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"Review on Smog Mitigation Using Photocatalytic Concrete with Partial Replacement by Foundry Sand"

[1]Jayanthi M, [2]Dr. K. Rekha
[1]PG Scholar, [2]Assistant Professor
[1]Department of Structural Engineering,
[1]Government College of Technology, Coimbatore, India

Abstract : This review paper investigates the incorporation of titanium dioxide (TiO_2) into concrete, emphasizing its photocatalytic capabilities that contribute to mitigating air pollution and enhancing overall air quality. The integration of TiO_2 not only improves environmental conditions by catalyzing the degradation of nitrogen oxides (NOx) and volatile organic compounds (VOCs) into non-toxic byproducts but also strengthens the mechanical and durability aspects of concrete structures. Additionally, the study examines the sustainable practice of partially substituting fine aggregates with foundry sand a waste product of the metal casting process aiming to enhance material efficiency and promote waste utilization in construction. The paper critically analyzes current literature focusing on the mechanical behavior, durability and photocatalytic effectiveness of TiO_2 modified concrete, considering key parameters such as compressive and flexural strength, as well as resistance to environmental factors. While the advantages of TiO_2 enhanced concrete are promising, challenges remain, particularly regarding the consistency of photocatalytic performance over time, variability in structural properties, and the cost-effectiveness of widespread application. This review identifies existing research gaps and proposes directions for future development, particularly through the integration of foundry sand, to advance both environmental sustainability and structural performance in concrete applications.

IndexTerms – Titanium dioxide, Foundry sand, Sustainability and Air pollution.

I. INTRODUCTION

The rapid pace of urbanization, industrial expansion, and large-scale construction has led to a sharp increase in air pollution across cities. Major contaminants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), and particulate matter (PM2.5 and PM10) primarily originate from vehicular emissions, industrial activities, and construction processes. These pollutants are linked to serious health problems including respiratory and cardiovascular conditions and contribute to environmental degradation through phenomena like acid rain, smog formation, and climate change. Although initiatives such as the Clean Air Act have been implemented to regulate emissions, many urban areas continue to face persistent air quality challenges. As a sustainable approach to mitigating both air and land pollution, the integration of titanium dioxide and foundry sand into concrete offers a promising and environmentally responsible solution.

1.1 Titanium Dioxide

Titanium dioxide (TiO_2) is a widely used inorganic compound known for its high refractive index, strong UV light absorption and chemical stability. It exists in three crystalline forms anatase, rutile and brookite with anatase and rutile being the most commonly utilized in industrial applications. TiO_2 is extensively employed in paints, coatings, plastics, cosmetics and pharmaceuticals due to its excellent opacity, brightness and photocatalytic properties. In the construction industry it is incorporated into concrete and coatings to enhance self-cleaning and air-purifying capabilities through photocatalysis. Anatase is a metastable crystalline form of titanium dioxide (TiO_2) that exhibits exceptional photocatalytic activity and unique optical properties. It has a tetragonal crystal structure and is often preferred over other TiO_2 polymorphs, such as rutile and brookite for applications in photocatalysis, solar cells, and environmental purification. Anatase possesses a wide bandgap of approximately 3.2 eV, making it highly effective in absorbing ultraviolet (UV) light and facilitating oxidation-reduction reactions.

1.2 Foundry Sand

Foundry sand is a high-quality silica-based material that is primarily used in metal casting industries for molding and core-making processes. It consists of fine, uniform grains that provide excellent thermal conductivity, mechanical strength, and durability. After multiple casting cycles, the sand loses its binding properties and is discarded as waste foundry sand (WFS). Due to its physical and chemical characteristics, WFS has gained attention for its potential reuse in construction materials, including concrete, asphalt, and soil stabilization. Incorporating WFS as a partial replacement for natural sand in concrete can enhance sustainability by reducing environmental impact and conserving natural resources. The utilization of foundry sand aligns with circular economy principles, promoting waste minimization and resource efficiency in industrial applications.

II. LITERATURE REVIEW

Synergistic effects of nano titanium dioxide and waste glass powder on the mechanical and durability properties of concrete (2024)

Abhijeet Vidyadhar Baikerikar

In this study, cement is partially replaced by glass powder about 10% and Nano-TiO_2 about 0.5%, 1% & 1.5%. The strength properties are studied for 28 and 90 days. The compressive strength and flexural strength are gradually increase in strength for 1.5%T10%GP about 13% & 18%. The acid, chloride and sulphate attack test are conducted where there is decrease in compressive strength up to 18%, 6% and 10% for 1.5%T10%GP for the cubes under 90 days curing. Slight reduction in the CS was noticed as the temperature was increased from 150C to 300C. At 150C, NM strength was reduced to 1.17% whereas no reduction in Titanium dioxide and glass powder infused concrete. Noticeable changes were in 300C. NM strength was reduced by 7.42%, 1.5T10GP 6.62% at 300C.

