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Review Paper

Reviewing the degradation of environmental pollution in cement concrete structures using Nano-Titanium Dioxide

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ABSTRACT

The rising levels of pollution globally affect cement concrete structures and historical monuments by making them fade, stained, and dull due to settling of dust particles. Titanium Dioxide (NT) is a naturally occurred photocatalytic material when used with construction materials (CM), offers benefits such as environmental pollution degradation and self-cleaning action. Moreover, its application supplements in enacting the original appearance of the structure for longer times. The main aim of this review study is to summarize the current information available primarily on 'environmental pollution degradation and self-cleaning effect'. The standard tools for effective summarization of existing data like a) PRISMA analysis, b) VOSviewer, and c) Citespace were used. Further, the major research gaps, environmental impacts, concept of sustainability in relation to utilization of NT and future trends are incorporated. This review successfully concludes the potential application of NT in cement concrete structures for possible reduction of environmental pollution.

1 Introduction

Increasing pollution in the environment severely affects cement-based buildings and living beings. Environmental pollution is mainly associated with greenhouse gases like NO_x, SO_x, and Organic Matter (VOC) [1]. The emission of these gases leads to cancer and respiratory problems in living beings and declines the building's surface aesthetic appearance, which is anticipated to deteriorate over time [2]. The building's surfaces are often covered with continuous occurrences of organic and inorganic matter produced by the strong adhesion of dust and other compounds. The accumulation of dust particles on the building surface leads to stains and grim patches, resulting in a reduction in the aesthetic appearance and strength properties [3]. Self-cleaning is an important and innovative property for CM prevents dirt particles from settling on the surface, degrades organic microorganism growth, and maintains the aesthetic appearance and durability of the structure for a long time [4, 5]. Self-cleaning and greenhouse gases (NO_x, SO_x, and VOC) can be reduced in buildings by

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incorporating the photocatalytic composites in construction materials [6, 7]. The cement composite NT has been widely studied worldwide and gained significant attention over the last few years due to their excellent photocatalytic properties. The NT is one of the easy and novel approach to reduce the harmful gases and achieve self-cleaning effect in CM [8]. Moreover, NT is the most appropriate photocatalytic cement composite due to its higher stability level, easy availability, and non-toxicity in the environment [1–3, 9–12].

Nano-titanium dioxide NT is a widely studied photocatalytic nanomaterial with a bandgap of approximately 3.2 eV. When it absorbs photons with energies greater than this bandgap, an electron hole pair is generated. The electrons promoted to the conduction band (typically in the potential range of 0.5 to ~1.5 V) act as efficient reducing agents, while the holes remaining in the valence band function as strong oxidants. These redox potentials can mineralize and oxidize a broad spectrum of organic and inorganic contaminants in the building environment [13].

When NT based material comes in contact with UV light (Sunlight), it activates the photocatalytic properties, enabling self-cleaning, antibacterial action, and pollutant degradation properties. Furthermore, NT enhances hydrophilicity (water contact angle reduction) in the CM surface, which helps to improve the self-cleaning effect by producing hydro radicals on the surface. Through photocatalytic activity, organic molecules deposited on building surfaces are decomposed via photo-mineralization, allowing rainwater to easily wash away the resulting residues [14, 15].

2 Research significance and novelty

This review highlights the rising importance of utilization of NT as cementitious material, due to its exceptional photocatalytic and self-cleaning properties. By synthesizing and analysing the current literature, the study aims to consolidate the knowledge on the effective usage of different phases of NT particularly anatase and rutile in enhancing the environmental performance of concrete and mortar.

In fact, as per literature NT plays a crucial role in degrading several air pollutants such as NO_x, SO_x, VOCs, and microbial contaminants through UV-induced photocatalytic reactions, ultimately contributing towards improved air quality and sustainable infrastructure. This review offers a comprehensive understanding of the mechanisms, advancements, and practical applications of NT-modified construction material, paving the way for future research, innovation, and policy development in environmentally responsive construction technologies.

Herein, the novelty indicates the comprehensive bibliometric and systematic review of existing literature using different techniques of collection and analysing data such as PRISMA, VOSviewer and cite space. Moreover, this single source also covers the limitations of previous reviews that were commonly based on the manual and unsystematic approaches. It is well-intentioned to mention that the authors of this review have performed their best efforts in order to develop a single-valued source of knowledge that will aid researchers/readers in their future studies particularly linked to effective usage of NT. Herein, the review integrates multiple advance tools like as PRISMA for literature selection, VOSviewer for bibliometric mapping and CiteSpace for ongoing trends and cluster analysis.

Finally, a significant contribution has been added to this area of research using multi-dimensional assessment framework, which not only maps the existing research but also critically evaluates key thematic areas (such as environmental degradation and self-cleaning capabilities) of NT-based construction materials.

3 Methodology for bibliographic study

The NT-based CM review study is synthesized using several tools, including PRISMA analysis, VOSviewer, and the Citespace program. In manual review work, it's difficult to examine all critical and challenging studies, but with the help of these new tools and technology, we can easily review and represent the existing literature on NT-based self-cleaning CM. PRISMA analysis helps in the collection and screening of data from databases such as Science direct, ASCE and other peer reviewed platforms. In contrast, the VOSviewer keywords network map represents the NT properties in CM. Furthermore, the CiteSpace program gives a citation burst of the last 10 years (2014-2024) on reputable journals, keywords, and references.

A keyword network map represents the valuable information of NT-based published articles on ongoing scientific trends and hurdles over the course of research work [16]. Over the past many decades, numerous studies have been conducted to explore the performance of NT in CM. The manual review approach may not be efficient in considering all critical studies; the traditional program can easily identify and implement a network diagram of ongoing studies [17]. Fig. 2 represents the group of circles on NT-based CM with unique colour coding. This circle represents the keywords, whereas the size of the circles represents the frequency of articles collected from databases, and lines denote the links established between them.

