

Article

Eco-Efficient Mortars with High-Content Construction, Waste-Derived Aggregates Functionalized via Nano-TiO₂ for NO_x Abatement

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Abstract: This study elucidates the photocatalytic NO_x abatement efficacy of eco-efficient mortars incorporating construction waste-derived aggregates functionalized with nano-TiO₂. The research findings demonstrate a positive correlation between NO_x abatement efficiency and nano-TiO₂ substitution ratio, with recycled glass sand (RG)-based panels exhibiting superior performance compared to standard sand and recycled clay brick sand (RCBS)-based counterparts. The employment of ultrasonic dispersion as a nano-TiO₂ incorporation method yields enhanced abatement efficiency relative to direct mixing, attributable to improved photocatalyst dispersion and surface area accessibility. The loading capacity of nano-TiO₂ on recycled aggregates is observed to be positively influenced by the concentration of nano-TiO₂ solution, with recycled clay brick sand demonstrating the highest loading capacity. RG-RCBS panels are shown to exhibit higher NO_x abatement efficiency than standard sand (SS)-RCBS panels, with an optimal substitution ratio of 40% glass sand identified for maximizing abatement efficacy in RG-RCBS systems. A decline in NO_x abatement efficiency is observed with increasing NO_x flow rate and concentration, attributable to reduced pollutant residence time and excess pollutant load exceeding the panels' processing capacity. Prolonged curing time also results in diminished abatement efficiency, due to microstructural alterations within the mortar matrix and the accumulation of photocatalytic reaction byproducts. Collectively, these findings underscore the potential of recycled aggregate-based mortars, in conjunction with nano-TiO₂, as a viable eco-efficient strategy for NO_x abatement, highlighting the critical influence of material selection, photocatalyst loading, and operational parameters on system performance.



Academic Editor: George Z. Kyzas

Received: 19 May 2025

Revised: 17 June 2025

Accepted: 18 June 2025

Published: 19 June 2025

Citation: Zhang, X.-C.; Chen, X.-F. Eco-Efficient Mortars with High-Content Construction, Waste-Derived Aggregates Functionalized via Nano-TiO₂ for NO_x Abatement. *Processes* **2025**, *13*, 1944. <https://doi.org/10.3390/pr13061944>

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Keywords: construction waste; recycled aggregate; mortar

1. Introduction

Air pollution, a pressing global environmental issue, poses significant threats to human health, ecosystems, and climate stability. Among the various air pollutants, nitrogen oxides (NO_x) are of particular concern due to their role in the formation of photochemical smog, acid rain, and ground-level ozone, as well as their contribution to greenhouse gas effects and particulate matter pollution [1–5]. NO_x emissions primarily originate from high-temperature combustion processes in industrial activities, transportation, and energy generation, making their mitigation a critical challenge in urban and industrial areas [6,7]. Traditional NO_x abatement strategies, such as selective catalytic reduction (SCR) and absorption methods, often involve high operational costs, complex infrastructure, and

potential secondary pollution. Therefore, the development of cost-effective, sustainable, and environmentally benign NO_x remediation technologies is imperative.

In recent decades, photocatalytic oxidation has emerged as a promising approach for air pollution control due to its ability to utilize solar energy for the degradation of pollutants under ambient conditions [8,9]. Titanium dioxide (TiO₂), particularly in its nano-sized form, has been extensively studied as a photocatalyst due to its high chemical stability, strong oxidizing power, and non-toxicity. Nano-TiO₂-based photocatalytic materials can effectively oxidize NO_x into less harmful nitrate products under ultraviolet (UV) irradiation, offering a passive and energy-efficient solution for air purification [10]. However, the practical application of nano-TiO₂ in civil engineering and building materials remains hindered by several challenges, including the high cost of pure nano-TiO₂, difficulties in immobilization, and the need for efficient light utilization [11]. To address these limitations, the integration of nano-TiO₂ with construction materials, such as mortar and concrete, has been explored as a viable strategy for the development of eco-efficient photocatalytic building materials [12–14]. Mortars, as versatile and widely used construction composites, can serve as ideal matrices for the incorporation of nano-TiO₂, enabling the creation of functional surfaces with self-cleaning and air-purifying properties [15–17]. Furthermore, the utilization of construction waste-derived aggregates in such photocatalytic mortars offers a dual benefit: promoting environmental sustainability through waste recycling and enhancing the mechanical and functional properties of the mortar matrix [18,19].

Construction and demolition (C&D) waste, a major global waste stream, contains significant amounts of recyclable materials such as concrete, bricks, and glass [20,21]. The incorporation of recycled aggregates derived from C&D waste into building materials not only reduces landfill burdens but also conserves natural resources and energy associated with primary aggregate extraction [20]. Previous studies have demonstrated the feasibility of using recycled concrete, brick, and glass aggregates in various construction applications, including mortars and concretes, with performance comparable to or exceeding that of conventional materials. However, the application of these recycled aggregates in photocatalytic mortars for NO_x abatement has received limited attention, despite their potential to synergistically enhance both environmental and functional performance. The present study investigates the development of eco-efficient mortars with high-content, construction waste-derived aggregates functionalized via nano-TiO₂ for NO_x abatement. Specifically, the research focuses on the utilization of recycled red brick sand (RBS), recycled glass sand (RG), and standard sand (SS) as aggregate components in photocatalytic mortars. These aggregates were selected based on their availability, cost-effectiveness, and potential for photocatalytic enhancement. The study explores the effects of nano-TiO₂ incorporation methods, aggregate types, substitution ratios, solution concentrations, NO_x flow rates, concentrations, and curing ages on the NO_x abatement efficiency of the composite mortar panels.

The selection of RBS, RG, and SS as aggregates was guided by their distinct physical and chemical properties, which are expected to influence the loading capacity and photocatalytic activity of nano-TiO₂. RCBS, derived from crushed red bricks, is composed primarily of clay minerals and exhibits a porous structure, potentially enhancing the adsorption of pollutants and the dispersion of nano-TiO₂. RG, obtained from recycled glass, possesses high transparency and a smooth surface, which may facilitate light transmission and improve the photoactivation of nano-TiO₂. SS, as a conventional aggregate, serves as a baseline for comparison, providing insights into the relative performance of recycled aggregates. The incorporation of nano-TiO₂ into the mortar matrix was achieved through two methods: direct mixing and ultrasonic dispersion. Direct mixing involves the simple addition of nano-TiO₂ powder into the mortar mix during the preparation process, while

ultrasonic dispersion utilizes ultrasonic energy to disperse nano-TiO₂ particles in a liquid medium prior to their introduction into the mortar mix. The latter method is expected to enhance the dispersion uniformity and surface area of nano-TiO₂, potentially leading to improved photocatalytic performance.

The study systematically investigates the NO_x abatement efficiency of the mortar panels under varying experimental conditions. Specifically, the effects of nano-TiO₂ substitution ratio, aggregate type, incorporation method, nano-TiO₂ solution concentration, NO_x flow rate, NO_x concentration, and curing age on the photocatalytic performance were evaluated. The substitution ratio of nano-TiO₂ was varied to determine the optimal loading level for maximum abatement efficiency, while the aggregate type was altered to assess the influence of different recycled materials on photocatalytic activity. The incorporation method was compared to identify the most effective dispersion technique, and the nano-TiO₂ solution concentration was optimized to ensure efficient loading and utilization of the photocatalyst. The impacts of NO_x flow rate and concentration were examined to simulate real-world operational conditions and evaluate the panels' performance under varying pollutant levels. Finally, the effect of curing age was studied to understand the long-term durability and performance stability of the photocatalytic mortars.

2. Experimental Details

2.1. Materials

The cementitious matrix is formulated using Ordinary Portland Cement (OPC 42.5) as the primary binder, augmented with recycled clay brick powder (RCBP) (less than 45 µm) as a supplementary cementitious material to enhance sustainability. The aggregate component incorporates three distinct types: (1) high-purity standard sand with silica content exceeding 98%, (2) recycled clay brick sand (RCBS) derived from mechanically processed demolished brick waste, and (3) recycled glass sand (RG) obtained from crushed post-consumer glass bottles, collectively addressing circular economy principles.

A critical component of the photocatalytic formulation is the nano-TiO₂, specifically Degussa P25—a widely recognized benchmark material in advanced oxidation research. This commercial titania is produced through a proprietary aerosol flame pyrolysis process, yielding a nanocrystalline powder with mixed-phase morphology. The crystallite phase ratio is engineered to approximately 80% anatase and 20% rutile, containing minimal amorphous content, a configuration optimized to promote efficient charge carrier separation and enhanced photocatalytic activity. Its physicochemical profile is characterized by a high BET-specific surface area of $50 \pm 15 \text{ m}^2/\text{g}$, primary particle dimensions around 21 nm, and $\geq 99.5\%$ TiO₂ purity. The material demonstrates exceptional thermal stability with $\leq 2.0 \text{ wt.}\%$ ignition loss at 1000 °C and maintains a controlled acidity within pH 3.4–4.5 in 4% aqueous suspension. Tabular data in Tables 1 and 2 systematically present the elemental compositions and physical properties of the cementitious binders and aggregates, respectively, providing quantitative foundations for material performance evaluation, whilst Figure 1 provides the absorbance of recycled glass sand regarding UV-A light.

