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REVIEW ARTICLE

Synthesis and applications of nano aluminum dioxides

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Abstract

This review provides an overview of aluminium dioxide nanoparticles' synthesis, characterization, and applications in various methods. Aluminium dioxide is the main class of nanometal oxides used in different applications depending on the properties of the particles, which can control many chemical processes such as in imaging, catalysis, and environmental and medical applications. The reactivity of aluminum dioxide is mostly a candidate for various mechanical and energy research. It is noticed that the most abundant aluminum dioxide type is α- Al_2O_3 due to its higher density than other aluminum dioxide phases. Fabricating aluminum dioxide with a relatively small distribution has significant advantages in controllable deposition applications. It can give a high-quality surface area with small particle sizes, which favors forming films and catalytic activity. There is a broad range of methods to synthesize metal oxides, but the most widely used method is based on less time-consuming processes and green condition systems.

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1. Introduction

Significant attention has been focused on improving nanostructure materials in many chemical processes and industrial applications. Most scientists fabricate nanoparticles from ultrafine particles to produce nanoparticles with developed characteristics compared with bulk ingredients [1]. Many recent studies have shown that nanoparticles are efficient substances in some chemical systems [2] This significant idea came from researchers when they realized that the size of particles has improved with better physio-chemical characterization in Nano substances than average particle sizes. One general example is the properties of sliver metal as a nanomaterial: a characteristic optical property with a red color, which is the same in platinum and gold metals, while in other Nano sizes, it shows different properties; this means that the shape and size of particles is a significant factor which is used in various bio imaging applications [3,4]. Another example in this context is that Nano-semiconductor metals are distributed with increasing wide band gaps, which is essential to apply in producing photo catalysts and electronic devices. [5-7] Most nanomaterials offer new aspects and creative subjects to enhance our technology in many applications due to their wide range of control for different processes. It is shown that the simple molecules themselves can make a variety of small molecules which are significantly functionalized with more than one layer in the same structure, such as polymers, metal ions, and surfactants. These materials have unique chemical properties that are used in many studies. This review article will provide a comprehensive overview of classification, methods of determination, synthesis, and essential applications of Nano nanomaterials in detail. It also outlined the recommendations and future aspects of this field.

2. Nanomaterial classification

Nanomaterials are generally defined as materials ranging from 1 to 100 nm with one or more dimensions. The nanoparticles are mainly categorized into carbon nanometric, organic, and

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inorganic. The nanoparticles are prepared in various physio-chemical applications due to their unique properties to enhance materials like strength, sensitivity, high reactivity, and surface area. In sensor production, graphene (Gr) is one of the most widely used carbon nanotubes in electrochemical sensors. It is also found in other useful carbon nanotubes like carbon black, carbon nanofibers, ellipsoids or spheres, and fullerenes [8]. While organic nanomaterials are designed on organic matter, excluding carbon-based or inorganic-constructed nanoparticles, the non-covalent interactions for self-assembly are fundamental factors for transforming and supporting the molecules of organic nanoparticles into favourite structures such as micelles and nano polymers.[9] The formation of nanoparticles has illustrated that a large number of nanoparticles significantly depend on aggregated porous or polycrystalline microparticles; in some chemical processes, the shape of the particles changes despite maintaining the mass of the particles; it has various dimensions and distribution sizes, such as one dimension (D) or 2D and 3D or narrow particle size distribution. Figure 1. shows how the synthesis of nanoparticles changes the shape of particles in different ways. [10].

