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Review Article

New Trends in Self-Cleaning Materials for Different Purposes

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Abstract

Self-cleaning, as a well-known solution for various applications, has been the centre of attention amongst scientists. One of the properties that can be discussed in this scope is the application of various materials for different purposes. This covers a wide range of solar cell devices to building materials and indoor applications. Besides cost as one of the most important issues, using some materials without considering their long-term effects or irradiation source can be a sophisticated problem in this area. Hence, titanium dioxide (TiO2) with a combination of several materials, such as composites, can have competent capacity or even the potential of double self-cleaning properties. Current review gives a promising aspect to the knowledge of various combinations of TiO_2 with specific materials as a composite or polymer to improve and optimize the potential self-cleaning properties.

Keywords: Self-Cleaning; Composite; Titanium Dioxide (TiO2); Polymer.

Introduction

Today, the challenges for self-cleaning researchers are mostly about air pollution and environmental contamination in buildings specially on indoor and outdoor building surfaces [1,2]. Due to this wide range of self-cleaning applications, it is necessary to focus on various materials for different purposes [3,4]. These self-cleaning materials and derives involving chemicals such as ZnO/TiO2, IL/TiO2, Ag-SiO2-TiO2, etc. [5-9] with specific physicochemical characteristics have to be considered for all combinations [10]. Moreover, the products of this technology have successfully been commercialized in the area of environmental application [11], construction and building [12], textiles and fibres [13], and so on. In case of textiles, photo catalysis and superhydrophobicity- induced self-cleaning are two strategies which can be defined [14]. Fibrous polymer combined with hybrid of zinc oxide/graphene (ZnO/C60) make TiO2–ZnO–graphene nanofibers, which have high potential self-cleaning properties [15-18]. Environment and buildings contamination and infestation by insects adhered to various surfaces and solar panel can be cleaned simply via flowing water [19,20]. The other way, in order to decrease the costs for building maintenance from surface soiling, one effective and strongly applicable solution is the use of photo catalysts [21]. The most efficient material with photo catalytic potential, extreme stability, and low cost which is commonly used isTiO_2 [22-24]. Although TiO_2 can only be able to absorb UV light, that is 4% of total solar light, an important challenge in this way can be the enhancement of TiO_2 photo catalyst potential to absorb visible light more [25]. In this regard, there are some strategies to enhance the potential of TiO_2 visible light absorption [26]. One of these strategies that are more applicable is using noble metals and among all, noble metals that are now-a-days used, Ag is a common choice due to its functional ability [27]. According to potential activity of silver, this metal in contact with TiO_2 will be oxidized gradually [28,29]. Hence, this process needs another chemical material to avoid oxidation of silver. SiO_2 as an inhibitor of oxidation has the main role in Ag-SiO_2-TiO_2 composite [30-32]. Moreover, numerous syntheses composite have been produced from super hydrophobic materials [33] and stain removal materials [34] to protect building surfaces. The aim of the present review is to give an account of specific materials in conjunction with TiO_2 for the preparation of photo catalytic self-cleaning composite in the area of buildings and environment or the field of fibres and textiles as polymer combinations.

Applications and Features

Self-cleaning of a surface can be defined by two different mechanisms. First, it has the ability to connect to the surface wettability, and second, exhibit photo catalytic characteristics [35]. There are many articles that present research works with the purpose of understanding this matter that how contaminants affect the environmental conditions and buildings [36]. Moreover, they mention the impacts of the construction procedure, the self-cleaning reaction at nano-size scale, and through contexts [37]. Among other parameters, these recorded factors are based on visual observations and also have measurements of contaminated self-cleaning samples [38]. This review has tried to focus on a series of available self-cleaning materials that are currently used in industries. In order to find different kinds of materials for self-cleaning products and investigate some solutions for current and future issues, some materials have been applied in composite formulation. These composites have the potential to be applied for use in buildings and environment surfaces [39]. For clear examples in this area, it can be focused on wall and roof surfaces [40], photoactive composites [41], silica materials [42], zinc oxide materials [43], etc., for use in industry. The demonstration of self-cleaning materials includes a lot of information about properties [44], and manufacturers [45] which are provided by manufacturers due to evaluate the application of self-cleaning materials in their products [46].