Table 1. Chemical compositions and physical properties of cement.

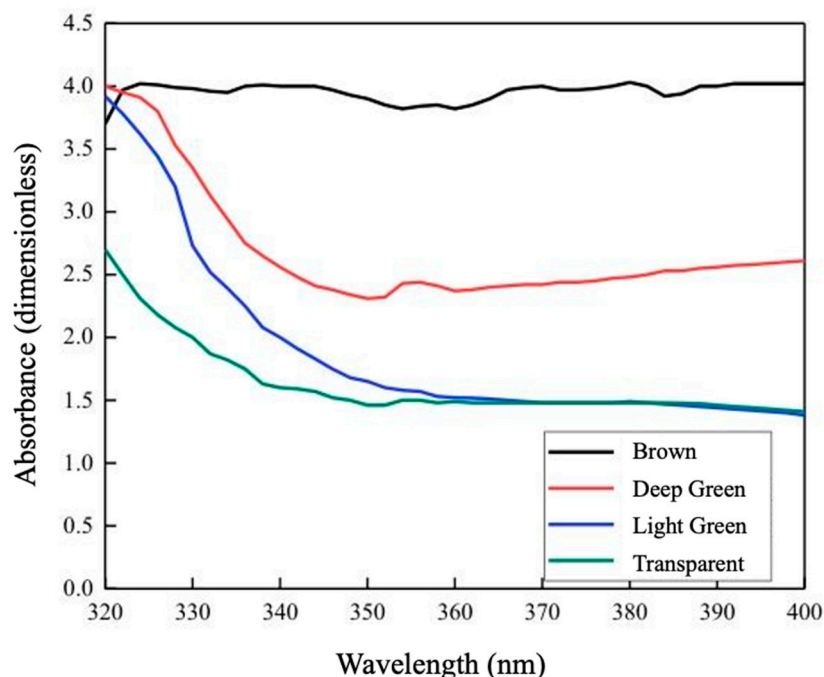
Notation	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	CaO (%)	MgO (%)	LOI (%)	D. (kg/m ³)
Content	19.41	5.43	4.06	64.15	2.64	1.22	3165

Note: D.—apparent density.

Table 2. Chemical compositions and physical properties of aggregates.

Notation	SiO ₂ (%)	Fe ₂ O ₃ (%)	Al ₂ O ₃ (%)	CaO (%)	MgO (%)	K ₂ O (%)	Na ₂ O (%)	SO ₃ (%)	D. (kg/m ³)	W.A. (%)
RCBS(P)	67.52	5.35	14.4	6.04	2.25	2.19	0.74	0.65	1365	16.7
RG	68.74	0.53	2.87	11.6	1.23	0.49	10.85	-	1478	0

Note: RCBS(P)—recycled clay brick sand and recycled clay brick powder; RG—recycled glass sand; D.—apparent density; W.A.—water absorption.

**Figure 1.** Absorbance of recycled glass sands regarding UV-A light.

2.2. Sample Preparation

The functionalized aggregates in this study refer to recycled clay brick sand, recycled glass sand, or standard sand with uniform particle size distribution (1.18–2.36 mm) loaded with nanoscale TiO₂. To address the agglomeration tendency of nanomaterials, ultrasonic disintegration was employed using a sonicator (Figure 2a) to disperse nano-TiO₂ particles in aqueous suspension, resulting in a milk-white colloidal solution (Figure 2b). The fabrication protocol comprising four sequential stages is presented as follows:

Stage 1: Aggregate Purification.

The collected RCBS, RG, and SS were initially rinsed with deionized water to remove surface impurities, particularly ensuring the complete removal of residual clay brick powder from RCBS. Subsequently, the washed aggregates were dried in an oven at 105 ± 5 °C for 48 ± 2 h to eliminate residual moisture within pores.

Stage 2: Nano-TiO₂ Suspension Preparation.

Aqueous nano-TiO₂ suspensions were prepared at specified mass ratios (nano-TiO₂: deionized water = 1:100). The mixture was initially homogenized using a glass rod, followed by ultrasonic dispersion at 20 kHz for 1 h (3 s ultrasonic pulse ON and 2 s pause, temperature maintained below 40 °C).

Stage 3: Photocatalyst Loading Process.

The dispersed nano-TiO₂ suspension was incorporated into the dried aggregates (pre-treated in Stage 1) at a mass ratio of nano-TiO₂: deionized water: carrier = 1:100:80. After 2 min of mechanical stirring, the mixture was sealed with plastic film and allowed to stand

at ambient temperature for 24 ± 2 h to ensure effective adsorption of nano-TiO₂ onto the carrier surfaces.

Stage 4: Thermal Stabilization and Conditioning.

The functionalized aggregates were drained of excess solution and dried at 105 ± 5 °C for 48 ± 2 h. Subsequently, the materials were rinsed with deionized water to remove loosely attached nano-TiO₂ particles, followed by a second drying cycle to constant mass. The final modified aggregates are illustrated in Figure 3, demonstrating uniform particle distribution and effective immobilization of the photocatalytic nanoparticles.

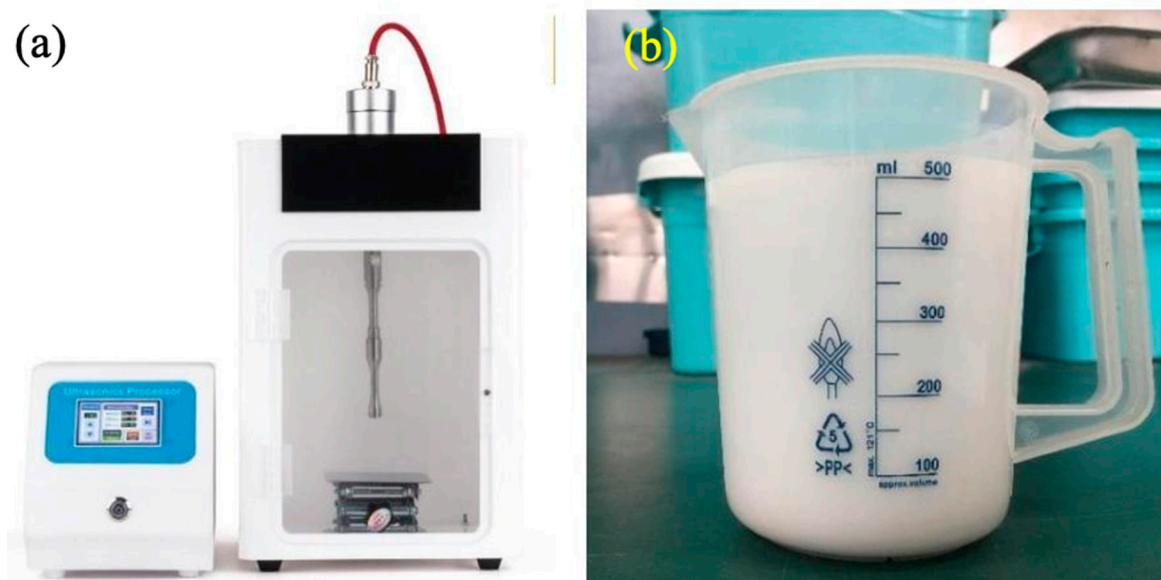


Figure 2. Ultrasonic vibration of nano-TiO₂ solution: (a) ultrasonic vibration device; (b) nano-TiO₂ solution after ultrasonic vibration.

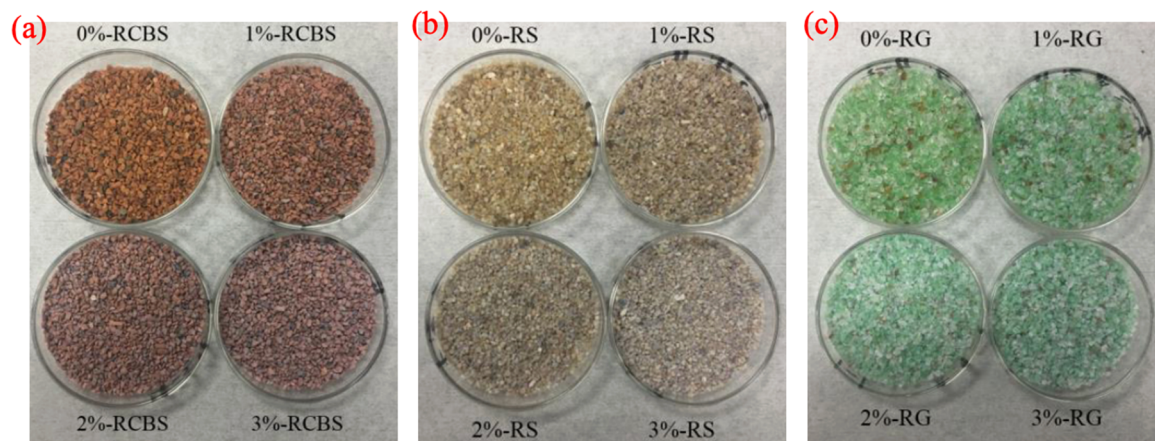


Figure 3. Nano-TiO₂-functionalized aggregates: (a) recycled clay brick sands; (b) standard sand; (c) recycled glass sands. Note: the percentage indicates the wt.% dosage of NT in soaking solution to treat aggregates.

