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Next-Gen TiO_2-ZnO/C_{60} Hybrid Photocatalyst for Urban Pollution Reduction in Construction & Infrastructure Applications

Abstract

With the building of new cities, urbanization has caused the building sector to be among the leading causes of air pollution. For instance, in cities, industrial air pollution accounts for 7 million annual deaths in the entire world. Recently, new ways of solving this problem have been approached, among them the use of photocatalytic materials in building materials, such as Titanium Dioxide (TiO_2), which started to be of interest due to their capability of decomposing pollutants like NO_x and VOCs. However, the large bandgap energy of TiO_2 restricts its efficiency under visible light, hindering large-scale and cost-effective applications. Because of this, there is a critical research gap in developing a large scalable visible light-activated photocatalytic material for building and construction applications. For this reason, further research is needed to extend the light absorption of TiO_2 into the visible spectrum and explore its practical application across various construction materials. This research aims to develop an innovative approach to urban pollution reduction by fabricating a next-generation TiO_2-ZnO/C_{60} hybrid visible light-activated photocatalytic composite material for exterior building and construction applications. A TiO_2-ZnO composite was synthesized by combining TiO_2 and ZnO in ethanol, followed by calcination at 400°C. The composite was then functionalized with 1–2% C_{60} in toluene, mixed, and calcined at 300°C in an inert atmosphere to optimize photocatalytic performance. The material was sprayed on concrete pavements and tested using the BET. XRD analysis confirmed the presence of TiO_2 (anatase) and ZnO (wurtzite) phases, ensuring successful composite synthesis. SEM images showed uniform dispersion and improved morphology with 2% C_{60} incorporation, enhancing surface structure. UV-Vis spectra demonstrated strong absorption in the visible range (400–500 nm), with the 2% C_{60} composite exhibiting higher absorbance, indicating superior activation under visible light compared to 1% C_{60}. Methylene blue degradation tests showed 100% efficiency within 2 hours, confirming complete pollutant breakdown. BET analysis showed a 22.12% increase in surface area, a 21.82% increase in Langmuir surface area, and a 20.86% improvement in t-Plot External Surface Area, indicating more active photocatalytic sites. Additionally, BJH adsorption cumulative pore volume increased by 25.81%, improving pollutant diffusion, while BJH cumulative surface area improved by 27.61%, enhancing interaction and demonstrating superior photocatalytic performance compared to the control. This photocatalytic composite material could be applied to construction materials, turning them into active green solutions that can effectively reduce urban air pollution, improve material performance, and pave the way toward sustainable, eco-friendly infrastructure for healthier cities and climate change mitigation.

Introduction

Urbanization and Air Pollution

- The construction industry is a major contributor to air pollution, causing 7 million premature deaths annually due to respiratory and cardiovascular diseases.

Environmental Impact of Construction

- Cement manufacturing generates 8% of global CO_2 emissions.
- Paints and coatings release VOCs, contributing to smog.

Limitations of Current Solutions (TiO_2)

- TiO_2 can break down NO_x and VOCs, but its large bandgap (~3.2 eV) limits activation to UV light (~5% of sunlight), reducing efficiency.

Research Gap

- Limited studies on extending TiO_2's activity into the visible spectrum.
- Lack of integration into construction materials for large-scale urban applications.

Research Aim

- Develop a TiO_2-ZnO/C_{60} hybrid composite with visible light activation and enhanced pollutant degradation.
- Explore scalable fabrication and integration into coatings, concrete, and façades for sustainable cities.

Motivation

Urban air pollution, largely driven by construction activities, contributes to **7 million premature** deaths annually and accounts for up to 20% of total NO_x emissions in some cities. Additionally, cement manufacturing generates **8% of global CO_2** emissions, while paints and coatings release VOCs, worsening air quality. Photocatalytic materials, particularly TiO_2, have shown promise in degrading pollutants, but their effectiveness is limited to **UV light (~5% of sunlight), restricting large-scale application.** Studies have explored doping and composite strategies to extend TiO_2's visible light activity, yet challenges remain in efficiency and integration into construction materials This research aims to develop a TiO_2-ZnO/C_{60} hybrid composite with enhanced **visible light** activation and improved pollutant degradation. By exploring scalable fabrication and integration into coatings, concrete, and façades, this study seeks to advance self-sustaining air-purifying materials for urban environments.

