REVIEW ARTICLE

Review of Green Synthesis and Anticorrosion Applications for Yttrium Oxide Nanoparticles

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ABSTRACT

Corrosion processes cause considerable losses in industry and the economy. Corrosion inhibitors have been used in both inorganic and organic forms for a long time. Nanomaterials are more effective at preventing corrosion than traditional materials because they have a higher surface-to-volume ratio. Metal oxide nanoparticles (NP) are also novel in a variety of technological applications due to their distinct physical and chemical properties. Due to their higher dielectric constant and thermal stability, yttrium oxide (Y_2O_3) nanoparticles (NPs) are well known for technical applications. It is frequently utilized in electrochemical applications, photodynamic treatment, and other sectors as a host material for a range of rare-earth alloying elements. As a polarizer, phosphor, biosensor, laser host material, and for bioimaging, Y_2O_3 NPs has also been employed. Anti-corrosion characteristics of yttrium oxide nanoparticles are appealing regarding the formation of a smooth adsorbed layer on metal surfaces or alloys. This review focuses on Y_2O_3 NPs promising usage and developments in corrosion-inhibiting applications. The processes of green, chemical, hydrothermal and sol-gel nanoparticle synthesis are discussed.

Keywords: Anti-corrosion applications, Green synthesis, Rare earth metals, Yttrium oxide.

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INTRODUCTION

The utilization and ubiquity of rare earth metal nanoparticles (NPs) have grown in recent years. A substance that is utilized and produced in the form of rods, sheets, nanotubes, and NPs for its electrochemical uses. Researchers have developed organic nanomaterials such as liposomes, dendrites, albumin-coated NPs, polymeric and lipid NPs. Metallic NPs are made of various metals, magnetic materials, metal oxides, and quantum dots.[1] The characteristics of yttrium oxide (Y_2O_3), a kind of important rare earth element, as an inorganic NP are reviewed in this paper. According to a recent geological assessment of the United States,[3] yttrium is employed in ceramics, metallurgy, and phosphors and has an estimated rare earth element proportion of 0.12%. In 2018, China produced the majority of the world's yttrium oxide, which was thought to be 7000 tons. Australia, Canada, China, and India are the top four countries that produce yttrium reserves. As a component of salts, liquid reactive molten alloys, and uranium-resistant refractory ceramic, Y_2O_3 is used in atomic reactors.[4,5] Metal-oxide-semiconductor devices also create a fantastic protective coating that serves as an alternative to silicon dioxide. It is frequently employed as a high-temperature resistant sealant and abrasive in the ceramic sector. It also serves as a paint for jet engines and an oxygen sensor in autos. It won't rust as a result of the cutting tools.[6,7] It is the best alloy, a grain refining additive, an anti-oxidizer, and a high-temperature conductor in metallurgy. Yttrium derivatives are used in the electrical areas of microwave surveillance, internet technology, temperature monitoring, optoelectronic devices, photoreactions, and fluorescence spectroscopy. The different electrical properties, chemical stability, and enhanced hardness of Y_2O_3NPs have all been documented in the literature. They added that it can be used in solar energy systems, lithium-ion batteries, and parts for rare-earth-doped lasers.

Researchers have found that acetaminophen may be detected with good electrocatalytic activity using a mixture of carbon nanotubes (CNTs) and Y_2O_3. Y_2O_3 NPs, which are rare earth materials, have all the necessary characteristics for phototherapy,[8] biological imaging,[9] luminescence,[10] and nuclear power systems.[11] A surprisingly high refractive index, a wide band gap (5.8 eV), a strong dielectric constant, and a high thermal stability area are among these characteristics.[12] Y_2O_3 Nps were produced using a thermal process, and they had diameters and edge lengths on the order of micrometers.[13]