The aforementioned nano-TiO₂-functionalized aggregates (NT-A) are then used to prepare the photocatalytic mortar as per the mix proportions in Table 3. The freshly prepared mixtures were initially cast into steel molds with precise internal dimensions of $100 \times 100 \times 5$ mm. The molds were then covered with plastic film to prevent moisture loss and maintained under controlled ambient conditions (23 ± 2 °C, $50 \pm 5\%$ RH) for 24 h to allow proper setting. Following this curing period, the hardened specimens were carefully demolded and transferred to a standard conditioning chamber regulated at 20 ± 2 °C

and relative humidity exceeding 95% until testing age. This controlled environment was maintained until the specified testing age to ensure optimal hydration processes and sufficient strength development.

Table 3. Mix proportions of the mortar containing functionalized aggregates (by wt.%).

Notation	Water	Binder		Functionalized Aggregates		
		Cement	RCBP	RCBS	SS	RG
100SS				-	2.5	-
80SS-20RCBS				0.5	2.0	-
60SS-40RCBS				1.0	1.5	-
40SS-60RCBS				1.5	1.0	-
20SS-80RCBS				2.0	0.5	-
100RCBS	0.5	0.75	0.25	2.5	-	-
20RG-80RCBS				2.0	-	0.5
40RG-60RCBS				1.5	-	1.0
60RG-40RCBS				1.0	-	1.5
80RG-20RCBS				0.5	-	2.0
100RG				-	-	2.5

Note: The consumption of cement in each sample is 150 g; RCBP—recycled clay brick powder.

2.3. Testing

The photocatalytic reactor system employed in this study adheres to JIS R1701-1 standards, which was used in a previous study [22], featuring a hermetically sealed configuration to prevent gas leakage and ensure experimental integrity. The schematic diagram of the apparatus is presented in Figure 4, comprising three integrated modules:

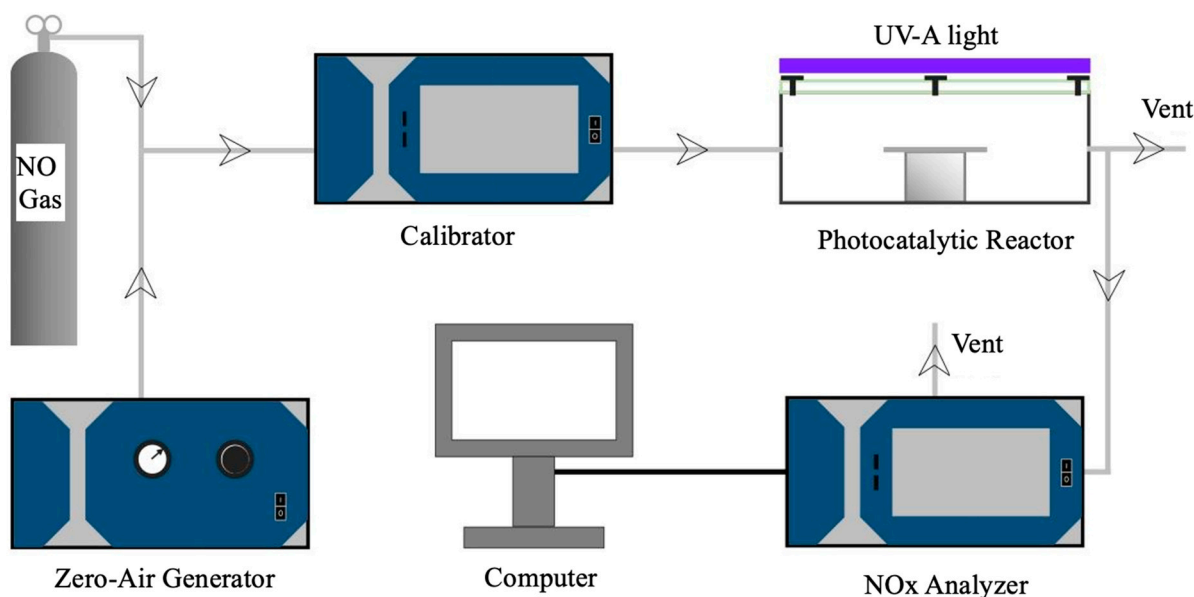


Figure 4. Testing equipment of NOx abatement.

Gas Generation Module:

This component integrates a zero-air supply system with a calibrated gas dilution system. By precise mixing of zero air and certified standard gases (NO), the module enables continuous generation of target pollutants at specified concentrations and flow rates, ensuring reproducible test conditions.

Photocatalytic Reaction Chamber:

As detailed in Figure 4, the reaction chamber maintains internal dimensions of 300 mm (length) $\times$ 150 mm (width) $\times$ 125 mm (height). A specimen holder is positioned such that its surface aligns horizontally with the chamber's gas inlet and outlet ports to ensure uniform gas distribution. Two UV-A fluorescent lamps (Philips, Amsterdam, The Netherlands) are mounted in parallel on the chamber's transparent lid, emitting ultraviolet radiation within the 300–400 nm wavelength range to activate the photocatalytic process. The irradiance of UV-A radiation on the sample surface was determined as 50 W/m² (LS125, Linshang, Shenzhen, China).

Gas Analysis System:

This module incorporates high-precision (0.1 ppb resolution) gas concentration analyzers (Model T200, Teledyne, Thousand Oaks, CA, USA), which is used to determine the real-time monitoring of NO levels via the chemiluminescence method. The system is interfaced with a data acquisition computer, which automatically records concentration values at 1 min intervals. This configuration ensures continuous, accurate documentation of pollutant degradation kinetics throughout the experimental duration.

The integrated design of this apparatus enables systematic investigation of photocatalytic efficiency under controlled environmental parameters, providing an accurate platform for evaluating material performance in air purification applications.

Photocatalytic reactions were conducted under controlled ambient conditions (25 ± 3 °C) with relative humidity maintained at $30 \pm 5\%$. Experimental parameters were systematically varied based on specific objectives: NO concentrations were set to 200 ppb, 400 ppb, 600 ppb, 800 ppb, and 1000 ppb with corresponding flow rates of 1.0 L/min, 2.0 L/min, 3.0 L/min, 4.0 L/min, and 5.0 L/min. Prior to UV irradiation, a pre-conditioning phase was implemented where test gases were circulated through the reactor for at least 30 min. This protocol ensured complete displacement of residual air and the establishment of steady-state gas flow conditions. Subsequently, UV lamps were activated to initiate photocatalytic reactions, with each mortar panel exposed to NO_x for 45 min. Real-time concentration measurements were recorded at both reactor inlet and outlet ports. Triplicate tests were performed for each panel, with average values reported as final experimental outcomes. Given the propensity of NO to oxidize into NO₂ under ambient conditions, the NO_x analyzer provided simultaneous monitoring of both species. Observed NO₂ concentrations remained below 20 ppb across all experiments, validating the use of NO_x degradation efficiency as the primary performance metric. The photocatalytic degradation efficiency (ω) was calculated using the following formula:

$$\omega = \frac{C_0 - C_1}{C_0} \times 100\%$$

where C_0 represents the inlet concentration and C_1 is the outlet concentration of NO_x. This methodology ensures accurate quantification of photocatalytic activity under controlled reactant conditions.

The 40RG-60RCBS mortar samples, fabricated using 1% nano-TiO₂ loading with 40% glass sand substitution, is used to systematically investigate the effects of varying NO_x generation flow rates and concentrations on the photocatalytic efficiency of the panels. A dual-pronged experimental framework was adopted: (1) Flow Rate Variation Analysis: Maintaining a constant NO_x concentration of 800 ppb, the flow rates were systematically varied at 1.0, 2.0, 3.0, 4.0, and 5.0 L/min; (2) Concentration Variation Analysis: Under a fixed flow rate of 3.0 L/min, NO_x concentrations were adjusted to 200, 400, 600, 800, and 1000 ppb. The experimental NO_x flow rates and concentrations were precisely controlled via a calibrated gas dilution system. To minimize hydrodynamic disturbances and ensure accurate measurement of photocatalytic activity, the mortar panels were positioned on

an adjustable platform such that their surfaces aligned vertically with the inlet and outlet ports of the photocatalytic reactor chamber. This configuration effectively negated potential artifacts arising from non-uniform gas flow distribution across the panel surface. Quantitative results are obtained under varying flow conditions (800 ppb, 1.0–5.0 L/min) and concentration gradients (3.0 L/min, 200–1000 ppb), respectively. The data provides critical insights into the operational parameters governing the photocatalytic performance of these hybrid mortar systems under dynamic pollutant conditions.