Cementitious Composites

Currently, engineered cementitious composite (ECC) has been accepted as bendable concrete with a potential of hundred times tensile ductility than normal [47]. This extra high tensile potential has been recorded through some materials and components via a specific guideline [48,49]. Some applications of ECC, like low weight front is piece [50], simply repair the surface [51], and sidewalk [52], and cause self-cleaning property to be added into the construction material. These self-cleaning materials have the ability of keeping clean the building surface and cost reduction through decreasing maintenance process. One of the examples that used this composite to achieve its self-cleaning purpose is the Jubilee church in Rome Italy [53]. There is another advantage for self-cleaning material like white cement in this building which is surface solar reflectivity in order to keep the building in low temperature. All the surfaces with self-cleaning characteristics have been determined with a potential of keeping clean itself without any extra human intervention [54]. In this regard, two phenomena of hydrophilic and hydrophobic are the most applicable trends of self-cleaning treatment. Through the phenomenon of hydrophobicity, the surface will be cleaned by producing water droplets that roll down from the surface along with contamination. On the other hand, this cleaning surface happens in hydrophilic surfaces by producing sheeting water which carries away contamination and dust [55]. Besides hydrophilic and hydrophobic characteristics, photo-catalysts are used to decompose dust and contaminations on buildings' surface. By this action, all contamination compounds caused by polluted air, remove and change to clean compounds [56]. To this purpose, TiO2 is broadly used as photo catalyst and can be found in three types, called Anatase, Brookite, and Rutile [57]. The most band gap energy belongs to Anatase with 3.2 eV energy in response to 385 nm wavelength of UV. All of the time that photo-catalyst surfaces are under shining light, the photons with sufficient energy equal to or higher than the photo-catalyst's band gap produce a generation of electron pairs. In this situation, the electron pair which is separated, causes the oxidation reduction [58]. TiO2 has been accepted as a photocatalysis since Fujishima and Honda in 1972 published "Honda-Fujishima Effect" [59]. TiO2 is broadly used for the degradation of contaminants on different substrates which are under irradiation with sunlight or artificial light. Moreover, it has been mentioned that TiO2 has the effect of photo-induced hydrophilicity [60]. This phenomenon produces a flat film of water between two surfaces of substrate and dusts that causes contamination to slide down. Viewing the result of an experiment, Cassar et al. reported that by adding TiO2 to cement, photo catalytic properties into concrete engaged. The results for their experiments proved that TiO2 with cement are able to decompose compounds on the surface [61]. Moreover, other researchers indicated that TiO2 with micro-size particles in the concrete, caused degradation and deactivation of large molecular dust and contaminants [62]. Also, in another experiment, self-cleaning concrete in combination with TiO2 were fabricated. They showed that this concrete had the potential of decomposing CO2 [63]. From this section, it can be concluded that TiO2-ECC besides mechanical properties, has the potential of wettability, dust and contamination pick-up, and self-cleaning properties.

Cotton Fibre Composites

Due to consumer request, the application of self-cleaning in textile has made the thread market more fantastic. Subsequently, it is natural that wide research and experiments be performed in this arena [64-66]. It is possible to use TiO_2 and its derived as self-cleaning materials on various surfaces which have been involved in stainless steel, glass, activated carbon, and textile [67]. As a sample of extra sensitive and high photo catalytic material, TiO_2 can be a suitable representative in self-cleaning area [68]. TiO_2 in nano-sized scale, has the potential to degrade dust, contamination, and pollutant dye like Methylene Blue Acid Orange [69], Ethyl Violet Dye [70,71], Methyl Orange [72,73], and also degrade some air pollutants [74,75]. It has been reported that TiO_2 has been coated on some specific textiles such as cotton fabric through the polymerization process by using nano TiO_2 copolymer [76] and also TiO_2 has potential of functionalizing cotton fabric [77]. There is no data to explain about functionalization stability through the washing process. One novel research has succeeded to achieve the stability after washing through coated TiO_2 on cotton fabric by roller padding [71]. There is another coating process through TiO_2 and cellulose for two basic purposes: firstly, with the aim of self-cleaning, and secondly, for constant hardness.