Enhancing Mechanical Properties and Antimicrobial Activity of Portland Cement through Titanium Oxide Incorporation (2024)

Siti Nooriza Abd Razak, Nasir Shafiq

This paper explores the enhancement of mechanical properties and antimicrobial activity in Portland cement (PC) through the incorporation of titanium oxide (TiO_2). It highlights the influence of factors such as microbes, allergens, environmental conditions, pollutants, and substandard building materials on indoor air quality and human health. The study evaluates the integration of TiO_2 Nano powder into PC to improve both antimicrobial effectiveness and structural performance. TiO_2 was added at concentrations of 0.5%, 1.0%, and 1.5% by cement weight, and tests were conducted to assess slump flow, compressive strength, and flexural strength. Antimicrobial activity was measured using an agar diffusion test against four bacterial strains: Escherichia coli, Staphylococcus aureus, Enterococcus faecalis, and Pseudomonas aeruginosa. The results indicated that incorporating TiO_2 enhanced mechanical strength, with 1.0% TiO_2 yielding the best performance. Additionally, bacterial growth inhibition was most effective at 1.5% TiO_2. The findings suggest that incorporating a small percentage of TiO_2 into PC significantly improves its strength and antimicrobial properties, making it a suitable material for environments requiring high hygiene standards such as hospitals

Strength Properties and Electrical Resistivity of Nano-Titanium Dioxide (TiO2) Modified Lightweight Foamed Concrete (2023)

Afiya Abdul Sattar, MD Azree Othuman Mydin

The study examines the impact of different concentrations of nano-TiO_2 on the mechanical and durability characteristics of lightweight foamed concrete (LFC), aiming to improve its performance for structural uses. Various percentages of TiO_2 were added to the concrete mix, and their effects were assessed through tests measuring compressive strength, flexural strength, and electrical resistivity.

The results showed that the inclusion of nano- TiO_2 enhanced both the compressive and flexural strengths by improving the cement matrix and refining the microstructure, which resulted in better load-bearing capacity. Additionally, the electrical resistivity of the modified LFC increased, suggesting improved durability, particularly in resisting moisture and chloride penetration. The study focused on Titania Nano Particles (TNP) in lightweight foamed concrete with a density of 980 kg/m^3 and evaluated six different weight fractions of TNP: 0%, 1%, 2%, 3%, 4%, and 5%. The key properties measured included slump flow, electrical resistivity, compressive strength, splitting tensile strength, and bending strength. The results indicated that the strength improved as TNP content increased from 1% to 2%, but began to decline when the concentration reached 3% to 5%. This indicates that the optimal TNP concentration for enhancing strength properties lies between 1% and 2%. Any further increase beyond this range led to diminishing returns, with the potential for slight reductions in performance due to particle agglomeration. The study concludes that nano-TiO_2 is a promising additive for improving both the mechanical strength and durability of lightweight foamed concrete, making it more suitable for sustainable construction applications.

A comprehensive review of titanium dioxide nanoparticles in cementitious composites (2024)

J. Jenima, M. Priya Dharshini

The paper provides an in-depth analysis of the mechanical and durability test results of titanium dioxide (TiO_2) nanoparticles in cementitious composites. TiO_2 nanoparticles have been found to significantly enhance the mechanical properties of cement, which include compressive, flexural, and tensile strength. The results indicate that adding TiO_2 nanoparticles in concentrations ranging from 1% to 3% by weight of cement produces the most favorable improvements in these mechanical properties. In particular, the compressive strength increases due to the enhanced formation of the calcium silicate hydrate (C-S-H) gel, which strengthens the cement matrix. The flexural and tensile strengths also show improvements due to the increased bond between the cement particles and the TiO_2 nanoparticles. However, when the concentration exceeds 3%, the mechanical properties tend to decrease due to the agglomeration of nanoparticles, which disrupts the cement matrix. The optimal TiO_2 concentration for improving compressive, flexural and tensile strength was found to be 1% to 3% by weight of cement. At these levels, the compressive strength showed an increase of up to 25% compared to the control mix, while flexural and tensile strengths improved by approximately 15-20%. Beyond 3%, the mechanical properties began to decline due to nanoparticle agglomeration, which disrupted the microstructure. In terms of durability TiO_2 nanoparticles significantly reduced the permeability of cement, enhancing resistance to carbonation, freeze-thaw cycles, and sulfate attack. The optimal concentrations (1%-3%) resulted in about a 20-30% improvement in carbonation resistance, while freeze-thaw cycle resistance and sulfate attack resistance showed enhancements of up to 25%. The study concludes that TiO_2 at 1%-3% by weight of cement yields the best balance of improved strength and durability, with diminishing returns at higher concentrations due to agglomeration effects

Effect on concrete strength and durability with partial replacement of cement by Nano-titanium dioxide (nano-TiO_2) and ground granulated blast furnace slag (GGBS): A Review (2023)
Urvashi Vaid, Dr. Balwinder Lallotra
The paper discusses various studies that explore materials Nano-titanium dioxide (nano-TiO_2) and ground granulated blast furnace slag (GGBS) influence both the mechanical properties and the long-term performance of concrete.The review indicates that incorporating nano-TiO_2 into concrete enhances its compressive, tensile, and flexural strength. This improvement is attributed to nano- TiO_2's ability to promote better hydration reactions, resulting in a denser microstructure.
Addition of nano- TiO_2 contributes to increased resistance to environmental pollutants, making concrete more sustainable and eco-friendlier. The paper reports that nano- TiO_2 is most effective when added in amounts ranging from 0.5% to 2% by weight of cement, with the optimal results typically observed at 1%. GGBS, a byproduct of steel manufacturing, is also investigated for its impact on concrete durability. The inclusion of GGBS helps reduce permeability and increases concrete's resistance to chemical attacks such as those from sulfates and chlorides. The review highlights that replacing 25% to 30% of cement with GGBS offers notable durability improvements without compromising mechanical strength.
The combination of nano-TiO_2 and GGBS in concrete yields superior results. Optimal performance is achieved when nano- TiO_2 is used at 1% and GGBS at 25-30% of the cement content. This blend not only enhances the mechanical properties of concrete but also improves its long-term durability providing a more resilient material suitable for sustainable construction applications. The synergistic effect of both materials leads to concrete that exhibits higher strength, reduced shrinkage, and enhanced resistance to corrosion.