The study also systematically investigates the influence of curing duration on the NO_x photocatalytic degradation efficiency of composite photocatalytic mortar panels, following the preparation mix ratios established in the preceding section. Specifically, both recycled clay brick sand-based and glass sand were synthesized with 1% nano-TiO₂ loading (by mass ratio of nano-TiO₂: deionized water: carrier = 1:100:80). The 40RG-60RCBS, containing 40% glass sand substitution was employed as the matrix material. The panels were cured under controlled conditions and their photocatalytic performances were evaluated at 3, 14, 28, and 90 days of curing. NO_x gas with a flow rate of 3.0 L/min and an initial concentration of 800 ppb was used as the target pollutant. It provides quantitative evidence for the temporal evolution of catalytic activity in these hybrid systems.

3. Results and Discussion

3.1. Effect of Incorporation Dosage and Method of Nano-TiO₂ on the NO_x Removal

Figure 5 provides comparative visual analytics of the photocatalytic NO_x abatement efficiencies exhibited by mortar panels fabricated via two distinct nano-TiO₂ incorporation methodologies—conventional mechanical mixing and ultrasonic-assisted dispersion—across three aggregate variants (recycled clay brick sand, standard sand, recycled glass sand) and varying nano-TiO₂ substitution ratios. The experimental data reveal a monotonic increase in NO_x photocatalytic removal efficiency with elevated nano-TiO₂ substitution ratios (1–5% by weight) across all aggregate types and incorporation methods. Notably, the recycled clay brick sand-based panel with 1% nano-TiO₂ substitution exhibited the least efficiency (29.29%). In contrast, the recycled glass sand-based panel with 5% substitution achieved the highest efficiency (47.54%) among all tested configurations.

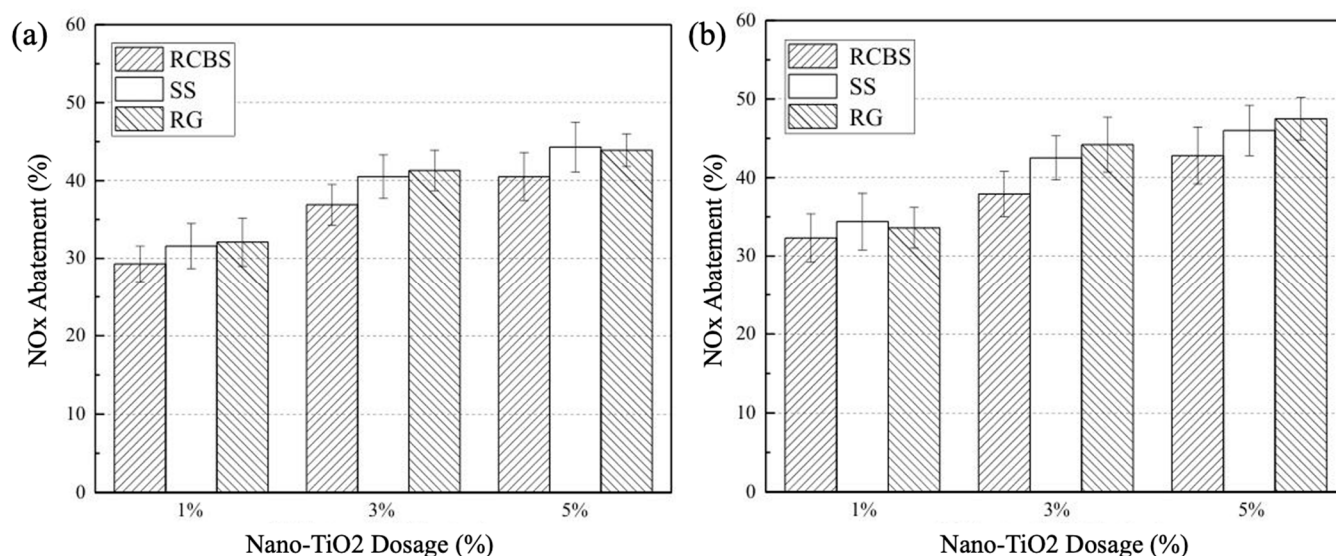


Figure 5. NO_x abatement of mortar containing varied nano-TiO₂ dosage by (a) traditional intermixing; (b) ultrasonic mixing.

Irrespective of the nano-TiO₂ incorporation technique (direct mixing vs. ultrasonic dispersion), recycled glass sand- and standard sand-based panels consistently outperformed recycled clay brick sand-based panels in terms of NO_x photocatalytic abatement efficiency when subjected to equivalent substitution ratios. Specifically, under direct mixing conditions and equivalent substitution ratios, the photocatalytic NO_x removal efficiencies of glass sand- and standard sand-based panels were comparable. However, under ultrasonic dispersion conditions with equivalent substitution ratios, glass sand-based panels demonstrated superior photocatalytic NO_x abatement efficiencies compared to standard sand-based counterparts.

The photocatalytic NO_x abatement efficiency of mortar panels is governed by two primary factors: (1) Nano-TiO₂ content. Under controlled mortar-to-sand and water-to-cement ratios, the packing density of aggregates critically influences the nano-TiO₂ distribution within the cementitious matrix. Higher aggregate packing densities result in more densely compacted cement paste, facilitating uniform dispersion of nano-TiO₂ particles throughout the mortar matrix. The result is consistent with a previous study stating that the surface property and microstructural features of photocatalytic cementitious materials impact the purification efficiency [23,24]. Consequently, for equivalent nano-TiO₂ substitution ratios, panels with denser aggregates exhibit greater cement paste volume per unit mortar, thereby increasing the effective nano-TiO₂ content. Among the tested aggregates—recycled clay brick sand, standard sand, and recycled glass sand—standard sand demonstrated the highest packing density ($\rho_{\text{standard}} > \rho_{\text{glass}} > \rho_{\text{clay brick}}$). In addition, the porous microstructure of clay brick sand, characterized by rough surfaces and abundant micropores, induced partial cement paste infiltration into these voids during mixing. This phenomenon reduced the accessible nano-TiO₂ content per unit volume, directly correlating with the lowest NO_x abatement efficiency ($\eta_{\text{clay brick}} = 29.29\%$ at 1% substitution) among all panel types. (2) Aggregate light transmittance effects. Photocatalytic reactions in mortar panels are UV-dependent processes. For non-transparent aggregates, the effective photocatalytic area is spatially confined to the panel surface. Among the three aggregates, only recycled glass sand exhibited optical transparency, enabling UV light penetration into deeper areas of the panel via refractive and reflective pathways. This optical property significantly expanded the effective photocatalytic reaction zone. The performance implications were thereby twofold: Under baseline mixing conditions, glass sand-based panels achieved NO_x abatement efficiencies (η_{glass}) comparable to standard sand-based panels (η_{standard}). Under ultrasonic dispersion, the optimized nano-TiO₂ distribution in glass sand-based panels further enhanced light utilization, resulting in superior NO_x abatement performance ($\eta_{\text{glass}} > \eta_{\text{standard}}$ at 5% substitution).

Figure 6 provides comprehensive visual evidence of the photocatalytic NO_x abatement efficiencies exhibited by three distinct mortar panel types—recycled clay brick sand-based, standard sand-based, and recycled glass sand-based—across varying nano-TiO₂ incorporation methodologies and substitution ratios. The empirical data reveal a consistent trend wherein ultrasonically dispersed panels outperform their directly mixed counterparts in terms of NO_x photocatalytic removal efficiency across all tested nano-TiO₂ substitution levels. This performance disparity stems from the inherent challenges associated with nanoscale particle dispersion. Specifically, the ultrafine dimensions of nano-TiO₂ particles predispose them to agglomeration, which significantly compromises their reactive surface area and distribution uniformity within the mortar matrix. Ultrasonic dispersion, however, effectively disrupts these agglomerates, promoting homogeneous nano-TiO₂ distribution throughout the panel structure. Consequently, ultrasonically treated panels exhibit not only elevated concentrations of catalytically active nano-TiO₂ but also enhanced interfacial contact between the photocatalyst and NO_x molecules. These synergistic effects—improved

dispersion uniformity and augmented reactive surface area—culminate in the superior photocatalytic performance observed in ultrasonically dispersed panels compared to directly mixed formulations.

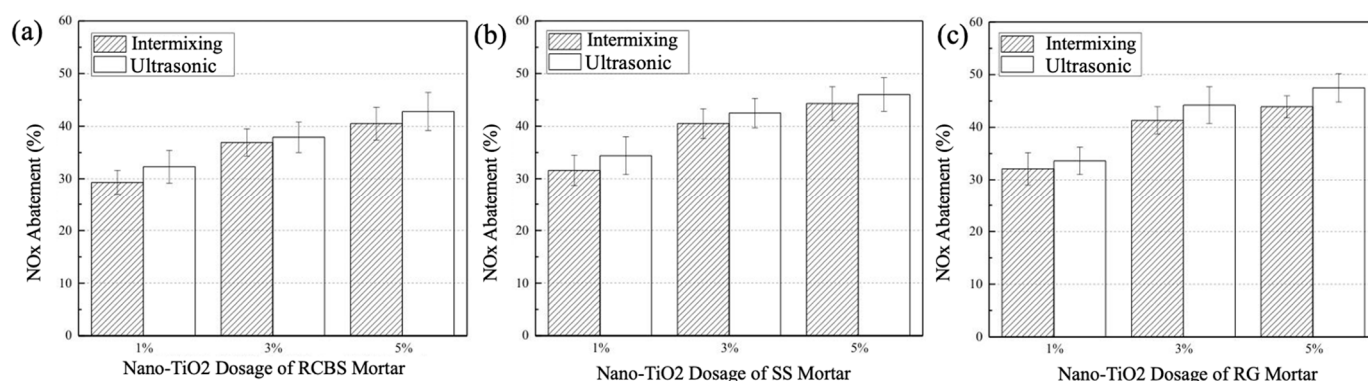


Figure 6. NOx abatement of mortar containing varied nano-TiO₂ dosage by (a) recycled clay brick sand mortar, (b) standard sand mortar, and (c) recycled glass sand mortar.