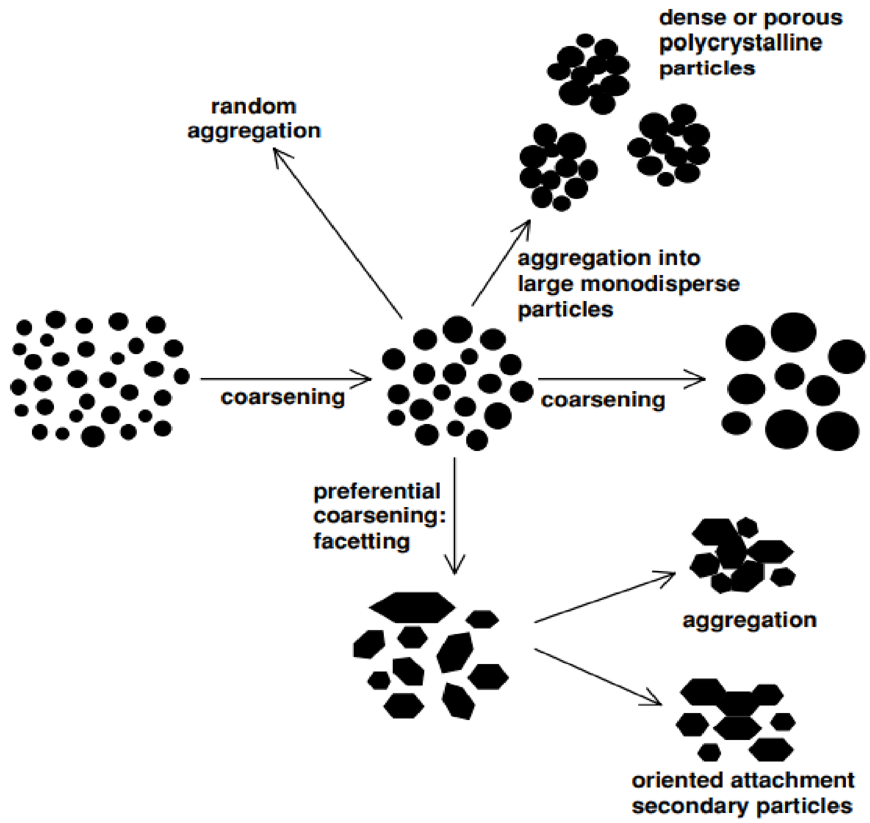

Figure 1: Diagram described how the shape of nanoparticles changing [10]

The inorganic nanomaterials are basically comprised of metals or oxide metals; most of these metals are produced from conductive or semiconductor metals, for example, TiO2, Al_2O_3, ZnO, and silver nanosubstances. Composite nano substances are also considered in many compositions of different multiphase nanoparticles. The main composition of these substances is based on one phase nanoscale dimension or combined with more extensive bulk-type materials such as metal-organic compounds. In some cases, composite nanomaterials are formed from organic or polymer metals or ceramic or carbon-based nanoparticles [10,11] The fundamental factor for synthesized nanomaterials depends on the desired properties in specific applications, such as surface area, morphology, and size of particles. Figure 2 illustrates an example of the chemical structure of aluminium oxides as nanoparticle materials [12]. The phase conversion of amorphous to crystalline alumina nanophase can be based on different factors, firstly, the type of chemical process, chemical structure kinetics of heating rate and crystal size. Grain alumina has a variety of amorphous phases, such as δ, θ, γ, ρ and κ. These transformation phases are generally established dependent on thermodynamically stable phase in bulk form. The phase of Al_2O_3 is formed from the conversion of γ to δ to θ then, nano-aluminium dioxide [14] In this case, Al_2O_3 has a density higher than γ-Al_2O_3 by a volume reduction of around 10%, and the final forming to α-Al_2O_3 needs an annealing temperature of 1100 °C. This chemical process is an example of a strategy to produce nanometals. It can show how the chemical reaction converts the properties of metals into different phases and various categories of friction and hardness properties [15].