Titanium dioxide (TiO_2) based photocatalyst materials activity enhancement for contaminants of emerging concern (CECs) degradation: In the light of modification strategies (2022)
Chukwuka Bethel Anucha
The article outlines several strategies to improve the photocatalytic activity of titanium dioxide (TiO_2) for environmental remediation, particularly in degrading contaminants of emerging concern. One approach is heteroatom doping, which involves incorporating non-metal atoms like nitrogen or sulfur into the TiO_2 structure to narrow the bandgap, extending its light absorption into the visible range and reducing electron-hole recombination. Another strategy is dye or metal sensitization, where TiO_2 is combined with dyes or metal complexes to enhance its ability to absorb visible light and improve photocatalytic performance under visible light exposure. Metal oxide/semiconductor coupling is another method, where TiO2 is integrated with other semiconductors to create heterojunctions that enhance charge separation and broaden light absorption. Similarly, heterojunction construction involves forming junctions between TiO_2 and other semiconductors to promote efficient electron transfer, thus improving photocatalytic performance by reducing recombination rates. Additionally, surface morphology regulation by creating nanostructures increases the surface area and active sites of $TiO_{2,}$ thereby boosting interactions with pollutants. Lastly, hybridization with carbonaceous and other nanomaterials, such as graphene or carbon nanotubes, enhances electronic conductivity and provides additional active sites, further improving the photocatalytic efficiency of TiO_2. These modification techniques collectively enhance the photocatalytic capabilities of TiO_2 making it more effective in environmental applications like pollutant degradation
Among the various methods, metal oxide/semiconductor coupling, also known as heterojunction construction, is particularly effective in enhancing the photocatalytic efficiency of TiO_2. This method improves charge separation, reduces recombination, and expands the light absorption spectrum, making TiO_2 more efficient under both UV and visible light conditions. By integrating TiO_2 with other semiconductors such as ZnO, CdS, or similar materials, heterojunctions are formed that promote the efficient transfer of electrons and holes, leading to better photocatalytic activity. This strategy addresses two key limitations of TiO_2 its limited absorption to mainly UV light and the quick recombination of the generated charge carriers. Numerous studies have demonstrated that metal oxide/semiconductor coupling delivers enhanced photocatalytic performance, particularly in the breakdown of organic pollutants, making it one of the most promising methods for environmental applications.

A Review of the Effect and Optimization of Use of Nano-TiO_2 in Cementitious Composites (2021)
Mohammed Gamal Al-Hagri, Mahmud Sami Donduren
This paper reviews the effects and optimization of incorporating nano-titania (NT) in cementitious composites. It explores how NT influences the properties of cement-based materials, addressing common limitations such as low tensile strength and susceptibility to chemical penetration. The findings indicate that adding NT to cementitious composites significantly reduces workability while shortening both initial and final setting times. Moreover, NT enhances compressive, split tensile, and flexural strength, particularly during early curing stages (1–7 days), due to its nano-filler properties and hydration acceleration effects. Additionally, NT improves the resistance of mortar and concrete to water, chloride, and gas penetration by refining their microstructure, as confirmed by SEM analysis.

Titanium Dioxide as a Photocatalyst to Create Self-Cleaning Concrete (2021)
Hansaraj Dikkar
This study investigates the use of titanium dioxide (TiO_2) as a photocatalyst to develop self-cleaning concrete, particularly for pavement applications aimed at improving air quality and reducing pollutants in urban areas. The research examines the effects of TiO_2 incorporation on concrete performance under photocatalytic conditions. Experimental results indicate that adding 0.5% TiO_2 enhances compressive strength, while higher concentrations (1% and 1.5%) lead to a decline. Spectrophotometry analysis reveals that at 0.5% TiO_2 absorbance increases, demonstrating its ability to capture photon energy from the environment. These findings confirm the environmental sustainability of TiO_2 enhanced concrete. Additionally, concrete pavements facilitate better exposure of TiO_2 particles to UV light, thereby improving pollutant removal efficiency.

Hybrid effect of nano-alumina and nano-titanium dioxide on Mechanical properties of concrete (2020)
Muhammad Atiq Orakzai

This study examines the effect of combining nano-alumina (nano- Al_2O_3) and nano-titanium dioxide (nano-TiO_2) on the mechanical properties of concrete. While previous research suggests that nanoparticles can enhance concrete performance in construction applications, the paper systematically investigates the impact of using multiple nanoparticles in tandem. The nanoparticles were added in varying dosages between 0.5% and 2% by weight of cement.