3.2. Effect Aggregate Type on the NOx Abatement

Figure 7a illustrates the nano-TiO₂ loading efficiencies of recycled clay brick sand, recycled glass sand, and standard sand substrates following immersion in solutions with varying nano-TiO₂ concentrations. The data reveal a universal concentration-dependent increase in loading efficiency across all substrates. However, under identical nano-TiO₂ solution concentrations, recycled clay brick sand consistently demonstrated the highest loading efficiency, followed by recycled glass sand, with standard sand exhibiting the lowest values. Notably, recycled clay brick sand showed a nearly linear loading efficiency increase as the solution concentration rose from 1% to 3%, whereas recycled glass sand and standard sand displayed attenuated growth rates between 2% and 3% compared to the initial increment from 1% to 2%.

The recycled clay brick sand matrix is characterized by a complex hierarchical porosity, comprising numerous fissures and micropores that contribute to its high specific surface area. This intricate surface morphology provides not only abundant but also geometrically advantageous sites for nano-TiO₂ adhesion. The inherent roughness of the clay brick sand surface further enhances the mechanical interlocking of nano-TiO₂ particles, resulting in significantly improved adhesion strength. Microstructural analysis in Figure 7b–f reveals deep pore formations within the clay brick sand-based photocatalyst. Energy-dispersive X-ray spectroscopy (EDS) confirms the presence of nano-TiO₂ within these pores, as indicated by elevated oxygen (O) and titanium (Ti) elemental concentrations. In contrast, recycled glass sand presents a relatively smooth surface texture with limited porosity. While occasional convexities and microcracks may arise from mechanical stress during recycling, these features are sparse compared to the extensive fissure networks in clay brick sand. Consequently, the available nano-TiO₂ adhesion sites on glass sand are substantially fewer, and the adhesion strength is significantly weaker. Microscopic examination demonstrates this disparity: EDS analysis identifies concentrated nano-TiO₂ deposits on convex surface features (Point 44), while flat regions (Point 46) show negligible Ti concentrations, with dominant oxygen (O) and silicon (Si) signals indicating minimal nano-TiO₂ adhesion.

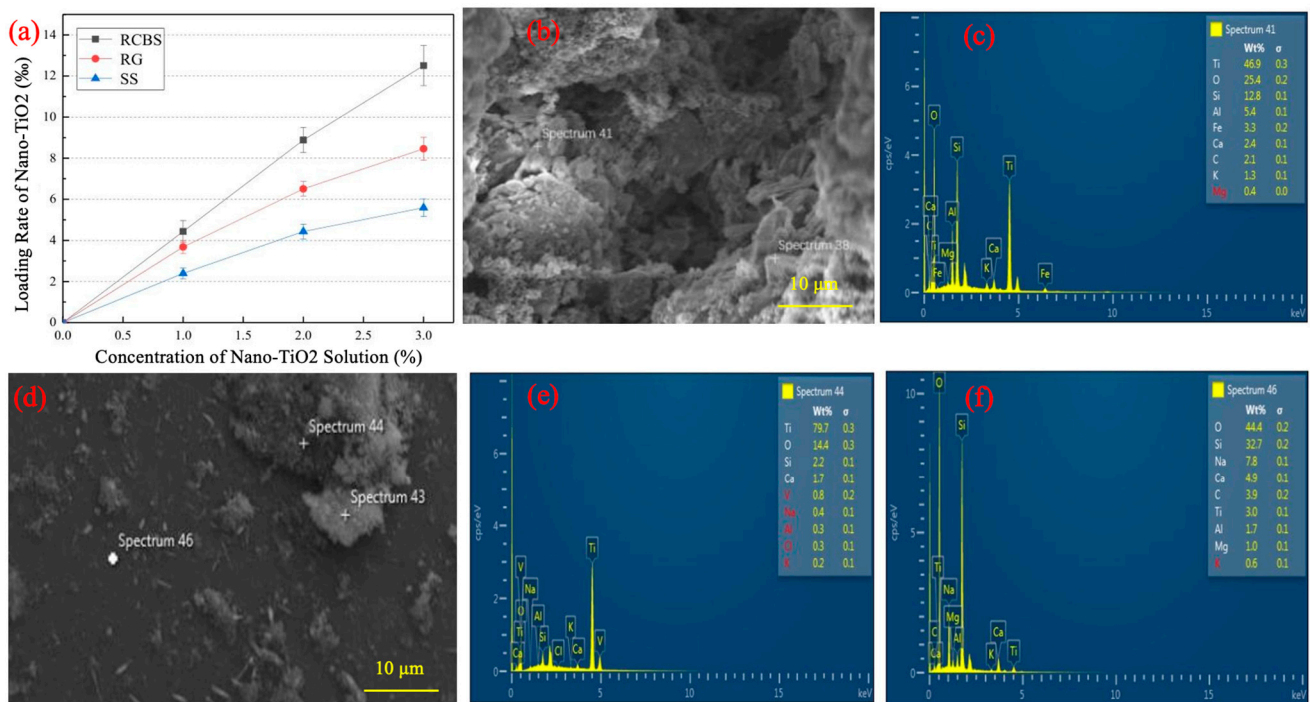


Figure 7. Loading rate of various aggregate types on nano-TiO₂ and the SEM-EDX micrographs: (a) loading rate; (b) micrographs of nano-TiO₂-modified recycled clay brick aggregate; (c) EDX result at point 41; (d) micrographs of nano-TiO₂-modified recycled glass aggregate; (e) EDX result at point 44; (f) EDX result at point 46.

Standard sand, with its smooth, non-porous surface, provides the least favorable conditions for nano-TiO₂ adhesion. The absence of fissures or micropores restricts adhesion to the outermost surface layer, and the smooth texture results in weak van der Waals bonding. From a materials science perspective, the clay brick sand matrix inherently offers superior nano-TiO₂ loading capacity due to its hierarchical porosity and rough surface texture, which synergistically enhance both the quantity and quality of adhesion sites. Recycled glass sand, while partially compensating through surface convexities, exhibits significantly lower loading efficiency. Standard sand, devoid of beneficial surface features, demonstrates the weakest loading capacity. These observations collectively explain the experimental trend where recycled clay brick sand exhibits the highest nano-TiO₂ loading efficiency under identical solution conditions, followed by recycled glass sand, with standard sand performing the poorest.

3.3. NO_x Removal of Mortar Prepared by Various Nano-TiO₂-Modified Aggregates

Figure 8 provides a comprehensive visual analysis of the photocatalytic NO_x abatement efficiencies achieved by mortar panels under varying substitution ratios. The experimental data demonstrate a distinct performance disparity between the two panel types: RG-RCBS panels consistently exhibit superior NO_x abatement efficiencies compared to SS-RCBS panels across all equivalent substitution ratios. For SS-RCBS panels, an inverse relationship is observed between the substitution ratio of standard sand-based photocatalyst and NO_x abatement efficiency. Specifically, increasing the standard sand substitution ratio results in a progressive decrease in NO_x abatement efficiency. This phenomenon can be attributed to the inferior photocatalytic activity of standard sand-based mortar, which may stem from their lower surface area and reduced nano-TiO₂ dispersion efficiency.

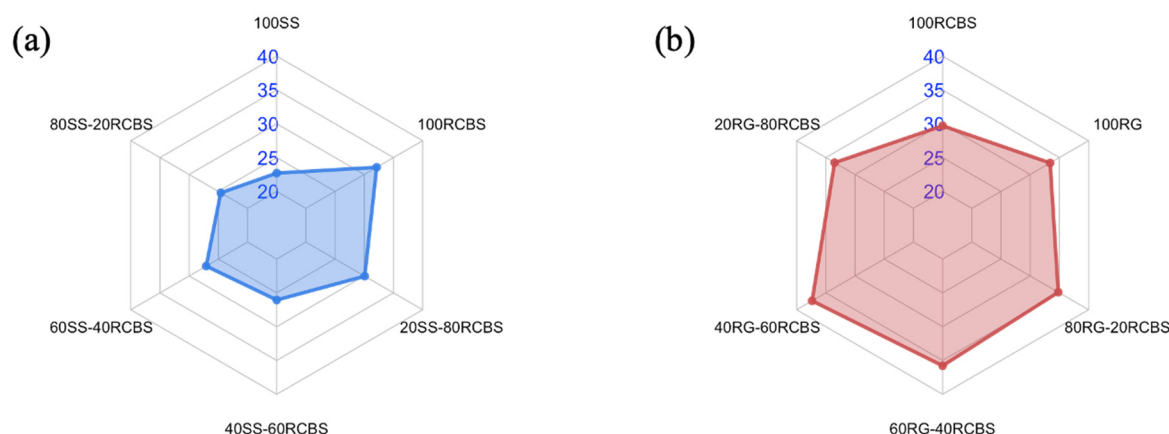


Figure 8. NO_x removal of mortar with various aggregate types and substitutions: (a) standard sand-recycled clay brick sand; (b) recycled glass sand-recycled clay brick sand.