In order to improve cotton fabric hardness, it is common to use starch as coating material [78-80] although hardness of starch is not constant because of characteristics of starch which will be dissolved in the presence of water [81]. On the other hand, coating fabrics using cellulose causes constant hardness even in the presence of water [82]. Some other researches achieve through the application of different cellulose coated for different purposes like using cellulose as a barrier of high oxygen [83], using as bioactive composite [84,85], and coating of the wood for confident packaging [86,87]. Only after changing the structure of cellulose, it will have melting potential. Moreover, it is highly stable and insoluble in most common and applicable organic solvents. Due to strong hydrogen bonding in cellulose, it has a remarkably stable structure [88]. Among all various kinds of solvents, only some of them such as NaOH-CS_2 [89], Ionic Liquid [90-92], 60% H2SO4 [93] have the potential to make cellulose dissolve [94]. Although cellulose degree of polymerization will be decreased by dissolving in 60% H2SO4 [95], in this case, successful and active coating is in the first level of importance.

Photoactive Composites

Due to extraordinary potential of photoactive materials such as antibacterial activity, water and air pollution removal, and self-cleaning characteristics, they have been widely considered as researchers' concern [96-99]. TiO_2 as a well-known material in this area has specific characteristics like low toxicity, low cost, and high photo-activity properties with a good stability regarding thermal and chemical properties [100,101]. To this aim, coating technique is developed through post-deposition of TiO_2 and other photoactive materials onto a substrate, like textiles, glass, polymer or metals [102]. Today with the growth of knowledge, there are some composites like waterborne paints where TiO_2 is one of the main combinations of their formulation [103]. But, there is a challenge in this way which is the aggregation of the TiO_2 in combination that leads to decreasing the efficiency of TiO_2 activity. One technique in order to decrease this problem is fixing TiO_2 as a form of a film inorganic hybrid [104]. Although this technique needs the presence of TiO_2 as a film on the surface, still this kind of TiO_2 distribution is not a good guarantee for the complete performance of TiO_2. Hence, a core–shell system from TiO_2 in core and polymer in the shell produces only Titania in the film, but TiO_2 is not accessible so there is a poor photoactive property. In theory, desired target is producing a film covered by TiO_2 on the surface of the core. To achieve this goal, it needs to focus on interplay between kinetics and thermodynamics activity of components, which it strongly belongs to recipe and strategy of components polymerization in combination [105-108]. There are various strategies for making a hybrid that among all of them, the best one is system of Pickering stabilization [109]. In this system, nano particles which normally are inorganic solid nanoparticles (NPs) are responsible for the stability of the dispersion. Applying this system prevents adhesion and poor gloss leading to migration during film formation [110]. Similar to a lot of inorganic hydrophilic materials, in order to increase the adsorption of NPs, modification of the surface is essential [92,93,111-114]. Besides preventing any problem with using this system, Pickering-stabilized latexes improve adhesive mechanical characteristics [115] and the coating process [116,117]. Due to all these advantages mentioned, polymer researchers have focused on hybrid materials which can be used as emulsion [118] or as mini-emulsion polymers [119]. Clays are the most usual Pickering stabilizers which are already used [120] and in second grade silica in NPs size [121]. However there are many other inorganic materials like graphene [122], magnetite [123], cerium dioxide [124] or zinc oxide [125].