3.3 Cite space burst on journal, keywords and references

The citation burst program based on the Kleinberg's algorithms which is used to represents the most citation burst on journal, keywords, institution, authors and references based [18]. The Citespace analysis facilitate to analysing increasing research interest on particular regions within short time duration [19]. In this review paper, only three factors consider journal, keyword and references based. In Fig. 3 journal-based citation burst is represents the top 25 journals who have high citation burst on self-cleaning concrete with incorporation NT (2014-2024).

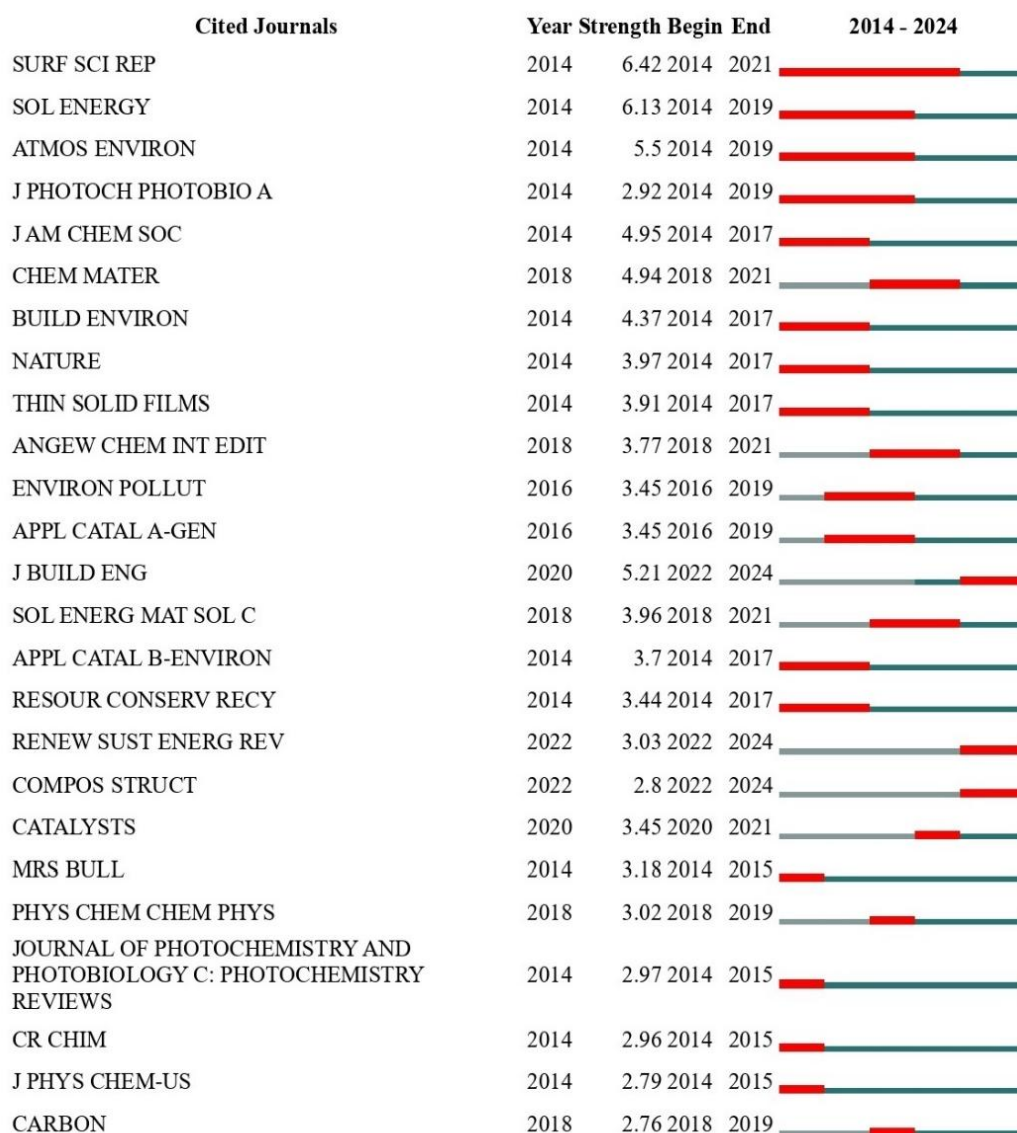


Fig. 3 - Top 25 Journals with strongest citation burst

Fig. 4 represents the top ten citation burst on NT based CM in context self-cleaning surface in duration (2014-2024). The red and green line in Fig. 4 represents the review time duration, journal citation and keyword citation burst duration respectively [20]. The strength number depicts the frequency of citations for the related journal, keywords and reference across the designated years. The citation burst reveals that the highly growth of research on self-cleaning and environmental pollution were taken into account on NT based CM [21]. This review study mainly focuses on the impact of NT on the photocatalytic, pollution degradation in buildings [22–24].