In contrast, RG-RCBS panels display a non-linear performance trend. As the glass sand-based mortar substitution ratio increases from 0% to 40%, the NO_x abatement efficiency of RG-RCBS panels shows a significant enhancement. Optimal performance is achieved at a 40% substitution ratio, where the abatement efficiency increases from 32.13% (0% substitution) to 41.70%, representing a substantial 29.79% improvement. Beyond this critical threshold, however, further increasing the glass sand substitution ratio to 100% (100RG) leads to a decline in abatement efficiency, with the value decreasing to 36.77–11.82% lower than that at 40% substitution. This observation suggests the existence of an optimal glass sand substitution ratio, beyond which excess glass sand may compromise the structural integrity of the mortar matrix or reduce the effective nano-TiO₂ exposure. Collectively, these findings underscore the enhanced photocatalytic NO_x abatement performance of RG-RCBS panels compared to their SS-RCBS counterparts. The optimal glass sand-based photocatalyst substitution ratio of 40% represents a critical parameter for maximizing NO_x abatement efficiency in mortar panel applications.

The preceding section examined the nano-TiO₂ loading capacities of various aggregates, with recycled clay brick sand demonstrating the highest loading efficiency followed by recycled glass sand, and standard sand showing the poorest performance. In SS-RCBS mortar panels, an increase in the substitution ratio of standard sand leads to a decrease in the total nano-TiO₂ content per unit panel volume. This reduction in available photocatalyst directly correlates with a gradual decline in NO_x photocatalytic abatement efficiency. Recycled glass sand, however, possesses superior UV transmittance properties, which significantly enhance the photocatalytic activity of composite panels. Studies have confirmed that light-colored glass variants (e.g., clear or green glass) effectively transmit UV radiation, whereas brown glass absorbs nearly all incident UV light. As schematically illustrated in Figure 9, glass sand facilitates the penetration of external UV light into a deeper area through refractive and reflective pathways. This phenomenon activates nano-TiO₂ particles embedded within the pores of recycled clay brick sand, thereby increasing the concentration of effective nano-TiO₂—particles directly participating in NO_x photocatalytic degradation. Under equivalent substitution ratios, SS-RCBS panels exhibit lower total nano-TiO₂ content compared to their RG-RCBS counterparts. Furthermore, standard sand functions as an opaque barrier, absorbing and blocking light transmission. Unlike glass sand, it does not efficiently direct external light sources into the deep pores of recycled clay brick sand. Consequently, SS-RCBS panels contain fewer effective nano-TiO₂ particles than RG-RCBS panels, resulting in reduced NO_x photocatalytic abatement efficiencies.

These observations collectively highlight the critical role of aggregate optical properties in optimizing photocatalytic performance within the mortar systems.

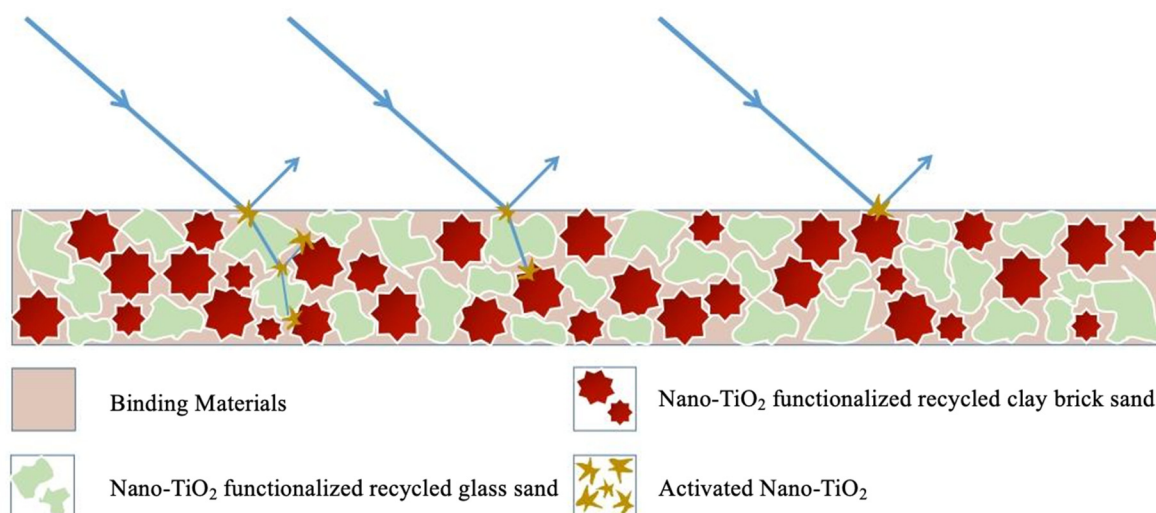


Figure 9. Light propagation pathways in nano-TiO₂-loaded, recycled clay brick sand and glass sand-based mortar panels.

Regarding RG-RCBS mortar panels, the total nano-TiO₂ content decreases with increasing glass sand substitution ratio, yet the overall light transmittance of the panel improves simultaneously. This enhanced light transmittance facilitates a more efficient utilization of UV radiation, thereby increasing the effective nano-TiO₂ content—defined as the fraction of nano-TiO₂ particles actively participating in photocatalytic reactions. Within the substitution range of 0–40%, the positive effect of increased effective nano-TiO₂ content outweighs the negative impact of reduced total nano-TiO₂ content. Consequently, the NO_x photocatalytic abatement efficiency of RG-RCBS panels rises as the glass sand substitution ratio increases from 0% to 40%. However, beyond this critical threshold of 40% substitution, the decrease in total nano-TiO₂ content becomes excessively pronounced. The detrimental effect of diminished total photocatalyst availability surpasses the beneficial influence of improved light transmittance and effective nano-TiO₂ utilization. Therefore, when the glass sand substitution ratio exceeds 40%, the NO_x photocatalytic abatement efficiency of RG-RCBS panels begins to decline with further increases in substitution ratio. This non-linear performance trend underscores the existence of an optimal glass sand substitution ratio at 40%, where the interplay between total nano-TiO₂ content and light transmittance is most conducive to photocatalytic NO_x abatement.

3.4. Effect of Flow Rate and Initial Concentration on the NO_x Removal Efficiency

Figure 10 presents comprehensive visual data on the photocatalytic NO_x abatement efficiencies of mortar panels under varying operational parameters. Specifically, the left subgraph illustrates the abatement efficiencies at a constant NO_x concentration of 800 parts per billion (ppb) with different gas flow rates, while the right subgraph depicts the efficiencies at a fixed flow rate of 3.0 L/min with varying NO_x concentrations. The results demonstrate a clear trend: under identical NO_x concentrations, the abatement efficiency decreases with increasing NO_x flow rate; conversely, under constant flow rates, the efficiency diminishes as NO_x concentration increases.

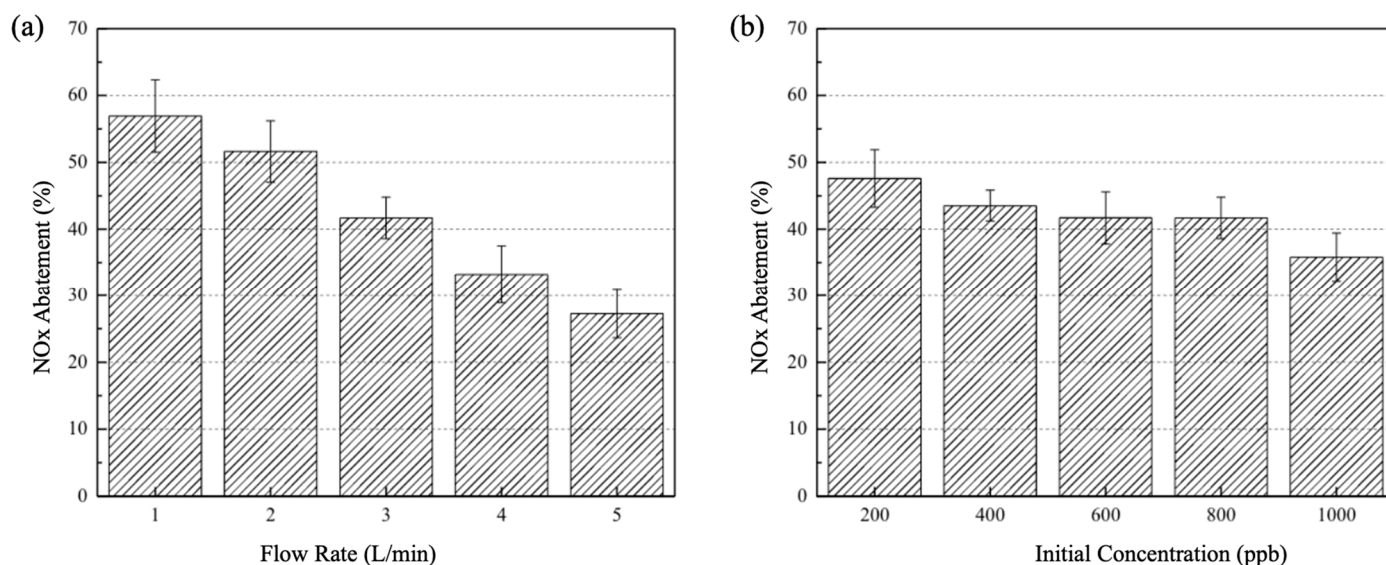


Figure 10. NOx removal of mortar under various (a) flow rates and (b) initial concentrations.