Methodology

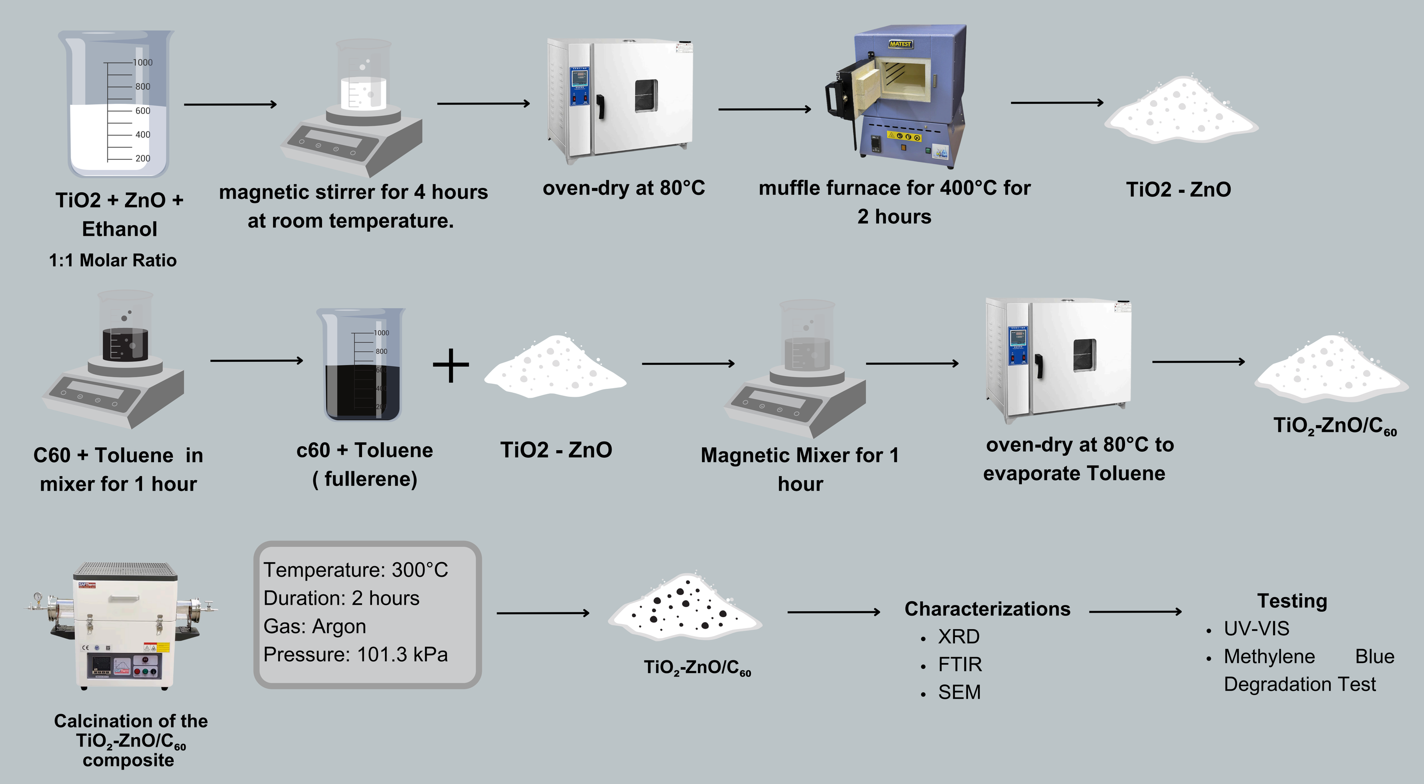

Figure 1: Fabricating Photocatalytic Methodology

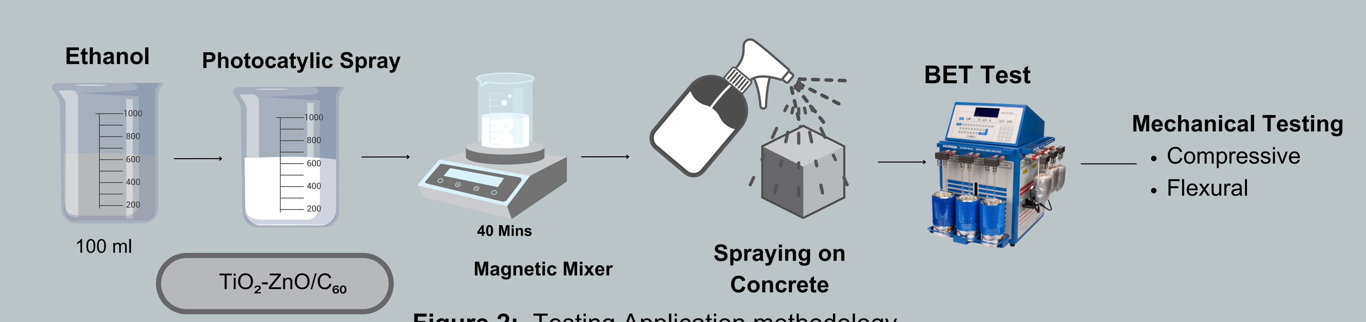

Figure 2: Testing Application methodology

Applications

Contact

RaseelAlharbi2007@gmail.com

+966 56 391 3391