Nanocomposites

By referring to the chemistry base on definitions, there are some liquids which have been called ionic liquids. Due to specific characteristics, among various kinds of ionic liquids, imidazolium-based type has been the centre of researches' attention [126]. These specific characteristics include high ionic conductivity, non-flammability, and negligible vapour pressure have answered a lot of questions in the field of chemistry [127]. Also, a lot of ionic based materials like nanocomposites and hybrids have been derived from these chemicals. Between these two kinds of materials, nanocomposites not only in practical, but also in fundamental studies, has the main role [128]. In the section of nanocomposite materials, one of the most important characteristics, wettability, could be a novel season in surface solution. Two characteristics have categorized them in hydrophobic level that are low tension in liquid surface [129] and tuneable potential [130]. With this explanation, it clears that in photo catalytic studies, nanocomposites wettability has been surveyed seriously [131]. Besides mentioned abilities, these nanocomposite materials have the potential of photo-induced stability [132], and combination with photo catalysis such as SnO_2, ZnO, TiO_2, and so on. TiO_2 has been known as the most famous photo catalytic materials. Also, it could be also applied in photovoltaic devices widely [133]. In this area, one of the researchers called Wang and colleagues investigated TiO_2 which has reversibly wettability potential switchable to dark phase and UV irradiation phase [134]. Photo catalytic activity mixing with wetting behaviour, encouraged researchers to use the ability of TiO_2 for the purpose of surface self-cleaning [135]. On the other hand, with improvement in coating various materials of TiO_2 and nanocomposites, different combinations such as TiO_2/nanocomposites and graphene/TiO_2/nanocomposite have been investigated specially in the field of surface chemistry [136]. Different techniques can be applied in this regards like sputtering, sol–gel technique, LBL technique and so on. The most applicable technique is LBL which is used for making thin layer films from TiO_2 and nanocomposite [137]. With the attention to similar wettability of TiO_2 and nanocomposites, nano/TiO_2 could be a suitable composite in self-cleaning studies.

Silica Composites

Rolling down rain drops on the surface of lotus leaves is a very common phenomenon in rainy days. For the first time, two researchers who are called Neinhuis and Barthlott, through microscopic study, observed a waxy hydrophobic surface on the lotus leaves [138]. With attention to lotus leaves, surface energy low in nano scale structure, water drops simply role down from the surface of leaves. Passing through the way, these water drops carry on dust and contaminations which finally lead to clean surface [139]. Using this natural phenomena of self-cleaning from nature, led to a group of researches with the aim of making hydrophobic surface coatings on different kinds of substrate such as wood, metals, glass, and so on [140]. Morphologically using raspberry (RB)-like shape particles for fabrication of these surfaces can be an acceptable suggestion. In this area, quite a few researches have been performed to make hydrophobic surface coating by applying RB-like shape particles [141,142]. Previously, RB-like shape particles have been made through fixing nano-sized particles on bigger sized particles [142]. As a preliminary research in this area, it was reported by Ming and colleagues for the first time [143]. To assemble a hydrophobic surface, they fixed nano silica particles of bigger sizes as a core, which were applied on an epoxy polymer, and then all of them were coated by polydimethylsiloxane (PDMS). Other researchers, Tsai and Lee, assembled nano silica particles of bigger sizes using glass as a substrate, coated by dodecyltrichlorosilane [144]. In another research, Puretskiy and Ionov used nano silica on polyglycidylmethacrylate as a core [145]. Qian and colleagues applied nano silica on polyacrylicacid, then covered by dodecyltrichlorosilane [146]. It can be stated that in all of RB-like particle experiments applying nano silica post coated by modified chemicals to achieve hydrophobic surface is almost common.

Conclusion and Future Research

This article reviewed different materials which can be applied in various industries and buildings as composites for self-cleaning properties. In all cases, TiO_2 has the main role of this phenomenon. Through the photo catalytic activity together with hydrophilic properties of TiO_2, this opportunity would get possible to degrade organic materials by UV radiation. Hence, whenever there is some water, these degraded materials would be washed down from the surfaces. For further research and studies, there are many other opportunities in the case of photo catalytic self-cleaning activity together with hydrophilic properties. These applications could be in cases of indoor building substances through using nanocomposites. Furthermore, outdoor substances, which need to be cleaned regularly but are difficult and expensive by this technique, would be simpler, cheaper, and last forever.

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