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Mechanical research was done on the effectiveness of nano yttrium oxide on Ti6Al4V's calcium phosphate coating, which is a potential bio-ceramic fiber[14] Films of yttrium stabilized zirconia were made using Y_2O_3, a very effective and practical composite material.[15,16] Yttrium oxides unfilled 4f orbitals cover eight electrons located in the outer $5s^2 5p^6$ orbital region, according to research by Azimi and his team.[17] This shielding effect can make it difficult to adsorb interfacial water molecules. Depending on the deposition technique, the surface chemical environment and roughness of thin films can significantly impact wetting characteristics.[18] Lei and his team[19] discovered that there was less oxygen in the hydrophobic Y_2O_3 thin film with the lowest water contact angle. When oxygen is rare, oxygen vacancies are produced quickly and are kinetically better suited for the attachment of OH, increasing the surface's hydrophobicity. Reactive magnetic coil spit has been used in various experiments to create thin films of Y_2O_3.[20] Because of its great properties, such as efficient deposition potential, high adherence to a wide variety of substrates, and applicability for industry-wide deposition. Additionally, handling and bombarding several active species in the reaction vessel, including atoms, positive ions, electrons, and high-energy negative oxygen ions, makes the sedimentation process an extremely time-consuming procedure. Studies of industrial chemistry and its applications show that it is beneficial to deposit a thin layer of nano-yttrium oxide at room temperature and then treat it using a simple procedure after heat treatment to guarantee that the surface has the desired wetting and a fine and adequate structure.

Yttrium Oxide NPs Green Synthesis

Various physical and chemical synthesis techniques, including hydrothermal synthesis, the sol-gel method, and green synthesis, have been used to produce Y_2O_3 NPs. It is important to note that although if the synthesis schemes and methods are identical, characteristics, such as physiochemical qualities, are dependent on the potentials of the particles. In this review, we present the green technique for preparing Y_2O_3NPs with anti-corrosion applications. Many researchers are interested in the green technique for the synthesis of Y_2O_3 NPs due to its effectiveness. Various investigations have revealed plant-based nanoparticles that use different plant parts (leaf, fruits, and pods). Characterization procedures were used to investigate and confirm the NPs as-prepared, for instance, scanning electron microscope (SEM), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), UV-visible (UV), and transmission electron microscopy (TEM). Y_2O_3 nanoparticles are utilizing leaf extract from *Acalypha indicia*. Biological synthesis nanomaterials with 24–67 nm sized particles. The appearance of Y-O-Y proved that the synthesized nanoparticles were produced.[22] Additionally, Nagajyothi and his team[23] were successfully used forsythia fructose aqueous fruit extract to prepare yttrium oxide NPs (Y_2O_3 NPs). The structural and morphological features of Y_2O_3 NPs were carefully examined utilizing FTIR, SEM, TEM, and XRD tools. The results contribute to the fact that the nanoparticles have a flower, flake-like shape. The total findings demonstrated that green-synthesized NPs successfully suppressed kidney cancer cells. Synthesis is less expensive, safer, and more environmentally friendly than physical and chemical procedures. The aqueous extract of Liriopeplaty leaves was used to make yttrium oxide NPs, and without the use of any additional components, Basavegowda and his coworkers found that the extract acts as a reducing agent when applied to a solution of yttrium nitrate hexahydrate.[24] The molecules in the created NPs functioned as a heterogeneous and environmentally friendly catalyst, resulting in the synthesis of a chemically and physiologically effective substance (3-thiazolidin-4-ones). Rebeca and his team[25] shown the viability of manufacturing nano-yttrium oxide (Y_2O_3NPs) in the presence of different precursors and P-123 poloxamer by employing the sol-gel method. Yttrium nitrate and yttrium chloride were used as the main raw ingredients to make methanol. This research looked at the anti-oxidant properties of yttrium oxide synthesized with different concentrations of P-123 poloxamer. Sundarajan and Kannan invented Y_2O_3 NPs[8] employing *A. indica* aqueous extract as the chelating agent UV-vis spectrograms of all the calcined NPs were analyzed, and Y_2O_3 was identified at 284.0 nm. XRD results showed that the structure of Y_2O_3NPs was amorphous. FTIR was used to detect a strong band at 588 cm^{-1} using the surface-bridging oxide nanoparticles used in this study. This band indicates the presence of the Y-O-Y asymmetric expansion mode of the vibration, while the sharp band at 565 cm^{-1} is attributed to the (Y-O) stretching vibration. The presence of the Y-O-H and Y-O-Y groups in the nanostructure is represented by the bands at 873, 1216, 1085, and 1026 cm^{-1}. Forsythia fruit extract in fructose solution is used in another study to illustrate the use of a green stage process system. It was recently announced that the creation of Y_2O_3 NPs was successful,[26] and it was shown that the produced nanoparticles had an anticancer impact on harmful microorganisms. The nanoparticles have a size of 11 nm. The green synthetic technique proved inexpensive, ecologically friendly, and has less harmful chemical side effects. This method is strongly advised as an alternative to costly physical and chemically generated Y_2O_3 NPs, which are seen as a potential option for medical investigations. Two separate precipitation procedures, which resulted in the precipitates ammonium hydroxide and ammonium hydrogen carbonate, were used by Khajelakzay and his team to produce yttrium oxide nanopowder.[27] Yttrium nitrate was used as the primary salt to produce the precursors for yttrium hydroxide and carbonate, which have approximate chemical formulas of $Y(OH)_3$ and $Y_2(CO_3)_3$, respectively.[28] XRD measurements reveal that annealed samples include a cubic yttrium oxide feature. SEM and TEM images show that samples contain a variety of sized and shaped agglomerated and non-agglomerated NPs. The optimal parameters for the formation of NPs were found to be 3 hours of aging time, ammonium hydrogen carbonate as a precipitant, and a calcination temperature of 1000°C.