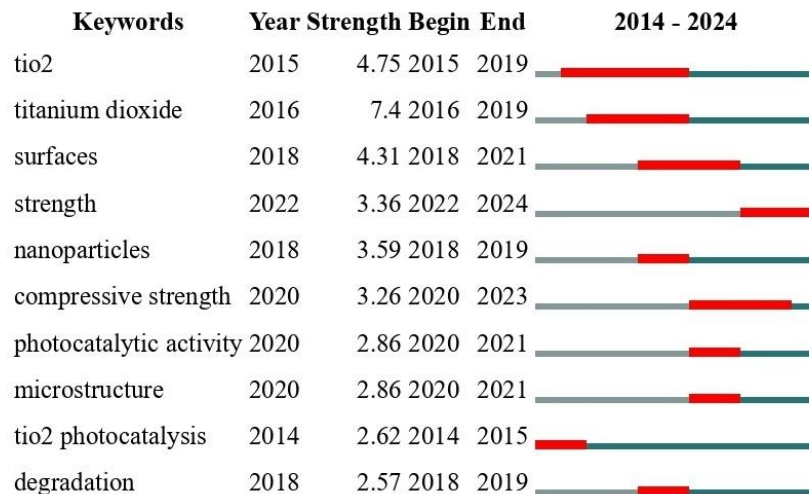


Fig. 4 - Top 10 keywords with strongest citation burst

4 Nano-Titanium Dioxide as catalyst in CM

Nano-Titanium dioxide is widely used as the "golden" heterogeneous photocatalyst due to its nontoxicity, easy availability, and chemical stability. Over the past 20 years, NT heterogeneous photocatalysis has gained popularity due to energy and environmental concerns, including the direct splitting of solar H_2O into H_2 and the breakdown of contaminants in the air and water at low concentrations. While NT heterogeneous photocatalysis has made significant progress, there are still many unanswered questions. This is a fascinating issue for engineers and essential scientists/researcher. A typical NT photocatalytic system has multiple fundamental processes, such as reactions, charge carrier generation, separation, transfer, recombination, and bond breaking/formation, that must be investigated comprehensively to create and characterize novel photocatalysts. The mechanisms of photocatalytic and a deeper knowledge are essential, and this can only be accomplished by precisely outlining each of these key processes.

In the 1960s, nanomaterials emerged as a field of nanotechnology in construction materials. The nanomaterials have proven to be more applicable fillers in cement-based CM. The production of nanomaterials mainly depends on two main approaches: a) "Top to bottom approach", b) "Bottom to up approach", illustrated in Fig. 5. In the first approach, the larger structure breaks down into nano-sized particles without changing parental properties. In the second approach, the well-known "molecular technology" is used; this methodology produces nanomaterials at the atomic level through assembly. This approach can be chosen depending mainly on the suitability and behavior of the material.

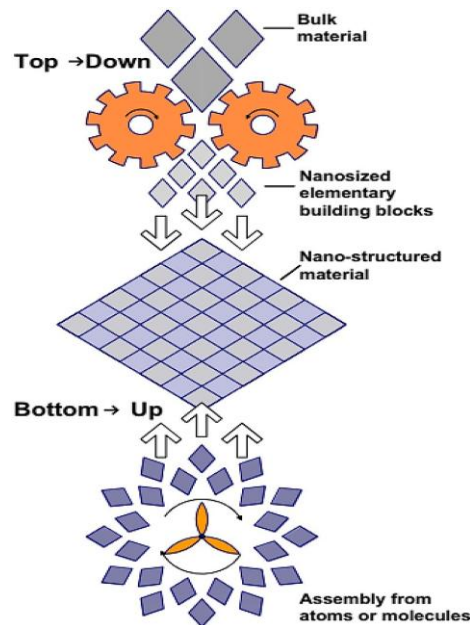


Fig. 5 - Top to bottom and Bottom to up approaches [25].

5 Production approaches of NT

5.1 Top to Bottom approaches

5.1.1 Mechanical milling

Mechanical milling is an easy and cost-efficient technique to produce the nano materials. The mechanical process simply involves placing a powder charge in high energy mill, where by grinding particle size and combining particles converts them into new phases [26]. Machine milling process also known as ball milling is one of the most common grinding techniques where small size balls impact the powder charge, by sliding on the surface of mill chamber or falling freely as shown in Fig. 6 [27, 28]. The energy generated by the small steel balls, along with the material (particle) properties, temperature and other factors, affects the size reduction [29]. Higher temperature in ball mill produces mostly intermetallic phases, while lower temperature may produce nano-amorphous and nano-crystalline phases [30, 31].

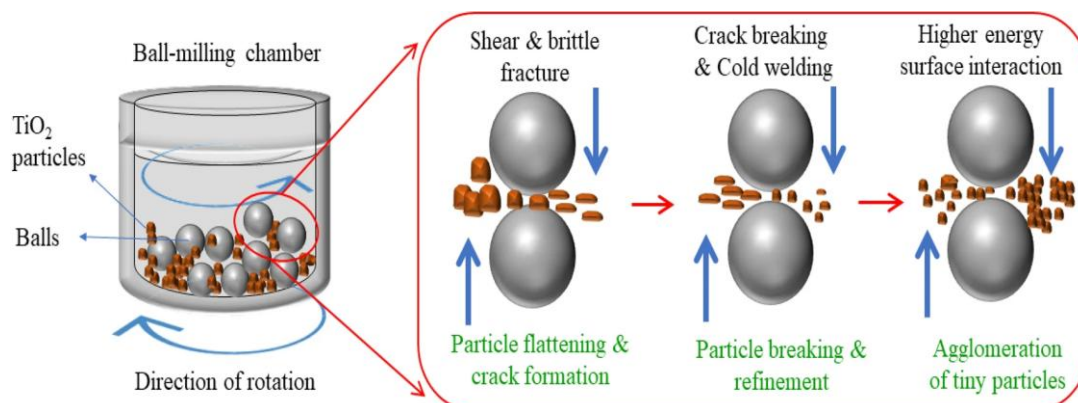


Fig. 6 - Mechanical milling approach [32].

5.1.2 Sputtering

Sputtering is a technique in which high energetic particles of plasma or gas hitting hard on the surface of solid and microscale particles are distinct from it [33]. During this sputtering deposition, a group of atoms is physically ejected from

the solid surface when the high-energy gaseous ions hit it with high frequency [34]. In the sputtering “Magnetron”, “Radio Frequency Diode,” and “Direct Current Diode” are the main effective approaches to carrying out the sputtering procedure [35]. Sputtering is typically carried out in an evacuation chamber into which the sputtering gas is introduced, after high voltage is applied to the cathode target, where free electrons collide with the gas, resulting in gas ionization. Gas ions generate positive charge and come into contact with the cathode target, the ions moving so rapidly by the electrical field and hitting the target surface to expel into atoms [36, 37]. The sputtering process is illustrated in Fig. 7.