To assess the effects, the researchers performed compressive and splitting tensile strength tests on cylindrical specimens measuring 100 mm x 200 mm, followed by flexural strength tests on 150 mm x 150 mm x 450 mm beams after a curing period of 28 days. The findings revealed that the combination of nano- Al_2O_3 and nano- TiO_2 led to a more compact and denser microstructure, with fewer pores. The optimal dosages were identified as 0.5% nano- Al2O3 and 1% nano- TiO_2 by cement weight, which resulted in increases in compressive strength (42%), splitting tensile strength (34%) and flexural strength (28%) compared to the control mix.

Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) analyses showed that the combination of nano-Al_2O_3 and nano-TiO_2 improved the pore structure of the concrete, contributing to its enhanced mechanical performance. The nanoparticles act as nucleation sites, promoting the formation of additional calcium silicate hydrate (C-S-H) gel and controlling the growth of calcium hydroxide ($Ca(OH)_2$) within the cement matrix. The study concludes that the combination of both nano-particles offers greater benefits than using them individually, resulting in concrete with improved mechanical properties

Experimental Study on Photocatalytic Degradation Efficiency of Mixed Crystal Nano-TiO_2 Concrete (2020)
Zhan Guo, Chenxiang Huang

The research conducted by Zhan Guo, Chenxiang Huang, and Yu Chen explores the photocatalytic properties of mixed crystal nano-TiO_2 in concrete, particularly its efficiency in degrading pollutants under both UV and solar light exposure. Two integration techniques were assessed: the internal doping method (IDM), which involves mixing nano- TiO_2 directly into the concrete, and the spraying method (SPM), where a nano- TiO_2 slurry is applied to the surface. Methyl orange (MO) was chosen as the test contaminant to measure degradation efficiency. The findings revealed that SPM-treated concrete demonstrated superior performance, achieving a peak degradation rate of 73.82% when a 10 mg/L nano- TiO_2 slurry was used, outperforming the IDM approach in pollutant breakdown. Surface texture significantly influenced results, as unpolished samples exhibited greater degradation efficiency than polished ones, likely due to a larger active surface area. Pollutant concentration also played a role, with higher MO levels leading to diminished photocatalytic performance. The effectiveness of degradation varied based on the light source, with UV exposure proving more efficient than solar irradiation, highlighting the energy dependency of the reaction. From an application standpoint, the study recommends SPM for environments requiring high photocatalytic efficiency, such as self-cleaning building surfaces, while IDM is better suited for infrastructure needing enhanced durability, like road pavements. Overall, this study underscores the potential of nano-TiO_2 enhanced concrete in environmental protection and sustainable construction, emphasizing the necessity of refining application methods, optimizing surface conditions, and considering light exposure to maximize pollutant removal efficiency.

Comparison of anatase and rutile TiO2 nanostructure for gas sensing application (2020)
S. A. Hamdan, I. M. Ibrahim, I. M. Ali

The gas sensing performance of anatase and rutile TiO_2 nanostructures is compared. TiO_2 a well-known semiconductor material, has been widely studied for its gas sensing applications due to its ability to interact with gases and change its electrical properties. The paper investigates how the nanostructured forms of anatase and rutile TiO_2 influence the sensitivity, selectivity, and response time when exposed to various gases. The research demonstrates that anatase TiO_2 due to its higher surface area and better catalytic properties, exhibits superior gas sensing performance compared to rutile TiO_2 It shows better sensitivity to gases such as ammonia and carbon dioxide. On the other hand, rutile TiO_2 while having a lower surface area, offers a more stable response and higher durability under certain conditions. The study also evaluates the influence of factors like temperature, gas concentration, and humidity on the sensing behavior. The study highlighted that anatase TiO_2 outperformed rutile in sensitivity, which suggests a significant difference in their respective performances. Typically, anatase TiO_2 shows up to 30–40% higher sensitivity compared to rutile TiO_2 in gas sensing applications, depending on the specific gas and environmental factors.

Removal Effect on Stormwater Runoff Pollution of Porous Concrete Treated with Nanometer Titanium Dioxide (2019)
Xiao Liang, Suhua Cui

This paper reviews the application of TiO_2 in porous concrete (TPC) as an innovative and environmentally friendly technology for managing runoff water pollution. Nano TiO_2 is incorporated into porous concrete at varying concentrations of 0.5%, 1%, and 1.5%. The study examines the permeability, mechanical properties, and water purification performance of TPC using different techniques to assess its environmental impact. Additionally, aquatic toxicity tests using zebrafish and alkali dissolution experiments were conducted to evaluate potential environmental effects. The photocatalytic oxidation properties of TPC were analyzed for the removal efficiency of three common pollutants: methylene blue, total phosphorus, and ammonia nitrogen. The pollutant removal rate ranged between 60% and 90%, demonstrating effective purification. Furthermore, zebrafish embryos were cultured in TPC leachate to assess long-term ecological safety, with a 91.7% hatching rate observed at 0.5% TiO2 indicating minimal toxicity to aquatic organisms and the environment.

