, automotive and petrochemical industry.

1. Introduction

The enhancement of surface properties of steel alloys has always been challenging for their use in sophisticated engineering such as petrochemical processes, aerospace, manufacturing, machinery industry, automotive industries, and energy transformation because of its outstanding corrosion protection and their mechanical properties (Balakrishnan et al.). Corrosion is a electrochemical reaction which happen because of the presence of O_2, H_2O, and ions of $F^-$and Cl^- (Bertolini and I Wiley Horwood). The gaseous such as CO, CO_2, NO_2 and SO_2 are equally responsible for the corrosion. Nearly 30% of all equipment failures are caused by corrosion from the marine environment, which necessitates either whole or partial equipment replacement or repair. In a shorter period of time, these materials corrode due to their harsh environment. Steel corrosion in marine environments is affected by factors including seawater hardness, alkalinity, and salinity (R. A. V, Lau, and Ramakrishna). A further illustration is the automotive industry, where corrosion issues are constantly discovered at gear assemblies, carburetors, pistons, engine bearings, hose couplings, shock absorbers, exhaust system components and fuel injectors etc (Chintada, Koona, and Bahubalendruni). Corrosion shortens the metallic equipment's lifespan and raises the cost of service and maintenance. Therefore, enhancing stainless steel's high-temperature oxidation protection, chemical stability, superior wear and abrasion protection, and extending its lifespan (Bu et al.) is of utmost importance. To increase mechanical strength, wear and corrosion resistance, magnesium is alloyed (Ramalingam). Due to its capacity to resist corrosion and provide additional strength, Zn coating on ordinary carbon steel has been a longstanding practise in the engineering sectors (Enyi et al.).

1.1. Anti-Corrosion Coating

In many industries, steel degradation in highly corrosive conditions is a severe problem. To solve this problem, it is crucial to have a basic understanding of the corrosion process where corrosive electrolyte meets steel exterior. One of the greatest ways to stop corrosion is using a functional covering comprised of nanocomposite materials. Anti-corrosion coatings fall under three general categories: (i) organic coat; (ii) inorganic coat; and (iii) metallic coat. Most often, organic coatings are employed to prevent outside corrosion on carbon steel structures and pipelines (R. A. V, Lau, and Ramakrishna). O_2, H_2O, and other corrosive ions are typically blocked from reaching the metal surface by an organic coating, which serves as a physical barrier. Coating permeability and sluggish adhesion are two serious problems with organic coatings (Deyab). Many approaches have been put out, and NPs can significantly contribute to alleviating the aforementioned problems. Surface modification, anodizing, enamelling, metallic coatings, and other processes are examples of inorganic coatings. These coatings are produced chemically, turning the metal's surface layer into a metallic oxide film or compound, which lessens corrosion. To leverage both of its qualities, an organic and inorganic coating combination is being investigated. Composites made of two or more phases, at least one of which is nanoscale, are called organic-inorganic hybrids. Because of this, the ultimate qualities of a nanocomposite are not only the total contributions of each phase, but also have special characteristics. Hybrid composites are classified as type I if they have vander walls, ionic, or hydrogen bonds as their interphase interactions, while type II hybrids have covalent bonding forces (Sanchez et al.). The nature of interface between various phases determine the ultimate quality of the nanocomposite.

There are several ways to prevent corrosion, including (i) passive barrier protection, which involves covering steel with a system of protective coatings that forms a rigid barrier to block exposure to O_2, H_2O, and salt (ions). An example of this type of coating is epoxy (ii) Active barrier protection: This type of corrosion prevention occurs when a primer (generally, reactive chemical substance) is applied to the steel surface, such as $Zn_3(PO_4)_2$, where the $(PO_4)^{3-}$ and Zn^{2+} ions serve as anodic and cathodic inhabitors, respectively (iii)Sacrificial barrier protection: It contains materials, such zinc or aluminium, that corrode in order to protect the substrate of the component from corrosion (Yeomans).