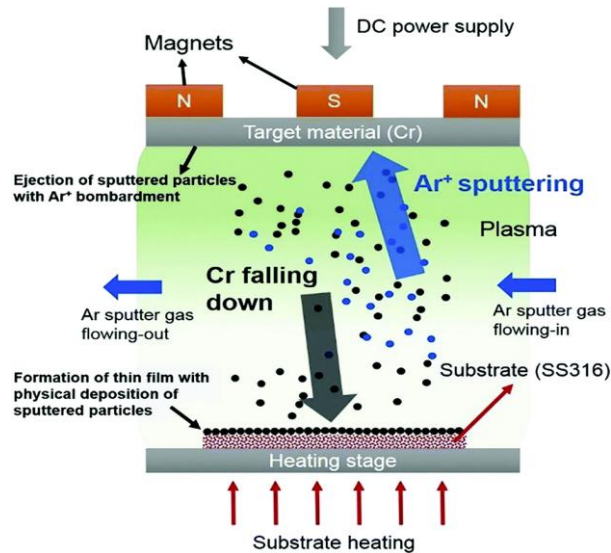


Fig. 7 - Sputtering approach [38].

5.1.3 Laser Ablation

The laser ablation approach involves an intense laser beam to strike a target material's surfaces. The sourced or already available fine particles are vaporized due to the high intensity of the laser beam, and nanoparticles are produced as illustrated in Fig. 8 [39]. The laser ablation method does not require any chemical or stabilizing agent to make this process as a green process [40]. The various types of nanomaterials can be generated with this method such as i) metal nanomaterials [41], ii) carbon nanomaterials [42], iii) ceramics [43], and iv) oxide composites. An interesting novel technique is the utilization of pulsed laser ablation in liquid to produce monodisperse colloidal nanoparticle solutions without the necessity of ligands. The modification and changes may occur in wavelength floucnce and laser salt additions to manage the distribution and obtain a particular size of nanomaterials [44].

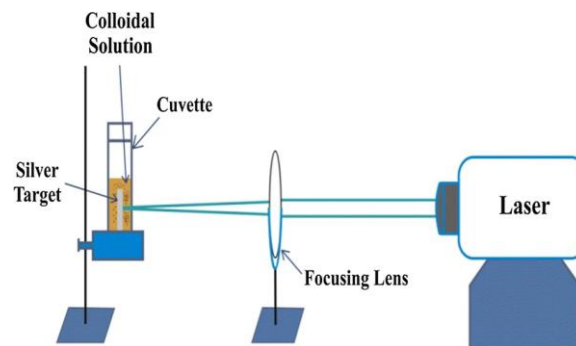


Fig.8 - Laser ablation approach[42] [45].

5.2 Bottom to up approaches

The bottom-up approach incorporates critical components into larger structures through nanoscale physical and chemical processes. Because of the smaller unit size, the technique produces a more meaningful completion than the top-

down technique. This method is inspired by biological systems, where natural forces of life use chemical equivalents to construct structures. Some of these approaches are discussed below.

5.2.1 Sol-Gel approach

Sol-gel technique chemically wet procedure and commonly used to for the production on nanoparticles (TiO_2 , SiO_2 , ZnO etc.). The Sol-Gel technique widely employed to produce the high quality (purity) metal-oxide-based nanoparticles. The reason behind the namely this process sol-gel because the liquid state precursor changes their state into sol during generating metal oxide nanomaterial, and sol transformed into network structural form which recognised as a gel [46]. The usually metal alkoxides identified precursors for the sol-gel technique for manufacturing nanomaterials. This technique performed in many steps for the production of metal-based nanoparticles. In 1st step, the metal-based oxides mainly hydrolysed in water (H_2O) or alcohol to produce sol. In 2nd step condensation occurs, which results reveals that the rise in solvent viscosity and generation of voided structure. “Hydroxy-(M-OH-M)” or oxo “(M-O-M)” ties formed during the condensation, resulting in the production of “metal -hydroxy” or “metal-oxo-polymer” in solution [47].

The condensation or polycondensation continuous thought-out the aging process, resulting characteristics and porosity changes in formed structure. With the increasing age, the colloidal particles fill the space and reduce porosity in structure, by aging process, gel converted into dried, which eliminates water organic substances. Furthermore, calcination is used to produce nanomaterials. The Sol-Gel approach has many advantages like i) cost effective, ii) produce homogeneous materials, iii) low temperature, iv) Simple process to produce complex composites and microstructure as represented in Fig. 9 [48,49].

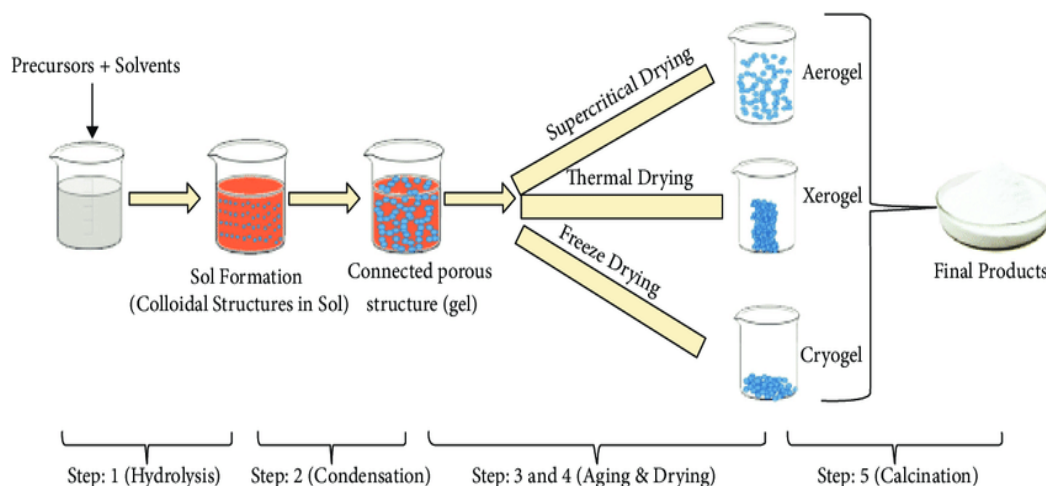


Fig. 9 - Sol-Gel approach [49]