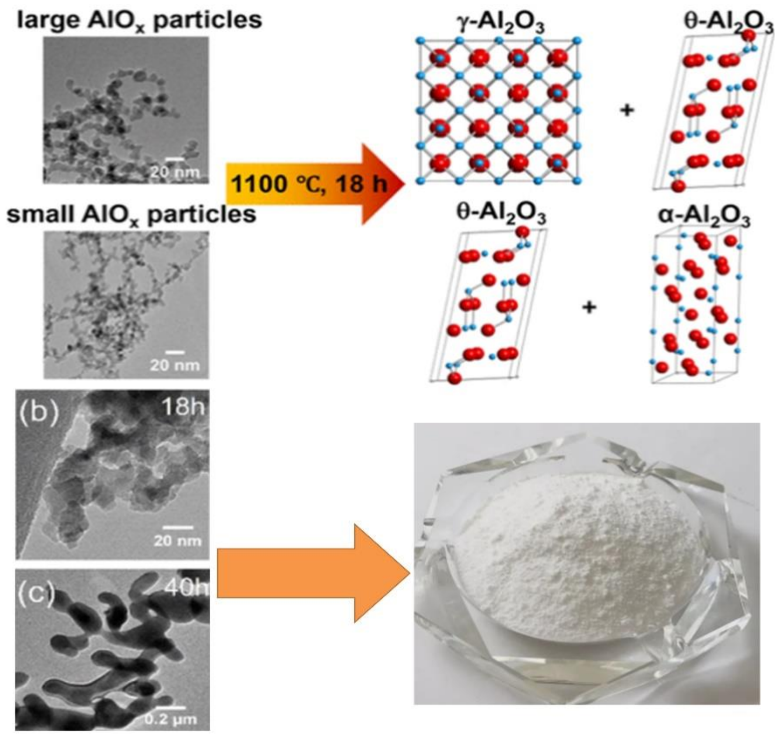

Figure 2: Nano aluminum oxide powder by using chemical processes [13]

3. Methods for determination and characterization of Al_2O_3

There has been a variety of methods mentioned in the literature to synthesize nanoparticles that are important to use in chemical applications such as amorphous nanoparticles, precipitation [16], sol-gel process [17], spinning [18], pyrolysis [19], chemical vapour deposition [20] and electrochemistry [21]. Chemical precipitation is considered one of the main strategies used to produce nano-size particles dependent on stopping precipitation. The two most common issues that could happen during the production in liquid medium are changing physical properties and the aggregation of tiny crystallites.

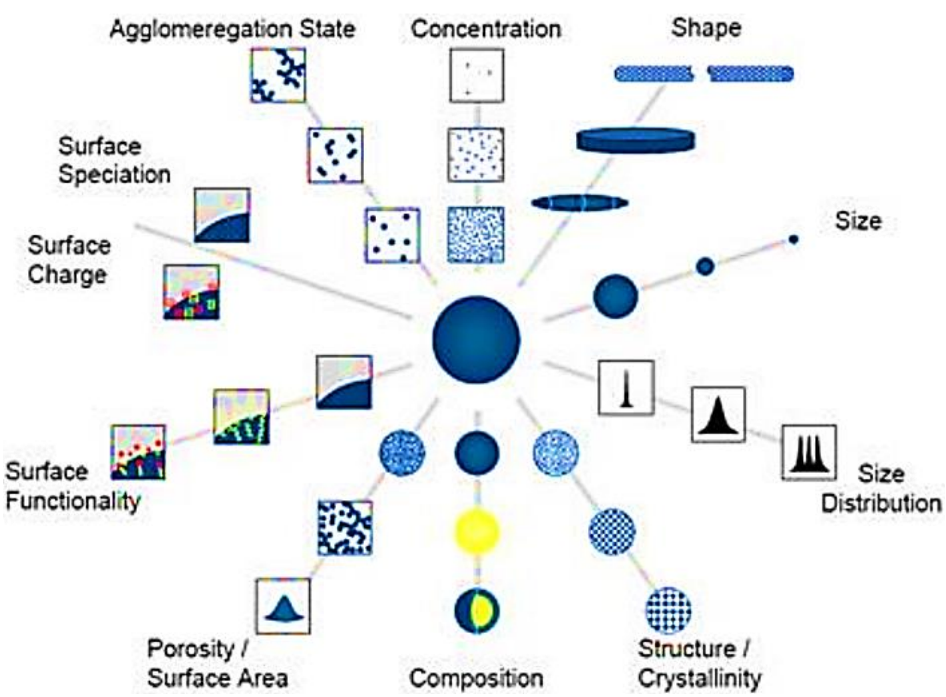

Figure 3: Various measurement techniques used to characterization of nanomaterials [12]