The mechanistic rationale underlying these phenomena can be dissected as follows: At a fixed NOx concentration, elevated flow rates reduce the residence time of NOx molecules within the photocatalytic reactor chamber. This abbreviated dwell time decreases the average contact duration between NOx molecules and nano-TiO₂ particles embedded in the composite panels, consequently lowering the photocatalytic reaction efficiency. Conversely, under constant flow conditions, increasing NOx concentration leads to a higher molecular flux of NOx within the reactor. Given the finite quantity of effective nano-TiO₂ particles in the composite panels and the continuous flow of NOx gas, the excess pollutant molecules exceed the panels' processing capacity, resulting in a decreased abatement efficiency. It is noteworthy that certain photocatalytic degradation studies [24] on alternative pollutants have identified an optimal pollutant concentration threshold. Below this threshold, increasing pollutant concentration enhances degradation efficiency due to increased mass transfer; beyond it, catalytic deactivation occurs, leading to reduced efficiency.

3.5. Effect of Curing Time on the NOx Removal Efficiency

Figure 11 illustrates the photocatalytic NOx abatement efficiencies of mortar panels at different curing ages. The results demonstrate a distinct temporal decline in abatement efficiency as the curing period increases. Specifically, compared to the 3-day cured panel, the NOx abatement efficiencies of panels cured for 28, 56, and 90 days decreased by 5.97%, 13.21%, and 21.99%, respectively. The underlying mechanisms contributing to this reduction in efficiency can be multifaceted. Prolonged curing periods facilitate ongoing cement hydration, which induces significant microstructural alterations within the composite mortar matrix. These changes, particularly the refinement of pore networks and reduction in porosity, directly influence the photocatalytic activity of the panels. The photocatalytic efficacy of such systems is contingent upon several factors, including pore structure, surface exposure conditions, pollutant properties, and ambient humidity [25]. It has been established that dynamic adsorption equilibrium, adsorption rate, internal mass transfer, and effective diffusivity all play critical roles in determining the overall photocatalytic abatement efficiency [26]. Furthermore, studies have shown a strong positive correlation between the adsorption coefficient of photocatalytic cementitious materials and their porosity [27,28]. As curing time progresses, the capillary pore count and total pore

volume diminish, potentially reducing the available surface area for pollutant adsorption and photocatalytic reactions [29,30].

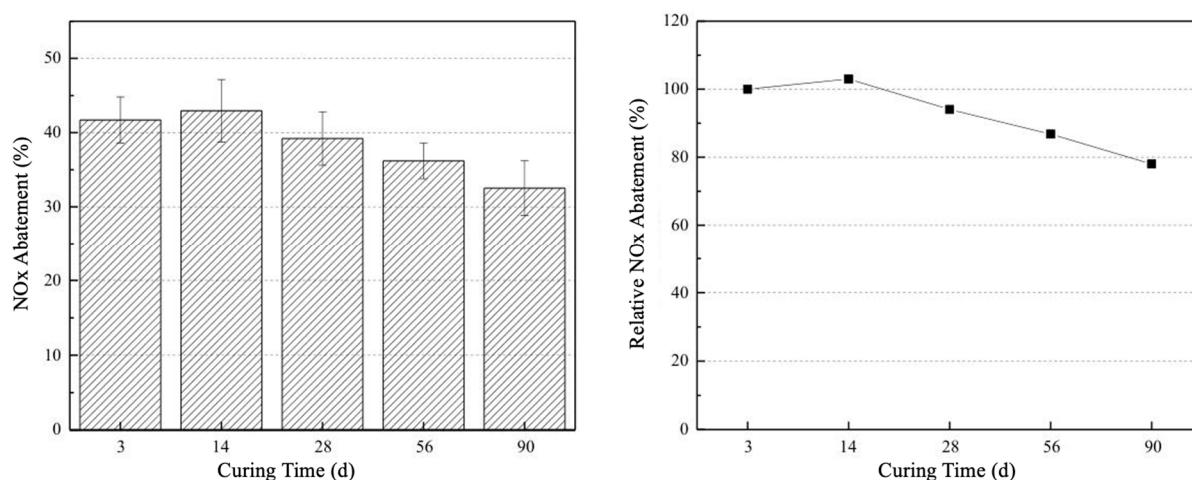


Figure 11. Effect of curing time on the NOx abatement: absolute value (left); relative value (right).

Concurrently, the accumulation of photocatalytic reaction products, such as HNO_3 , derived from the oxidation of NOx, gradually deposits on the effective nano- TiO_2 particles within the composite panels. This deposition process not only occludes active catalytic sites but also diminishes the contact area between NOx molecules and nano- TiO_2 during photocatalytic reactions, thereby reducing the overall abatement efficiency. Collectively, these phenomena—microstructural evolution during cement hydration and the aggregation of photocatalytic reaction products—synergistically contribute to the observed decline in NOx abatement efficiency with increasing curing age. These findings underscore the complex interplay between material microstructure, surface chemistry, and environmental factors in governing the long-term performance of photocatalytic cementitious materials.

4. Conclusions

The experimental findings demonstrate the critical interplay between material composition, microstructure, and photocatalytic performance in composite mortar samples, with key insights into NOx abatement efficiency. First, regardless of aggregate type or incorporation method, NOx removal efficiency increases with higher nano- TiO_2 substitution ratios, driven by greater availability of active photocatalytic sites. Second, aggregate selection significantly impacts performance: RG-RCBS samples outperform their SS-RCBS and RBS-RCBS variants due to differences in porosity, surface chemistry, and nano- TiO_2 dispersion capacity. Third, ultrasonic dispersion enhances nano- TiO_2 uniformity and surface exposure, surpassing direct mixing in photocatalytic activity. Fourth, nano- TiO_2 loading capacity correlates with solution concentration, with RCBS aggregates exhibiting superior adsorption stemming from their porous structure. Optimal performance is achieved with a 40% RG substitution ratio in RG-RCBS samples and a 1% nano- TiO_2 solution concentration, balancing pollutant degradation efficiency with mortar workability. Finally, operational conditions such as elevated NOx flow rates and prolonged curing reduce abatement efficiency, attributed to shortened pollutant residence time and microstructural changes, including pore refinement and photocatalyst deactivation. These results advance the development of sustainable, construction waste-derived photocatalytic mortars, highlighting the dual benefits of environmental sustainability and cost-efficiency. Optimized nano- TiO_2 parameters provide actionable guidelines for scalable applications, with future research prioritizing durability, system integration, and synergy with broader air pollution control

strategies. Collectively, this work underscores the potential of eco-efficient mortars to transform urban infrastructure into active air purifiers, aligning with global sustainability objectives.

Author Contributions: X.-C.Z.: Carrying out the measurements and experiments, draft writing; X.-F.C.: Methodology, reviewing, project administration, funding acquisition. All authors have read and agreed to the published version of the manuscript.

Funding: This project was funded by the [Natural Science Foundation of Fujian] under grant [No. 2023J01999], the General Project of the Fujian Provincial Education and Scientific Research Program for Young and Middle-aged Teachers and Researchers (Social Sciences) [NO. JAS24117] the [Startup Fund for Advanced Talents of Putian University] with grant number [2024051]. Additionally, it received support from the [Putian University Zixiao Scholars-Young Top Talent Program-2024] with grand number [2024174], and the [Mulan River Comprehensive Governance Research Institute of Putian University] with the project [No. ZX2024-12].