5.2.2 Hydrothermal and Solvothermal

The chemical reactions occur in a water based (aqueous) solution is namely hydrothermal or non-water based (non-aqueous) known as solvothermal, using several organic solvents like methanol, toluene and 1,4- butanol [50]. Under the condition low temperature ($<25^\circ$) and high pressure. The conditions high pressure and low temperature depend on the desired product production, sometimes it may be compulsory to heat a material at a lower temperature then melting point to form the crystallisation. The hydrothermal method used to synthesize “oxyhydroxide” or “Oxide”, whereas solvothermal used to synthesize non-oxide nanoparticles. The major role of temperature and pressure mainly boost the solubility, which is lead to enhancement on concentration of precursors in the aqueous and non-aqueous solvent to indorses crystal growth in nanocrystals [51].

Fig. 10 illustrates the major key factor of hydrothermal nanoparticle production and approach its capability to produce crystalline phases that may not be stable at their melting points. The major advantages of this approach offer highly quality

control in material composition, mass production and superior quality crystals. The major drawbacks of this hydrothermal approach are high cost, optimal grain size, quality and failure to detect crystal evolution during process [52,53].

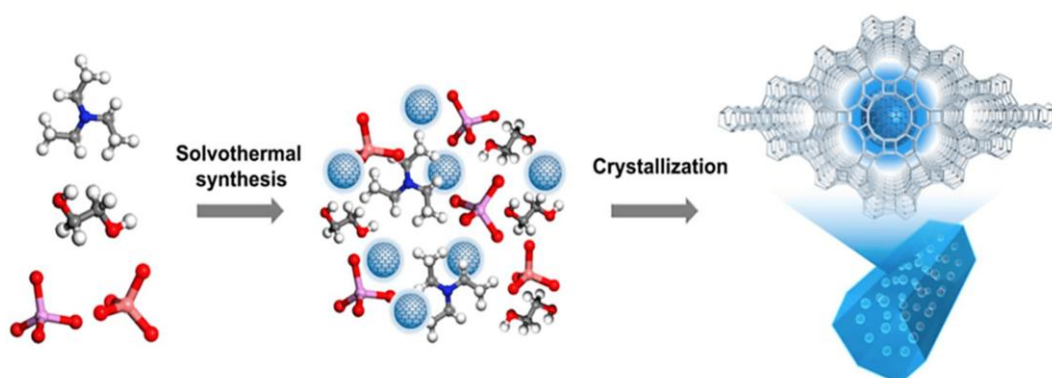


Fig.10 - Hydrothermal and solvothermal approach [53].

5.2.3 Microemulsion or reverse micelle approach

The microemulsion approach is latest approach in liquid phase methods generally used in synthesizing nanocrystalline materials. Based on the existing literature this approach is a viable alternate for producing metal oxide with its regulated characteristics. The microemulsion or reverse micelle approach has control over chemical reactions, particle shape, and size. On the other hand, surfactants are composed of hydrophilic and hydrophobic hydrocarbons that are dissolved in organic diluents as shown in Fig. 11 [54]. The feature of reverse micelle production in organic diluents can be employed to regulate nanomaterials development [55]. With the involvement of water, the polar head clusters of surfactant particles organise themselves around the water droplets, causing the aqueous stage to disperse into the oil stage. Because of the very small atmosphere inside the micelles, an aqueous diluent of raw material might be an ideal condition for the creation of NT. Reactions such as the hydrolysis of reactive raw materials and the deposition of metal salts in micelles can produce nanomaterial (NT) in the micellar medium. The end product is produced after diluent removal and calcination [51].

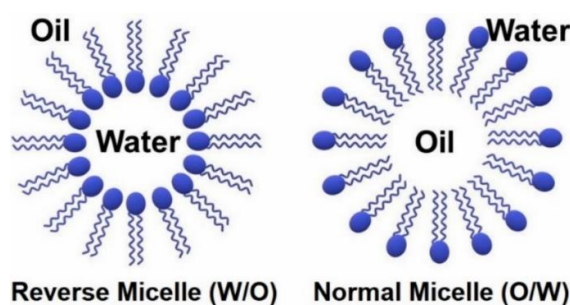


Fig. 11 - Microemulsion or reverse micelle approach [54].

5.2.4 Microwave approach

The microwave approach is modern approach for producing nanosized particles. Microwave approach uses microwave energy to heat and activate NT precursors and diluents in enclosed containers, resulting in the formation of NT particles. These particles are then combined with construction materials like cement or ceramics and cured in the appropriate circumstances. The microwave approach generates NT particles with remarkable crystallinity, concentration (purity), and a restricted size dispersal, which are evenly disseminated as spherical particles throughout building materials. This homogeneous distribution improves the consistency and durability of photocatalytic capabilities on the material surface [56]. Furthermore, researchers may accurately tune the reaction parameters to customise NT nanoparticle properties to specific material requirements. Such control extends to characteristics such as particle size and crystallinity, enabling a case-by-case optimisation of photocatalytic effectiveness [57].

6 Mechanism of photocatalytic activity in concrete structure

The NT contain crystalline particle arraigned in specific order and composed of numerous ions and atoms. The accumulation of ions and atoms overlapped over each other and generating distinct energy bands. The NT (semiconductor nanomaterials) contains two energy bands: i) High energy empty conduction band ii) Low energy full valence band. Furthermore, forbidden band located in between both of bands [58]. The photocatalytic reaction takes place when electron charged by UV-light with equal or more then band gap represented in Fig. 12 [59]. These parings trigger redox reactions neighbouring molecules. Excited electrons and holes contribute to several chemical reactions, including the process involves breaking down organic contaminants, synthesising hydrogen from water, and converting carbon dioxide into valuable chemicals.