Yttrium Oxides NPs as Anticorrosion

Yttrium oxide (Y_2O_3) is frequently used in nature in a range of applications, including those that require great corrosion resistance due to its low toxicity and excellent chemical, thermal, and mechanical stability. Because of its porous nature, Y_2O_3NPs may also be employed as a corrosion inhibitor carrier. Xiaorui and his team were successful in obtaining yttrium oxide thin films with different fine structures in the toxin mode and the metallic mode, respectively by using the deposition method and studying the effect of changing the deposition strength on the preparation of these films on silicon substrates by spraying magnetron with direct reactive.[28] After being annealed in the air at 400°C for the metallic mode films, which have amorphous or monoclinic structures, all samples of varying thicknesses fracture. However, thin films created by poisoning are amorphous and must be heated to change into the cubic phase, which is the most stable. Miyazaki and his colleagues placed Y_2O_3 NPs films using the pulsed EPD technique.[29] It was found that the best deposition conditions for this approach include employing a low concentration of yttrium nanoparticles in the presence of low pressure and high frequency. When the concentration of Y_2O_3 NPs in a solution was raised, the thickness of the film was considerably decreased. In the final Y_2O_3 NPs films, water and certain organics that were created from the Y_2O_3 NPs suspension solution may be discovered. The remaining water and organics had to be heated out of the resultant Y_2O_3 NPs films. The findings show that by deposition while varying the voltage in two or more phases, the thickness of the Y_2O_3 NPs dense layer may be adjusted. The corrosion resistance of an aluminum alloy created with a BTSE solution containing various yttrium oxide (Y_2O_3 NPs) nanoparticle concentrations was examined[30]. The corrosion resistance of the pre-treated aluminum alloy was examined using potentiodynamic polarization, and the shape of the coated layer produced was examined using a SEM. The study's findings demonstrated that adding modest quantities of yttrium nanoparticles to BTSE aqueous solutions increases the coated film's resistance to corrosion in a 3.5% NaCl solution. While the yttrium oxide NPs do not affect the electrode reaction, the silane layer protects the aluminum alloy by insulating it from the saline solution. Ni-W nanocrystalline alloy[31] coatings with different concentrations of Y_2O_3 nanoparticles (0–20 g/L) were effectively made utilizing the direct current electrodeposition method at an applied current density of 2 ampere/dm^2. The microstructure, morphology, chemical composition, microhardness, and electrochemical performance of the deposited coatings were carefully analyzed to demonstrate the key effects of the Y_2O_3 addition. According to the findings, Y_2O_3 NPs were evenly distributed throughout the composite coatings, improving their corrosion resistance. The best anti-corrosion performance was likewise shown by the composite coating electrodeposited from an electrolyte containing 10 g/L Y_2O_3 NPs. Qingwei and his colleagues used the composite electrodeposition approach while using ultrasonic and magnetic stirring to create composite coatings comprising Y_2O_3 and ZrO_2 NPs. Nanocomposite-based coatings' microstructure was examined using the SEM method. In order to investigate the effectiveness of coating nanomaterials for inhibiting corrosion, Tafel curves were used in a saline solution with 3.5 weight percent NaCl. The experimental findings demonstrated the compactness, fine grain, and lack of fractures of the composite coatings made under ultrasonic stirring. The inclusion of Y_2O_3 NPs and ZrO_2 NPs considerably increased the microhardness and corrosion resistance of the composite coatings when compared to Ni-W alloy coating.