Microstructure and durability properties of cement mortars containing nano-TiO_2 and rice husk ash (2016)
Ehsan Mohsenia, Farzad Naseri

investigates the effects of nano-titanium dioxide (nano- TiO_2) and rice husk ash (RHA) on the microstructure and durability of cement mortars. Nano- TiO_2 was incorporated into the mix at concentrations ranging from 0.5% to 3% by weight of cement, with the optimal dosage found to be 2%, which significantly improved compressive and flexural strength as well as durability. This concentration enhanced the microstructure by filling voids and promoting the formation of calcium silicate hydrate (C-S-H) gel, resulting in more efficient hydration. RHA was added in proportions ranging from 5% to 20% by weight of cement, with 10% providing the best results in terms of durability, improving resistance to chloride penetration and sulfate attack without compromising compressive strength. The study concluded that the combination of 2% nano- TiO_2 and 10% RHA offered the best overall performance, enhancing both mechanical properties and long-term durability. This combination showed significant improvements in resistance to water absorption, chloride ion penetration, and sulfate attack, presenting a promising solution for the development of sustainable and durable cement-based materials in construction. Higher concentrations of RHA, beyond 10%, led to a decrease in strength due to the reduced pozzolanic reactivity of the material. Scanning Electron Microscopy (SEM) images confirmed the formation of a denser microstructure with the inclusion of nano- TiO_2, improving the Interfacial Transition Zone (ITZ). Additionally, the rapid formation of hydration products in the presence of nano- TiO_2 as observed in X-ray Diffraction (XRD) analysis, contributed to the improved durability of the mortar. In conclusion, the combination of 15% RHA and 5% nano-TiO_2 was found to enhance the durability properties of the mortar after 90 days, demonstrating positive effects on water absorption, permeability, and strength

Quantification of NOx reduction via nitrate accumulation on a TiO_2 photocatalytic concrete pavement TiO2 photocatalytic concrete pavement (2012)
David James Osborn
They examine the effectiveness of TiO_2 coated concrete pavements in reducing nitrogen oxide (NOx) emissions through photocatalysis. The study, conducted at Louisiana State University in Baton Rouge, focuses on measuring nitrate accumulation on the pavement surface as an indicator of NOx degradation. The results demonstrate that the TiO_2 coated pavement effectively reduces NOx levels during the initial exposure period, with a noticeable decrease in photocatalytic activity after four days. However, the study also reveals that rainfall events help regenerate the photocatalytic activity, restoring the pavement's ability to degrade NOx. This regeneration suggests that the TiO_2 coated pavement can maintain long-term efficiency with appropriate environmental conditions. Osborn developed a field sampling method to collect nitrate salts deposited on the surface of the pavement, avoiding the need for core sampling. This technique was validated through comparison with laboratory measurements, proving its effectiveness for field assessments. The research also indicates that after six months of exposure to traffic and environmental conditions, the photocatalytic coating remains durable and functional, maintaining its NOx reduction capabilities. Environmental factors, including humidity, solar intensity, and wind conditions, were found to influence the photocatalytic performance, with optimal conditions enhancing its efficiency. Overall, the study highlights the potential of TiO_2 coated concrete pavements to contribute to NO_x reduction in urban areas, providing an innovative approach to mitigating air pollution. Furthermore, the nitrate measurement method developed in this study offers a practical tool for assessing the performance of photocatalytic surfaces in real-world settings, supporting the broader application of photocatalytic materials for environmental remediation. The TiO_2 concentration used in the study was 2% by volume in an aqueous solution. The spray coating applied to the pavement consisted of TiO_2 anatase nanoparticles with an average size of 6 nm, suspended in water at this concentration. This percentage was selected to balance photocatalytic efficiency and material optimization, ensuring effective NOx degradation while maintaining practical application feasibility.

Experimental study of photocatalytic concrete products for air purification (2009)
G. Husken, M. Hunger, H.J.H. Brouwers
The paper explores the effectiveness of photocatalytic concrete for air purification, utilizing titanium dioxide (TiO_2) as a catalyst to degrade nitrogen oxides (NOx), a major contributor to air pollution. Various TiO_2 concentrations, typically ranging from 1% to 5% by cement weight, were tested to determine the optimal amount for NOx reduction. Results indicated that photocatalytic activity peaked at 3-5% TiO_2 where NOx removal was maximized without significantly altering the concrete's mechanical properties. The research employed NOx degradation tests using a flow reactor setup to assess the pollutant reduction efficiency of TiO_2 treated concrete under UV light. Additionally, photocatalytic efficiency measurements were conducted to monitor the conversion of NOx into harmless byproducts like nitrates, while surface activity analysis examined the effects of light exposure, humidity, and TiO_2 distribution on performance. The findings highlight that TiO_2 enhances air purification by generating reactive oxygen species under UV light, which break down pollutants into less harmful compounds. However, beyond an optimal concentration of approximately 5%, performance gains diminish due to saturation effects and material limitations. This study suggests that incorporating photocatalytic materials into urban infrastructure, such as pavements and building facades, can contribute significantly to reducing air pollution and improving environmental quality.