1.2. Chemical Vapour Deposition

It is very old technique of material processing technology in which thin films heated substrate via chemical reaction of gas phase vapour (Morosanu). Since 1960, hard coatings, such as Al_2O_3, TiCN, TiC, and TiN have been applied to machining tools in order to extend their lifespan using thermal chemical vapour deposition (Powell and Oxley Kern and Ban Hintermann R. F. Bunshah and Blocher R. B. Bunshah). Recently, nanomaterials such as graphene, carbon nanotubes, and 2D transition metal dichalcogenides have emerged as the new alternative in electronics industry (Veprek Archer Laimer et al.) and serve very important requirement for successful CVD of these materials with fine structure and high purity.

1.3. Ceramic Film

The Ceramic film is getting attention because of its resistance to high temperature, wear and corrosion protection properties. Incorporating TiC particles into the Ni-P matrix, Afroukhteh et al. (Sahar, Dehghanian, and Emamy) found that the inclusion of surfactant improved the corrosion protection of the steel coated with Ni-P/0.1 TiC, particularly in the appearance of surfactant (polymeric). Afroukhteh et al. (Afroukhteh, Dehghanian, and Emamy) used nano Al_2O_3 in another study, and the findings revealed that raising the alumina content altered the surface shape and also improved corrosion protection. Incorporating electroless Ni-P-ZrO_2 nanocomposite coatings on mild steel substrates, Makkar et al. (Makkar, R. C. Agarwala, and V. C. Agarwala) found that these coatings have improved wear over Ni-P coatings. According to Radu et al. (Radu et al.), increasing nanometric alumina and micrometric alumina content increases corrosion resistance. This was demonstrated by the co-deposition of Al_2O_3 particles in electroless Ni-P coating. According to Sharifalhoseini et al. (Sharifalhoseini and Entezari), ZnO nanoparticles placed on the Ni-P layer's substrate surface greatly increased corrosion resistance.

1.4. Carbon NanoTube

A carbon nanotube is a tube made of carbon with diameters typically measured in nanometers. Since Iijima discovered carbon nanotubes in a carbon arc discharge tube in 1991 (Iijima), they are the subject of deep research because of fascinating chemical and physical properties. CNTs can be divided into 3 categories: single, double, and multiwall. They vary from one another in terms of length, diameter, densities, and mechanical properties, which affects how well suited they are for particular tasks (Asgari and Lohrasbi Picaud). CNTs can be produced in a number of ways, including catalytic method (I. V et al. Ivanov et al.), chemical vapour deposition (Danafar et al. Kumar and Ando), plasma enhanced CVD (Meyyappan Abdi et al.), electric arc discharge (Arora and Sharma Collins, Arnold, and Avouris), and chemical vapour deposition. In addition to being electrically conductive, light, and flexible like graphite, CNT are also strong as diamond and thermally conductive. Hence The characteristics of diamond and graphite are reported to exist in CNTs. Because of their high mechanical strength, high thermal conductivity, and ability to provide protection to thermal shock and crack growth, CNT nanocomposite materials such CNT- Al, CNT- Cu, CNT-Co, CNT-Ni, CNT-Fe, CNT-Ti, CNT-Mg, and others are widely employed (Radhamani, Lau, and Ramakrishna).

1.5. Graphene

A single sheet of atoms organised in a two-dimensional honeycomb lattice nanostructure make up the carbon allotrope known as graphene. Graphene, a revolutionary sheet of sp2 hybridised carbon atoms that is only one atom thick, has garnered a lot of attention recently because to its exceptional qualities, including outstanding electrical conductivity, a sizable theoretical specific surface area, and high mechanical strength. Because of its exceptional electrical, optical, mechanical, thermal, and electrochemical capabilities, graphene is an excellent electronic material for electrochemical sensing (Abdulazeez and Lawal). Industrial uses for pristine graphene, graphene oxide, reduced graphene oxide, and graphene nanocomposites include supercapacitors, biosensors, solar cells, and corrosion research.