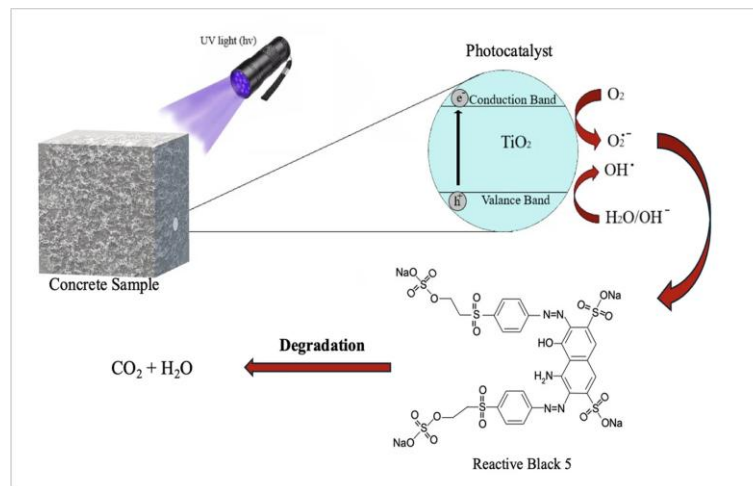
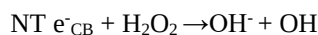
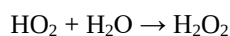
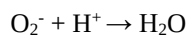
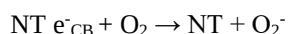
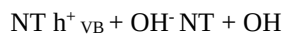
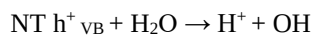
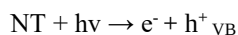


Fig.12 - Basic principle of photocatalytic mechanism [59].

During process of redox reactions concerning electron hole pair, when its photoelectrons react with O₂ and H₂O. photoelectrons react with O₂ produces super oxide radicals (O₂⁻) and reacts with H₂O produces Hydroxyl Radicals (OH[·]) [60–62]. The chemical compositions of redox reaction explained are as follow.

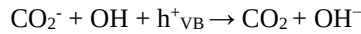
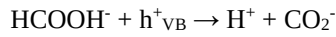
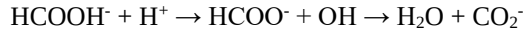
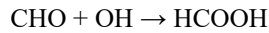
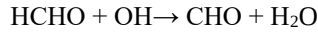


Redox reaction on the surface of cementitious material breakdown the environmental pollution due to photocatalytic property. Photocatalysis has several benefits, including high efficiency, moderate reaction conditions, and environmental friendliness, making it a feasible technique for sustainable chemistry, renewable energy production, and environmental remediation [63]. The working principle of photocatalytic activity and their effects on environmental pollution are discussed in the subsequent respective sections.

6.1 The working principle of photocatalysts in air purification

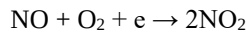
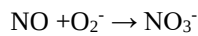
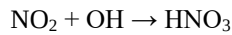
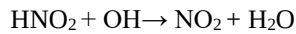
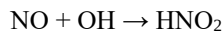
The existence of air pollutants degrades the environmental and possess hazardous effects on health of living animals and human being. The several types of air impurities in environment as earlier discussed like as NO_x, SO_x and VOC. The

NT incorporation in building CM facilitate in reducing air pollutants (Greenhouse gasses) [60]. Photocatalytic oxidation reduces VOC in air by using hydroxyl radical and superoxide radical generated by e^- hole pair with oxygen.



These active substances (OH , O_2^-) and e^- holes outbreak the organic substances, mineralizing in CO_2 , thereby improving air quality.

NO_x increased in nature day by day burning fossil fuel in moving vehicles, industries etc., which results dense smog and acidic rains [61,62,64]. NT based photocatalysis, under solar or UV light, removes low concentrations of NO_x by converting it into NO_3^- . The reaction pathway is as follows:



These equations show that $\cdot\text{OH}$, O_2^- convert NO_x to NO_3^- , thereby reducing NO_x concentration in the air [65]. Fig. 13 illustrated the mechanism of NO_x reduction due to photocatalytic effect in environment.

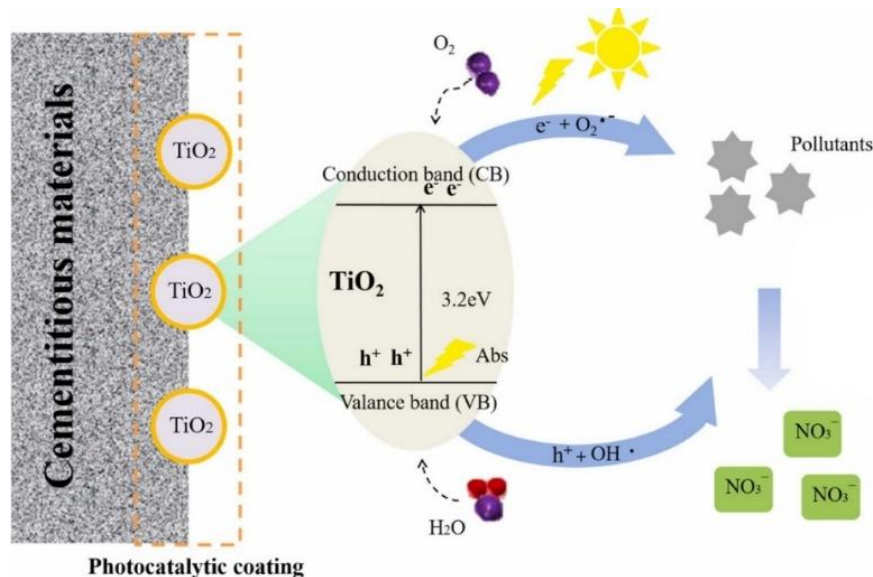
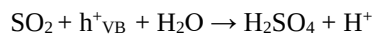
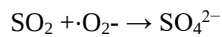
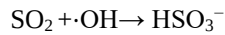


Fig. 13 - Schematic representation of NO_x reduction by photocatalytic effect [65].