Systematic review on the use of waste foundry sand as a partial replacement of natural sand in concrete (2024)
Gilberto Garcia and Rene Cabrera
The paper examines the potential of waste foundry sand (WFS) as a partial replacement for natural sand in concrete. The study compiles and analyzes various research findings to assess the impact of WFS on the mechanical and durability properties of concrete. Key findings indicate that incorporating WFS improves compressive strength up to an optimal replacement level, typically between 20% and 30%, beyond which workability and strength begin to decline due to increased water demand. Durability aspects such as chloride permeability, carbonation resistance, and sulfate resistance are also reviewed, with results showing that WFS can enhance certain properties while requiring careful mix design to mitigate potential drawbacks like higher porosity and shrinkage.
Key findings highlight that WFS contains residual binders, predominantly bentonite clays, which, along with its fine particle size and subangular to round morphology, contribute to reduced workability. The material's density ranges between 2.24 and 2.80 g/cm^3, while its absorption and fineness modulus vary from 0.33% to 7.77% and 0.50 to 3.20, respectively. WFS primarily consists of SiO2, with concentrations reaching up to 98.59%. In concrete, density changes remain minimal, between 1.45% and 3%, while workability decreases with higher WFS content. A replacement level of up to 10% has a negligible impact on workability, but beyond this, reductions between 20% and 80% can occur. Compressive strength can increase by 5% to 12% with up to 50% WFS replacement. In SCC, incorporating up to 20% WFS results in a workability reduction of 3% to 17% due to its fine particles and impurities, while a 15% substitution can enhance compressive strength by up to 14%. However, strength loss becomes more pronounced beyond 20% replacement.

Microstructure Analysis of Concrete with Pulverized Used Foundry Sand as Mineral Admixture (2023)
P M Salim and E V Prasad

The microstructural analysis of pulverized used foundry sand (PUFS) as a partial replacement of cement (0%, 5%, 10%, 15%, and 20%) was conducted using Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX), and X-ray Diffraction (XRD) to examine morphology, elemental composition, and mineral phases. SEM analysis showed that at 10% and 15% PUFS replacement, the matrix exhibited a denser structure with reduced porosity, indicating enhanced bonding and improved particle packing. However, at 20% replacement, voids and microcracks increased, suggesting weaker interfacial adhesion and potential strength reduction. EDX results confirmed that PUFS is rich in silicon (Si), aluminum (Al), and oxygen (O), along with minor amounts of iron (Fe) and calcium (Ca), supporting its pozzolanic activity. XRD analysis identified key crystalline phases, including quartz (SiO_2), mullite ($Al_6Si_2O_{13}$) and traces of metallic oxides, which contribute to secondary hydration reactions. The presence of reactive silica promoted additional calcium silicate hydrate (C-S-H) formation, enhancing strength at optimal levels. The findings suggest that PUFS replacement up to 15% improves microstructural properties, but at 20% replacement, increased porosity and microcracking may compromise durability and mechanical performance.

Analysis of the Technical Feasibility of Sustainable Concrete Production Using Waste Foundry Sand as a Fine Aggregate (2023)
Emily Noronha Marques, Carlos Perez Bergmann and Angela Borges Masuero

This study examines the feasibility of using waste foundry sand (WFS) as a fine aggregate in concrete production to enhance sustainability and reduce industrial waste. WFS, primarily composed of silica, is a byproduct of the foundry industry, with Brazil generating approximately three million tons annually. To assess its potential, concrete mixtures were prepared with 25%, 50%, and 100% WFS replacing natural sand. Mechanical and durability tests indicated that compressive strength improved with higher WFS content, while the modulus of elasticity remained largely unchanged. Water absorption tests showed no significant variations, and alkali-aggregate reaction analysis confirmed that WFS substitution did not compromise durability though 50% replacement approached the expansion limit, suggesting cautious application in structural foundations.
The elastic modulus remained comparable to that of conventional concrete, showing no statistically significant variation due to the similar particle size distribution of both sands. Absorption tests indicated no significant differences between the mixes, suggesting that WFS-based concrete performs similarly to standard concrete in terms of porosity. Alkali-aggregate reaction (AAR) analysis revealed no substantial variation among the tested mixtures; however, the 50% WFS replacement mix exhibited an expansion value of 0.18%, nearing the normative limit of 0.19%, warranting careful consideration for applications like foundations. The study also found that aluminum contaminants in WFS were neutralized within the cement matrix, mitigating potential environmental risks associated with landfill disposal. Overall, the findings confirm that WFS can be a feasible alternative to natural sand in concrete production, supporting sustainability by reducing waste and promoting resource efficiency, with substitution rates of up to 100% proving viable.

Insight into the perspectives of waste foundry sand as a partial or full replacement of fine aggregate in concrete (2023)
Sunit Kumar, Rahul Silori1, Susanta Kumar Sethy

The paper conducted a comprehensive review on the feasibility of using waste foundry sand (WFS) as a replacement for fine aggregate in concrete, considering both partial and full substitution. The study identified that an optimal replacement level falls between 20% and 30% by weight, where concrete maintains favorable mechanical properties. However, at complete replacement, significant declines in workability and compressive strength were noted, making it unsuitable for structural applications. The review also emphasized that variations in WFS composition, due to differences in its source, necessitate further research on its long-term durability and dynamic performance. Additionally, the authors proposed investigating the potential of incorporating supplementary waste materials or strength-enhancing additives to improve the performance of concrete containing WFS, particularly at higher replacement levels, to enhance sustainability in construction practices.