To prevent this, Oswald ripening and thermal coagulation were carried out using a suitable solvent with less water content at low temperatures during the synthesis with double-layer repulsion of crystallites. In a precipitation reaction, a type of surfactant is added in response to keep a separation between particles shaped. Then, centrifugation is used to separate the production nanocrystals, leaving the sample to dry [22]. Sol-Gel is another way to produce nanoparticles. Colloidal particles are found to be better molecules in some reactions than nanoparticles, such as tetraethoxysilane (TEOS) and tetraethoxysilane (TMOS), which produces silica gels. Most immiscible substances are preferred for the sol-gel technique because, during the synthesis of nanostructures, high-quality nanoparticle characterization occurs, especially in metal oxide nanoparticles. There are many types of organometallic for zirconium, aluminium, silica, and titanium in nonhomogeneous solvents or some emulsion media, such as in the production of nanomaterials using ionic liquids and water mixtures [23]. In sol-gel reactions, the pH factor is responsible for the hydrolysis reaction by replacing the OR-group with the OH-group. This will help to attack oxygen on silicon atoms in silica gel and allow the aggregation of particles to form silanol groups (Si-OH) produced siloxane bonds (Si-O-Si) by using a catalyst as an assistance factor in the condensation process to form elegant nanoparticles [24].

4. Applications of Nano aluminum oxides

4.1 Pharmaceuticals and biomedical applications

It is well known today that nanoparticles are becoming one of the most significant and basic materials in many branches of medicine, particularly drug delivery [25]. There are many reasons for using this kind of substance, such as that the most powerful of nanoparticles in the delivery of drugs into the body is the precision of dosage that they can release at a programmed phase at particular locations in the body. When nanoparticles are found to be a very beneficial tool for increasing the therapeutic efficiency of many drugs, they are also found to be very active in decreasing the number of side effects when used for drugs delivered in the existing techniques [26]. Recently, a broad range of nanomaterials has been considered in medical laboratories. Alumina nanoparticles have become good candidates for intravenous drug delivery into parts of the body that have very low pH and may have degraded other nanomaterials before they reach their destination. Aluminum toxicity concerns most people, especially in recent times when there have been many alleged connections between aluminum and cancer. The carcinogenic effect of aluminum has not been proven to date, but that is not to say that aluminum is not carcinogenic. Therefore, caution should be taken when applying aluminum nanoparticles in drug delivery. [27] Many scientists recommend a limit on the number of aluminum nanoparticles. Most details in this section of work can be seen in the literature [28].

4.2 Mechanical Industry

Some of the chemical industrial processes apply nano-Al_2O_3 as a primary substance to modify the performance of their production. According to Jiang et al.'s group, epoxy resins are commonly improved by using Al_2O_3, CaCO3, and silica. The data showed that the physical and chemical properties of epoxy were enhanced in terms of lower coefficient, wear resistance, and flame retardance [29]. Many research has been done to enhance the surface modification of base metal with the help of various type of nanoparticles by friction stir welding/processing [30-40]. However, another study illustrated that diglycidylether of bisphenol-A (DGEBA) epoxy resins in the presence of nano-Al_2O_3 developed cure behaviour, dynamic mechanical properties, and increased thermal stability due to the content of nano aluminium dioxide in the DGEBA resin. The suitable techniques to investigate the ability of nano-Al_2O_3 were mostly tested by dynamic mechanical analysis, scanning calorimetry, thermal analysis, mechanical analysis, and thermogravimetric analysis [25, 29].

4.3 Bacterial growth

Aluminium dioxide was found to be a vital factor in changing the properties of bacterial cell membranes and the respiration of the bacterial cells. It is noticed that some of the toxic ions affect the activity of DNA, while using nanoparticle substances enhances the antibacterial ability and protects DNA from damage. Aluminium nanomaterials were found to minimize bactericidal concentration in Pseudomonas aeruginosa in the presence of graphene at around 20 mg/ml disintegration of the cell wall after 60 min. Many previous studies have reported that nanoparticle metals are beneficial parameters for penetrating the walls and cell membranes of bacteria such as Listeria monocytogenes. The scientific information recommended the impact of nano substances on changing the properties of bacteria like aluminium dioxide in Aeromonas hydrophila and nanoTiO2 in Enterococcus faecalis. [26,41].