SO_x , primarily SO_2 , results from sulfur-containing fossil fuel combustion and significantly harms human health and ecosystems. It contributes to acidic rain, which erodes CM surfaces, reduces buildings ages, inhibits microbial growth, and alters soil pH . NT-based photocatalysts degrade SO_x when they come in contact with UV light and lower the SO_x impact on the environment. The chemical equations for SO_x degradation given below:



These reactions convert SO_2 into SO_4^{2-} through free radicals and photogenerated holes, mitigating its environmental impact.

6.2 NOx degradation in concrete structures

From past few years, tremendous progress has been achieved in the field of NT (catalysis) in CM. The main reason of this gain attention of NT photocatalysis to degrade environmental pollution, self-cleaning effect and enhance mechanical properties of CM. Table 1 represents the reduction of environmental pollution (NOx).

Table 1- Represents the NOx reduction incorporation NT in cement-based CM

	Author(s)	Year	Materials	UV Source	light	NOx Degradation efficiency (Percentage)
Blended Cement	Cárdenas et al. [69]	2012	0.5% -5% NT + PC	UV lamp	light	NOx removal amount 120 μmol/m²·h (after 65hr)
	Guo and Poon [70]	2018	2% - 5% NT + PC	UV lamp	light	Reduction in NOx 380 μmol/m²·h
			2%- 5% NT + White Cement			Reduction in NOx 500 μmol/m²·h
Mortar						
	Hüsken et al. [71]	2009	NT + PC	UV lamp	light	40%
	Chen et al. [72]	2011	2% -5% NT + PC	UV lamp	light	90%
	Pirola et al. [73]	2012	2% NT + PC	UV Lamp	light	80%
	Karapati et al. [74]	2014	0.5% 2.5% + PC	Sunlight		15%
	Pérez-Nicolás et al. [75]	2015	NT + PC	UV lamp	light	60.4%
	Pérez-Nicolás et al. [76]	2017	0.5% - 2.5%	Sunlight		38%
	Seo and Yun [77]	2017	1% -10% + PC	UV lamp	light	72%
	Yang et al. [78]	2019	5% NT + PC	UV lamp	light	85%
	Xu et al. [79]	2020	1-10% NT + PC + Fly ash	UV lamp	light	93%
	Xiong et al. [65]	2024	3% B-NT /MgAl-CLDH + PC	UV lamp	light	Reduction in NOx 23% in 30 min
Concrete						
	Guo et al. [80]	2017	5% NT + PC	UV lamp	light	25%-80%
	Si et al. [68]	2021	0.67% NT + PC	UV lamp	light	50%-60%
	Xu et al. [79]	2023	8:2 NT + Silane-Siloxane surface penetrant (Spray)	UV lamp	light	80% -85%

Fig. 14 represents the laboratory setup used to evaluate NO_x reduction in CM with a plug-flow reactor. The system comprises a gas supply unit, a quartz reactor, a UV light source (UV lamp), a UV cut-off system, and pollution measurement instruments. Furthermore, NO_x, recognized as a significant environmental pollutant, was selected as the target compound for decomposition. To replicate environmental conditions, NO gas was mixed with 20% O₂ and 80% N₂. This gas mixture was then passed through a gas-washing bottle containing demineralized water to achieve 50% relative humidity within the chamber. A mass flow control panel regulated the gas flow to ensure consistent experimental conditions [65–67].

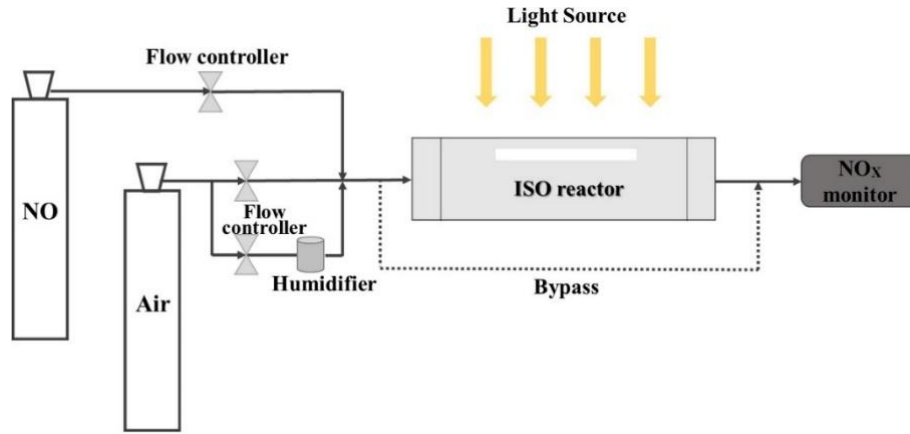


Fig. 14 - Representation of NO_x removal [65, 68].

To evaluate NO_x degrading efficiency, the test specimen NO_x removal ratio, quantity, and instantaneous rate were used as indicators. The eq. 1-3 for calculating NO_x removal ratio is as follows:

$$CNO_x(\%) = \frac{[NO_x]_{inlet} - [NO_x]_{outlet}}{[NO_x]_{inlet}} \times 100\% \quad (1)$$

CNO_x = NO_x degradation ratio in percentage.