2. Application

The research shows all nanocomposite shows improved quality and properties in comparison to macrocomposite (Okpala and Chikwendu). Therefore, nanocomposite open a new application in various field such including industrial, engineering, medicine, energy, electronics, household design etc.

2.1. Aerospace

Around 120,000 different materials have been used in aerospace structures; in this article, the properties of nanocomposites like MgB2, multi-walled CNT, and acrylonitrile butadiene styrene/montmorillonite nanocomposites are highlighted in the aerospace application because of less weight structures, protection against the extreme environment of space, and decontamination. The use of nanocomposites in a number of aircraft sector subsystems, particularly the self-healing quality of nanocomposite polymers, illustrates the industry's hopeful future (Guo et al.). Extreme temperatures and their consequences have a significant impact on aeronautical structures, particularly on the tribology behaviour. Alumina particles were added, which reduced the wear and friction resistance. The inclusion of alumina particles decreased the wear and friction resistance.As a result, to improve already established structures, nanocomposite materials including polytetrafluoroethylene and alumina were utilised (Burris and Sawyer).

2.2. Automotive Industry

The nanocomposites are implemented in automobile industry is to resist fracture and often occurance of wear and tear of the machine parts (Okpala and Chikwendu). Nanocomposites are often blend with plastic for strengthening the part of the automobile where efficiency is required. Hybrid electric vehicles, which also utilise nanocomposite materials, have substantially accelerated the development of lithium-ion batteries.To further improve the rate capability of Li/Na batteries, Kim (Kim et al.) and Ko (Ko et al.) created nanocomposites containing decreased graphene oxide.

2.3. Petrochemical

When pipelines, tanker ships, and rail cars cannot be used, the tanker trucks are used for transportation (Fadl et al.). In order to maintain the reliability of the truck body and stop the leaking of petroleum products during movement, it is imperative that these vehicles be protected from corrosion caused by the elements, UV radiation, chemicals, and water. By providing innovative materials with greater stability under diverse harsh circumstances, nanocomposite coatings serve a crucial function in handling of metal surfaces in the crude oil sector, particularly oil transportation vehicles made of

TABLE 1. **Comparison Table of the latest Research with their application**

Author Name	Nanomaterial Used	Application
V. V. Ramalingam et. al (2019)	Magnesium Alloy	Industrial and Biomedical Application
Xie et. al (2016)	Pristine Graphene	Biosensor
Oraon et. al (2016)	Pristine Graphene	Super capicitor
Yang et. al (2016)	Reduced Graphe oxide -Cu_2O nanocomposites	Antibacterial Application
Yuan et. al (2016)	Fe_2O_3/ Reduced Graphe oxide composite	Energy Storage
Ko and Kim (2018)	Graphene Oxide	Li/Na Batteries
Aydin et. al (2019)	Reduced Graphene Oxide	Solar Cell
Xue et. al (2019)	Graphene oxide-hydroxyapatite	Anti-Corrosion Pigment
A. Bhat et. al (2021)	CNT nanocomposite	Aerospace Application
Bu et. al (2016)	ZrO_2-TiO_2nanocomposite thin films	Corrosion Resistance
Yang et.al (2020)	Epoxy Nanocomposite coating	Corrosion Resistance
A. Kausar (2018)	Polyurethane Nanocomposite	Corrosion Resistance

steel (M et al.).

3. Conclusions

The anti-corrosion coating, ceramic films, chemical vapour deposition, graphene, carbon nanotube, and associated nanocomposites are examined in this review article along with their industrial uses. According to our analysis of the literature, anticorrosive coatings can keep the integrity of metallic surfaces. Additionally, nanocomposites have successfully supported ground-breaking achievements in the automotive, petrochemical, aerospace, etc. industries. The development of nanocomposite materials led to components with increased fatigue resistance, reduced volume and weight, resistance to temperature changes, etc.

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