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Special recognition goes to the ‘Testing Technology Center for Materials and Devices of Tsinghua Shenzhen International Graduate School’ for their invaluable testing-related services. Also, the authors would like to express their sincere thanks to Wen-Cong Lin from Fujian Nanyu Engineering Construction Co., Ltd., Jian-Sheng Zheng from Fujian Zhongyong Construction Engineering Co., Ltd., and Guo-Hui Yan from Jinxi Holding Group Co., Ltd., all located in Putian, China, for their invaluable assistance and support in the completion of this paper.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Si, H.; Zhou, M.; Fang, Y.; He, J.; Yang, L.; Wang, F. Photocatalytic concrete for NO_x degradation: Influence factors and durability. *Constr. Build. Mater.* **2021**, *298*, 123835. [\[CrossRef\]](#)
2. Chen, X.-F.; Jiao, C.-J. Effect of construction wastes on the rheo-physical behavior of photocatalytic mortar. *Case Stud. Constr. Mater.* **2022**, *16*, e01049. [\[CrossRef\]](#)
3. Chen, X.-F.; Jiao, C.-J. A photocatalytic mortar prepared by tourmaline and TiO₂ treated recycled aggregates and its air-purifying performance. *Case Stud. Constr. Mater.* **2022**, *16*, e01073. [\[CrossRef\]](#)
4. Chen, X.-F.; Jiao, C.-J. Experimental Investigation and Modeling of the Sulfur Dioxide Abatement of Photocatalytic Mortar Containing Construction Wastes Pre-Treated by Nano TiO₂. *Catalysts* **2022**, *12*, 708. [\[CrossRef\]](#)
5. Chen, X.-F.; Jiao, C.-J. Effect of physical properties of construction wastes based composite photocatalysts on the sulfur dioxide degradation: Experimental investigation and mechanism analysis. *Case Stud. Constr. Mater.* **2022**, *17*, e01237. [\[CrossRef\]](#)
6. Zhang, J.; Tan, H.; Deng, X. NO_x removal ability of photocatalytic cement-based materials with porous structure. *J. Clean Prod.* **2022**, *377*, 134396. [\[CrossRef\]](#)
7. Chen, C.; Tang, B.; Cao, X.; Gu, F.; Huang, W. Enhanced photocatalytic decomposition of NO on portland cement concrete pavement using nano-TiO₂ suspension. *Constr. Build. Mater.* **2021**, *275*, 122135. [\[CrossRef\]](#)
8. Xiong, X.; Xu, J.; Yang, Z.; Chen, W.; Zhang, J.; Marano, G.C. NO_x degradation by cement mortar containing B-TiO₂/MgAl-CLDH under visible light: Experimental and modeling. *J. Environ. Chem. Eng.* **2024**, *12*, 112548. [\[CrossRef\]](#)
9. de Rosso, L.T.; de Melo, J.V.S. Translucent photocatalytic concrete blocks for paving: Impact of service life on the textural characteristics and photocatalytic efficiency. *Mater. Struct.* **2023**, *56*, 142. [\[CrossRef\]](#)
10. Zhang, J.; Tan, H.; Zhang, G.; Li, G. NO_x removal capacity and compressive strength of photocatalytic cementitious materials with various color properties. *J. Environ. Manag.* **2024**, *356*, 120605. [\[CrossRef\]](#)
11. Fei, H.; Wu, J.; Zhang, J.; Zhao, T.; Guo, W.; Wang, X.; Yang, S.; Liu, G. Photocatalytic performance and its internal relationship with hydration and carbonation of photocatalytic concrete: A review. *J. Build. Eng.* **2024**, *97*, 110782. [\[CrossRef\]](#)
12. Zhang, N.; Schiller, G.; Azarijafari, H.; Cao, Z.; Xi, B.; Shan, Y.; Li, H.; Duan, H.; Yang, J. Contribution of concrete nitrogenation to global NO_x uptake. *Nat. Cities* **2024**, *1*, 457–468. [\[CrossRef\]](#)
13. Jiang, J.; Miao, Y.; Ran, Q.; Li, Y.; Li, Y.; Tao, Z.; Lu, Z. Highly activated pozzolanic materials to develop sustainable concrete: A new perspective from photoexcited nano-TiO₂. *Cem. Concr. Compos.* **2025**, *162*, 106149. [\[CrossRef\]](#)

14. Jiang, J.; Wang, H.; Lin, J.; Liu, Z.; Li, L.; Li, Y.; Li, Z.; Lu, L.; Li, Y.; Lu, Z. Accelerating mechanism of cement hydration by hydroxyl free radicals: New perspectives from photoexcited nano-TiO₂. *Compos. B Eng.* **2025**, *301*, 112524. [[CrossRef](#)]
15. Liu, D.; Kaja, A.; Chen, Y.; Brouwers, H.J.H.; Yu, Q. Self-cleaning performance of photocatalytic cement mortar: Synergistic effects of hydration and carbonation. *Cem. Concr. Res.* **2022**, *162*, 107009. [[CrossRef](#)]
16. Kalinowski, M.; Chilmon, K.; Jackiewicz-Rek, W.; Rakowski, B. The Influence of Selected Material Variables of Photocatalytic Cementitious Composites on the Self-Cleaning Properties and Air Purification Efficiency from NO_x Pollutants. *Sustainability* **2023**, *15*, 853. [[CrossRef](#)]
17. Prudente, I.N.R.; Santos, H.C.D.; Fonseca, J.L.; Barreto, L.S. Advancements in self-cleaning building materials: Photocatalysts; superhydrophobic surfaces; biocides approaches. *Constr. Build. Mater.* **2024**, *434*, 136700. [[CrossRef](#)]
18. Liao, G.; Yao, W. Upcycling of waste concrete powder into a functionalized host for nano-TiO₂ photocatalyst: Binding mechanism and enhanced photocatalytic efficiency. *J. Clean. Prod.* **2022**, *366*, 132918. [[CrossRef](#)]
19. Liu, H.; Deng, S.; Zhao, L.; Yang, L.; Qi, J.; Jiang, Y. Turning waste into treasure: Utilizing environment-pollutant graphite tailings as photocatalyst for photocatalytic building materials. *Case Stud. Constr. Mater.* **2024**, *21*, e03859. [[CrossRef](#)]
20. Lu, W.; Lou, J.; Webster, C.; Xue, F.; Bao, Z.; Chi, B. Estimating construction waste generation in the Greater Bay Area, China using machine learning. *Waste Manag.* **2021**, *134*, 78–88. [[CrossRef](#)]
21. Davis, P.; Aziz, F.; Newaz, M.T.; Sher, W.; Simon, L. The classification of construction waste material using a deep convolutional neural network. *Autom. Constr.* **2021**, *122*, 103481. [[CrossRef](#)]
22. Guo, M.-Z.; Ling, T.-C.; Poon, C.S. Photocatalytic NO_x degradation of concrete surface layers intermixed and spray-coated with nano-TiO₂: Influence of experimental factors. *Cem. Concr. Compos.* **2017**, *83*, 279–289. [[CrossRef](#)]
23. Chilmon, K.; Kalinowski, M.; Jackiewicz-Rek, W. Predictive Modeling of Air Purification Efficiency in Nano-TiO₂-Modified Photocatalytic Cementitious Composites Using High-Resolution EDS Mapping and Mercury Intrusion Porosimetry. *Purification* **2025**, *1*, 1. [[CrossRef](#)]
24. Chilmon, K.; Kalinowski, M.; Jackiewicz-Rek, W. Effect of Cement Substitution with Mineral Fillers on NO_x Air-Purification Efficiency and Photocatalytic Reaction Selectivity of Nano-TiO₂-Modified Cementitious Composites. *Materials* **2024**, *17*, 5775. [[CrossRef](#)]
25. Liu, G.; Xia, H.; Zhang, W.; Song, L.; Chen, Q.; Niu, Y. Improvement mechanism of NO photocatalytic degradation performance of self-cleaning synergistic photocatalytic coating under high humidity. *J. Hazard. Mater.* **2021**, *418*, 126337. [[CrossRef](#)]
26. Kotzias, D.; Binas, V.; Kiriakidis, G. Smart Surfaces: Photocatalytic Degradation of Priority Pollutants on TiO₂-Based Coatings in Indoor and Outdoor Environments—Principles and Mechanisms. *Materials* **2022**, *15*, 402. [[CrossRef](#)]
27. Wu, L.; Mei, M.; Li, Z.; Liu, S.; Wang, X. Study on photocatalytic and mechanical properties of TiO₂ modified pervious concrete. *Case Stud. Constr. Mater.* **2022**, *17*, e01606. [[CrossRef](#)]
28. Zhang, D.; Zhu, H.; Yang, Q.; Mao, M.; Li, J. Hydration kinetics; mechanical, and photocatalytic self-cleaning performance of permeable concrete reinforced with nano-TiO₂ hydrosol. *Constr. Build. Mater.* **2025**, *472*, 140830. [[CrossRef](#)]
29. Chen, K.; Qu, F.; Huang, Y.; Cai, J.; Wu, F.; Li, W. Advancing photocatalytic concrete technologies for design, performance and sustainable futures. *Adv. Nanocomposites* **2024**, *1*, 180–200. [[CrossRef](#)]
30. Khannyra, S.; Luna, M.; Gil, M.L.A.; Addou, M.; Mosquera, M.J. Self-cleaning durability assessment of TiO₂/SiO₂ photocatalysts coated concrete: Effect of indoor and outdoor conditions on the photocatalytic activity. *Build. Environ.* **2022**, *211*, 108743. [[CrossRef](#)]

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