4.4 Environmental

The recycling of substantial materials with nanoparticles was illustrated previously, and it has been shown that some nanoparticles are essential in helping release some contaminated substances [42] Recycling concrete with materials formed from large scales of particles was found to be more difficult than those created from nanostructured materials. It was discovered that nanoparticles have better mechanical properties at fresh than standard concrete and normal recycled concrete. This is because the workability of concrete is reduced by adding nanoparticles [43] It has also been evaluated that recycled concrete with nanoparticles can realize an analogous compressive strength to fresh standard concrete after 28 days; this is possibly achieved with 3% of nano silica mass [44] A study using nano-aluminium dioxide has been reported by Nazari et al. The results showed that adding nano Al_2O_3 developed the workability and compressive strength of binary blended concrete. This happens according to the replacement of nano aluminium dioxide by cement in the lime alumina-calcium sulfate (C-A-H) gel formation in concrete. It has also been found that pozzolan's main content is alumina, which can produce glassy or amorphous. The chemical reaction described is mainly the addition of pure 99.9% of nano-Al_2O_3 as an acceptable level to get a high Blaine fineness of around 60 m2/g, which could successfully develop the properties of cement [45].

4.5 Electrochemistry

In recent years, Al_2O_3 nanomaterial has attracted considerable attention in the electrochemical and electrochemistry fields. Several studies extended and improved methods to increase the performance of electrochemical systems using nanometal particles. Some semiconductors and metals were found to be appropriate in modified electrodes. Gamma Al_2O_3 was applied in constructed reference electrode with a glassy carbon electrode and coated the suspension surface of the electrode with Al_2O_3. The experimental data showed a high degree of adsorption and reaction motivation for the oxidation of E2 [46] Another study developed an effective method to estimate e the structure of Li-rich cathode. The aim was to provide an electrochemical system using an Al_2O_3 coating on the surface to avoid direct contact between the electrolyte and the cathode. The data obtained agreed with the stabilized basic structure of Li12Ni013Co013Mn054O2 during the dilithium/intercalation process [47] However, later, a group by Yoo *et al*. used the same apparatus as in the previous study to coat the surface with nano-sized Al_2O_3 particles of low concentration. Around 0.06 to 0.12 wt % were uniformly coated on the surface found in Li (Ni0.6Co0.2Mn0.2) O2. The electrochemical recorded a high initial discharge capacity of 206.9 mAh/g at around 0.05 C, over 3.0–4.5 V; it also showed about 94.5% improved capacity [48]. At the same time, a different amount of nano-Al_2O_3 is used to synthesize the Cu matrix via electro-less deposition. The results showed that Al_2O_3 particles were successfully coated with Ag to decrease the corrosion properties of copper with good electrical resistivity and less thermal conductivity with an increase of nano-Al_2O_3 particles [49]
Many investigations have studied and described the importance of Al_2O_3 and nano Al_2O_3 surfaces for electrochemistry applications. It can be seen in more detail in the literature, such as in the adsorption of contamination dyes and the removal of heavy metals using electrochemical measurements [50-55].

5. Conclusions

Nanoscale materials suggest an innovative range of promises in many scientific applications. Different industrial products found that most nanoscale materials are necessary substances to enhance some of the industrial progress in recycling, high-quality producing materials as in the drug field, and, in some cases, demand the value of materials such as antibacterial attributes in clothing. In various studies, it is essential to consider how nanoparticle applications can improve long-term effects. This can lead one to believe that the importance of nanoscale materials is not based on industrial applications. Still, it also shows evidence in previous studies that the key to preferring nanomaterials is mostly based on non-toxicity properties. To achieve this objective, nanoparticles can play an essential role in the growth of different applications. There is a constant need for further studies to find new nano-type materials with low-cost processing during the synthesis of nanoparticles that are less time-consuming with good properties such as particle size, surface area, and structure formed of crystalline.

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