Experimental Research on the Effects of Waste Foundry Sand on the Strength and Micro-Structural Properties of Concrete (2022)
K. Archaneswar Kumar, K. Rajasekhar and C. Sashidhar

The paper conducted an experimental study on the effects of waste foundry sand (WFS) as a partial substitute for fine aggregate in concrete. The research evaluated concrete mixes with WFS replacement levels of 10%, 20%, 30%, 40%, and 50%, assessing mechanical properties such as compressive, flexural, and splitting tensile strengths at curing ages of 7, 14, 28, 56, and 90 days. The findings indicated that up to 20% WFS replacement resulted in strength values comparable to conventional concrete, with deviations within ±5%. However, when WFS content exceeded 20%, a decline in mechanical properties was noted, reaching up to a 15% reduction at 50% replacement. Microstructural examination through Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) revealed a well-compacted and dense matrix at 20% WFS, similar to the control mix. Additionally, Thermogravimetric Analysis (TGA) confirmed that thermal stability remained unaffected up to this level. Overall, the study concludes that replacing up to 20% of fine aggregate with WFS is a viable and sustainable option without significantly compromising concrete performance

Reuse or Disposal of Waste Foundry Sand: An Insight into Environmental Aspects (2022)
Flavio Cioli

The paper examined the environmental considerations of reusing versus disposing of waste foundry sand (WFS), with a focus on its leaching behavior and potential applications. The study found that WFS is typically generated after being reused for 5 to 10 cycles. Leaching assessments were conducted using the Toxicity Characteristic Leaching Procedure (TCLP), Synthetic Precipitation Leaching Procedure (SPLP), and European standards EN 12457-2 and EN 12457-4 to evaluate the release of contaminants. The findings revealed that while most metal concentrations in WFS eluates remained within permissible limits, elements such as lead (Pb) and mercury (Hg) occasionally exceeded regulatory thresholds. Additionally, organic compounds like acetone and naphthalene were detected in the leachate. Although the study does not specify optimal WFS replacement percentages for construction materials, it highlights the importance of ensuring compliance with environmental regulations before reuse. X-ray diffraction (XRD) analysis was not explicitly reported in the study. Overall, the research emphasizes that with proper handling and adherence to regulatory guidelines, WFS can be repurposed effectively, reducing disposal concerns and supporting sustainable waste management practices

Engineering properties of concrete with partial utilization of used foundry sand (2017)
Thiruvenkitam Manoharan

The paper conducted a study on the use of used foundry sand (UFS) as a partial substitute for fine aggregate in M20 grade concrete. Concrete specimens were prepared with UFS replacement levels of 0%, 5%, 10%, 15%, 20%, and 25% by weight, and their mechanical, durability, and microstructural characteristics were analyzed at 7, 28, and 91 days of curing. The findings revealed that compressive strength, flexural strength, and modulus of elasticity remained similar to conventional concrete up to 20% UFS replacement, with a decline observed beyond this point. At 20% substitution, the compressive strength was nearly equivalent to that of the control mix, while higher percentages led to a reduction in strength. The split tensile strength showed improvement beyond 20% replacement, although other mechanical properties exhibited a downward trend. Durability assessments indicated that abrasion resistance and rapid chloride permeability for concrete incorporating up to 20% UFS were comparable to those of conventional concrete. The results showed that compressive strength remained nearly unchanged up to 20% UFS replacement, with only a slight variation of ±2% compared to conventional concrete, but decreased by approximately 5–8% beyond 20% replacement. Flexural strength remained stable up to 20% UFS, with variations of around ±3%, but dropped by 6–9% at 25% replacement. Split tensile strength increased slightly (about 4–6%) beyond 20% UFS replacement but was accompanied by declines in other mechanical properties. Durability tests indicated that abrasion resistance and rapid chloride permeability remained comparable to the control mix up to 20% UFS, showing variations of less than 3%, whereas beyond this level, permeability increased by approximately 7–10%. X-ray diffraction (XRD) analysis revealed the presence of crystalline compounds such as quartz and mullite, confirming that UFS can be safely incorporated at up to 20% replacement without significant negative effects on concrete performance.

Experimental analysis of waste foundry sand in partial replacement of fine aggregate in concrete (2017)
A.Naveen Arasu

The study examines the feasibility of utilizing waste foundry sand (WFS) as a partial replacement for fine aggregate in concrete, assessing its effects on strength and workability. Experimental analysis was conducted on M20 and M30 grade concrete by replacing fine aggregate with WFS at 10%, 20%, and 30%. The results indicate that for M20 concrete, an optimal compressive strength increase was observed at 20% WFS replacement, whereas for M30 concrete, the maximum strength was achieved at 10% replacement. Compared to conventional concrete, the compressive strength of M20 concrete increased by approximately 6–8% at 20% WFS, while M30 concrete showed a 3–5% improvement at 10% WFS. Flexural strength for M20 concrete remained stable up to 20% replacement but decreased beyond this, while for M30 concrete, a decline was observed at all replacement levels. The split tensile strength of M20 concrete increased by about 4–6% at 20% WFS, whereas M30 concrete exhibited a reduction of around 2–4% with increasing WFS content. Workability was marginally affected, with minor variations in slump and compaction factor. The study concludes that WFS can be effectively used as a sustainable alternative to fine aggregate in concrete, with a recommended replacement of 20% for M20 and 10% for M30 to achieve optimum performance while also addressing environmental concerns associated with WFS disposal.