[32]. To create modified coatings for steel substrate corrosion protection, the anti-corrosive pigments Y_2O_3 NPs/Imidazole were created and distributed in an epoxy formulation. FTIR verified the loading of imidazole into Y_2O_3 NPs, while TGA demonstrated the Y_2O_3 nanoparticles' loading capability. A combination of imidazole and yttrium oxide nanoparticles was created, distributed in an epoxy compound, and used as an anti-corrosion coating to protect steel alloys against corrosion. The produced composite was examined using FTIR spectroscopy, and the findings on imidazole loading in nano-yttrium oxide, together with those of thermal measurements utilizing thermos-gravimetric analysis (TGA) technology, demonstrated the loading efficiency of nanoparticles. According to EIS investigations, the modified coating exhibits stronger anti-corrosive capabilities than the reference coating, most likely due to an advantageous interaction between the inhibitors molecules and the polymer composite matrix. Iron alloy's corrosion rate increased in the presence of the undeveloped coating (Y_2O_3/imidazole), according to the data obtained using the EIS approach, whereas it decreased in the presence of the developed coating (Y_2O_3/imidazole). The cause of this behavior is that yttrium oxide NPs enhance the likelihood of imidazole attaching to the alloy's surface. This bonding is connected to the pH shift, which produces an insulating layer that shields the alloy from corrosion. After immersion testing in sodium chloride solution, XPS is used to check whether imidazole is present at the metal coating/coating interface[33]. Alviz and his team[34] investigated how to make coatings that would shield the P91 alloy from corrosion in an oxidizing industrial setting. To slow down corrosion under these circumstances, they also recommended using the PLD method and coatings made of nano-yttrium oxide. This method was effective in depositing these coatings, producing durable, sticky films. Additionally, prior to the oxidation investigations, it was established that P91 steel produces a Fe/Cr spinel layer under normal conditions. The coatings examination indicated oxide layers with a duplex structure and no protective action in the carefully selected oxidation environment at 650°C. Although, the rate of corrosion of the P91 steel decreased even though it was possible to reduce the transport of cations through the oxide layers by creating proof kites. Finally, it is found that coatings based on REO, such as yttrium oxide, may be able to slow down ferritic steel deterioration rates. Nevertheless, using the assessment window provided by the first 100 hours as a point of reference, they cannot avoid the P91 serious corrosion under industrial combustion settings. In order to prevent the quick Fe diffusion toward the exterior development of fragile iron layers, additional coating types should be considered. The effects of Y_2O_3 NPs concentration were clarified by applying ceramic coatings of Y_2O_3/Al_2O_3 to the surface of 6063 aluminum alloy using the MAO method[35]. The coatings were porous, and as Y_2O_3 NP concentration increased, so did the number of holes and the dimension of the microspores, which initially increased and later decreased. It was discovered that when the concentration of yttrium oxide nanoparticles fluctuated, the microscopic diameter changed as well, increasing first and then decreasing as the quantity of NPs rose. Al_2O_3 and Y_2O_3 were the main phases under various manufacturing conditions, and the content increased with the concentration of Y_2O_3NPs. The surface roughness of the coatings initially increased, reaching 3.21 m, then gradually dropping until it reached 2.404 µm. In contrast, as the quantity of yttrium NPs grew, the coatings' surface thickness increased, ranging from 17.8 to 22 µm. The coatings significantly reduced their friction coefficient to 0.42 while raising their surface hardness and corrosion current to 596.9 Hv and 1.133e-008 A, respectively.

CONCLUSION

Due to the many technical uses of NPs, research into them is crucial. The fundamental requirements for NP manufacturing are specific sizes and specified surface qualities since they are a leading nanomaterial in preventing corrosion in metals and alloys that are used in numerous application fields. This work reviewed the green synthesis techniques for yttrium oxide nanoparticles (Y_2O_3NPs) that were previously described. Additionally, Y_2O_3 NPs are essential in the study of metal corrosion. This study covered the physical and chemical characteristics that have an impact on their industrial uses, including their size, form, structure, and chemical makeup. Its unique properties, including a high dielectric constant and great thermal stability, were highlighted when compared to other inorganic NPs. Further research into yttrium oxide NPs synthesis and other applications, particularly in the corrosion of metals and alloys, can be built on the firm foundation provided by analysis.

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