NO_x (Inlet) = NO_x concentration at inlet in ppm

NO_x (Outlet) = NO_x concentration at outside in ppm

-NO_x degradation amount of the test specimen can be evaluated are as follows.

$$QNO_x = \frac{\int_0^T ([NO_x]_{inlet} - [NO_x]_{outlet}) dt}{VmAT} \quad (2)$$

QNO_x = NO_x degradation amount (μmol.m.⁻².h⁻¹)

T = Time duration

VmA = Volume of 1 mol ideal gram

NO_x removal rate can be calculated as follows:

$$RNO_x = \left| \frac{d[NO_x]}{Vmdt} \right|_{t=0} \quad (3)$$

RNO_x = NO_x degradation rate of the specimen in (mmol. L⁻¹.min⁻¹)

7 Mechanism of self-cleaning effect

Cement-based material structure, when exposed to the open environment, the external parts of the structure come into contact with environmental pollution, resulting in the structure losing its appearance and becoming dull. It happens because the binder used in building construction contains fatty acids and hydrocarbons, which lead to pollution sticking to it. The sticky pollution leads to a reduction in the appearance of the structure and produces airborne diseases [81–84]. The utilisation of a small amount of NT (photocatalysis) in CM provides self-cleaning effects and lowers the air pollution

effects in the building's environment [85,86]. Moreover, NT enhances the superhydrophilicity of the CM, and it works together to create a building surface that self-cleans over time[87]. The self-cleaning of cement-based materials can be tested in laboratory experiment RhB test, which is discussed in the separate subsequent section.

7.1 The RhB test

The RhB test (Discoloration) is to be conducted to check the self-cleaning effect of NT-based samples [3, 6, 59, 84, 88–92]. RhB solution surface coating degraded when exposed to sunlight or UV rays by the photocatalytic effect [1, 6, 59, 90, 93]. The self-cleaning effects are generally categorized into three phases: a) Active phase, b) Transitional phase, and c) stable phase. In the active phase, the discoloration action is rapid; in the transitional phase, the discoloration speed is slow compared to the action phase and last phase, where there is no further discoloration in the applied RhB solution on the sample surface [94, 95]. The Recycled Concrete Powder with NT (RCPT) used in an experimental work. The discoloration of RhB solution on the specimen surface with time is illustrated in Fig. 15 [96]

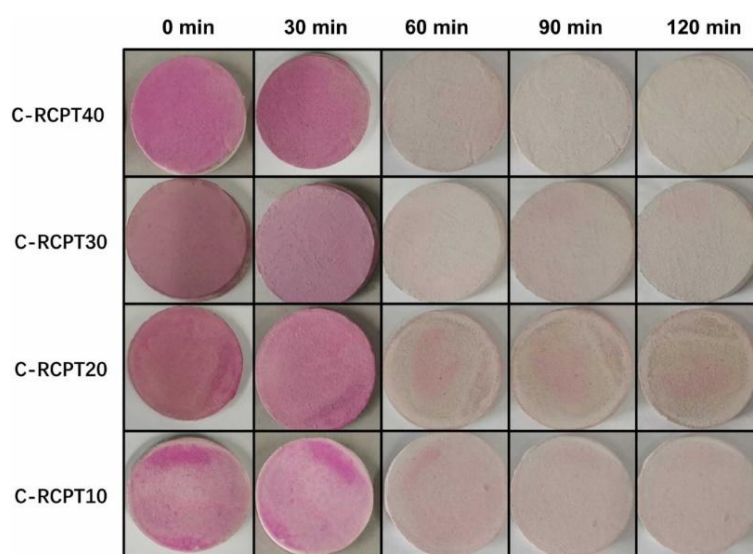


Fig. 15 - Discoloration of RhB solution / self-cleaning effect [96]

8 Cost analysis

The cost of NT is approximately thousands of times that of cement due to its potential benefits. The initial cost of NT mainly depends on the size of the particle (20-30nm) and purity level (>99%). In the existing literature, the optimum level of NT used is 3% by weight of cement, which is very small and affects the construction cost a little. Still, a small quantity of NT in CM improves environmental property and lowers the structures' maintenance cost. The photocatalytic property creates a healthy living environment for human beings, and the self-cleaning effect on the CM surface maintains the appearance of buildings for a long time, which can compromise the initial high cost of the material.

9 Research Gap

- The optimum range of incorporation of NT in CM is still a broad area for research to maintain CM environmental impact and strength properties.
- The incorporation of NT in CM enhances the overall cost of the materials. The cost of self-cleaning CM is higher than that of conventional CM, and an effective NT synthesise approach should be required to lower the cost of nanoparticle production and implementation.

- The high surface area of NT causes an agglomeration effect on the mechanical properties of CM. The impact of agglomeration increases the particle size, which leads to a lower photocatalytic efficiency as well as strength properties of CM. The proper deagglomeration approach should be required during batching of CM.
- Despite of advancement in incorporation of NT in CM, the catalytic (photocatalytic) efficiency of NT under visible light remains insufficient, and approach of by-product generation along with its evaluation criteria still unclear and open area for future research
- Self-cleaning effects in buildings occur due to photocatalytic activity or redox reaction. After self-cleaning effects, it left faded white patches, which led to the degraded appearance of a building inside elements. Further, investigation is a broad area for future research for the elimination of these white patches after self-cleaning.

10 Conclusions

- Nano-Titanium dioxide (NT) contains specific gravity merely 3.9 - 4.5, with the higher melting point near about 1854°C. The formation of NT by many approaches (Top-down and Bottom-up) in three forms Anatase, rutile and brookite.
- The formation of anatase in tetragonal shape, rutile in cubic shape and brookite in Orthorectic shape. The anatase and rutile used in CM to obtains photocatalytic efficiency and strength enhancing properties due to its chemical stability non toxicity and easy to synthesize. Whereas, the brookite difficult to synthesising and having low chemically stability.
- Nano-Titanium dioxide in CM have proved that capabilities to effectively photodegradation environmental pollution such as VOC, NOx and SOx. The efficiency of pollution (NOx) removal archived merely 80% - 90% and can be enhanced by incorporating fly ash in CM ie: mortar and concrete.
- The incorporation of NT in CM effectively provides the self-cleaning effect of buildings. The RhB solution used to check the discoloration effect (self-cleaning) under the UV light lamp or sunlight over the time period shown in Fig. 15, with three well known stages active, transmission and constant stages.

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