Mechanical and Durability Properties of Concrete Made with Used Foundry Sand as Fine Aggregate (2015)
G. GaneshPrabhu, Jin WookBang, ByungJaeLee, Jung HwanHyun and YunYongKim

The study examines the mechanical and durability properties of concrete incorporating used foundry sand (UFS) as a fine aggregate replacement at varying levels of 0%, 10%, 20%, 30%, 40%, and 50%. The results indicate that an optimum substitution level of 30% UFS provides the highest compressive strength, showing an increase of approximately 8–10% compared to conventional concrete. However, beyond 30% replacement, the strength gradually decreases due to increased porosity and weaker interfacial bonding. The modulus of elasticity remained comparable to conventional concrete across all replacement levels, with no significant variation. Water absorption and sorptivity tests showed a slight increase of around 5–7% at 30% UFS compared to control concrete, indicating a minor reduction in permeability.

The chemical analysis of foundry sand (FS) confirms its suitability as a material for concrete production. However, due to its fineness and highwater absorption, FS increases the water demand of concrete, leading to reduced workability, particularly when the substitution exceeds 30%. Across all curing ages, the mechanical properties of concrete containing up to 30% FS remained comparable to those of conventional concrete (CM), with CM exhibiting an average strength increase of 6.3% over the FS 30% mixture. In terms of durability, the chloride penetration value of CM was recorded at 420 coulombs, while the FS 30% mixture achieved 621 coulombs at 180 days, staying well below the ASTM C1202-97 maximum limit. The carbonation coefficient for mixtures with up to 30% FS remained within 6 mm/month, indicating good resistance to carbonation. Electrical resistivity tests showed that CM had only a moderate increase of 10.37% and 14.62% compared to FS 20% and FS 30% mixtures, respectively, after 180 days. However, the presence of sulfur compounds in FS contributed to increased sulfate resistance in Na_2SO_4 and $MgSO_4$ solutions promoting ettringite formation, which eventually led to concrete deterioration.

Properties of Self-Compacting Concrete Incorporating Waste Foundry Sand (2013)
Rafat Siddique and Ravinder Kaur Sandhu

The paper investigates the effects of incorporating waste foundry sand (WFS) as a partial replacement for fine aggregate in self-compacting concrete (SCC). Various SCC mixtures were prepared with WFS replacement levels of 0%, 10%, 20%, 30%, 40%, and 50%, and their fresh and hardened properties were evaluated. The results indicated that up to 30% WFS substitution provided optimal performance, balancing workability, strength, and durability. Workability decreased progressively with increasing WFS content due to its finer particle size and higher absorption, with reductions of up to 25% in slump flow at 50% replacement. Compressive strength exhibited a slight improvement at 10%–20% WFS replacement, with gains of around 5%–10% compared to the control mix, but beyond 30%, a decline of up to 15% was observed. Split tensile and flexural strengths followed a similar trend, showing marginal improvements at lower replacement levels but reductions of approximately 10%–20% at higher dosages. Durability assessments, including water absorption and chloride ion penetration, indicated that SCC with up to 30% WFS maintained performance comparable to conventional SCC, while higher substitutions led to increased permeability and reduced resistance to aggressive environments. The findings suggest that WFS can be effectively utilized in SCC up to a 30% replacement level, contributing to sustainable construction by reducing dependency on natural sand without significantly compromising mechanical and durability properties.

III. LITERATURE SUMMARY

Effect of Titanium Dioxide (TiO_2) on Concrete Properties

Workability

- TiO_2 decreases workability due to its fine particle size and high surface area leading to increased water demand.
- Incorporating 1.0%–2.0% TiO_2 results in a 10% to 30% slump reduction, depending on the mix design.
- A 0.5% to 1.5% TiO_2 substitution has minimal effect on workability, whereas beyond 2.0%, significant slump loss and poor flowability occur.

Strength Characteristics

- **Compressive Strength**: The addition of 0.5% to 2.0% TiO_2 increases compressive strength by 5% to 15% at 28 days, with the optimal range being 1.0% to 1.5%. However, beyond 2.0%, strength may decrease due to nanoparticle agglomeration and increased porosity.
- **Split Tensile Strength**: TiO_2 incorporation enhances split tensile strength by 4% to 12% at 28 days, with the 1.0% to 1.5% TiO_2 range providing the highest gains. At dosages beyond 2.0%, tensile strength declines due to weak bonding between cement hydrates and TiO_2 particles.
- **Flexural Strength**: The inclusion of up to 1.5% TiO_2 improves flexural strength by 5% to 10%, primarily due to matrix densification and crack-bridging effects. However, beyond 2.0% TiO_2 strength decreases due to uneven dispersion of nanoparticles.

Durability Characteristics

- **Chloride Penetration Resistance**: The incorporation of TiO_2 (1.0% to 2.0%) reduces chloride ion penetration by 15% to 30%, enhancing concrete durability against corrosion. Higher dosages beyond 2.0% may not significantly improve resistance due to agglomeration effects.
- **Water Absorption & Permeability**: TiO_2 modified concrete exhibits 10% to 25% lower water absorption, improving impermeability and resistance to moisture ingress. The optimal range for reducing permeability is 1.0% to1.5% TiO_2.
- **Carbonation Resistance:** TiO_2 addition enhances resistance to carbonation by reducing pore connectivity, particularly at 1.0% to 1.5% TiO_2 resulting in a 10% to 20% reduction in carbonation depth.
- **Sulphate Resistance**: Concrete containing TiO_2 (up to 1.5%) shows higher resistance to sulfate attack, reducing expansion and deterioration by 10% to 18%. Excessive TiO2 content (beyond 2.0%) may reduce sulfate resistance due to poor particle dispersion.

Air Pollutant Degradation by Titanium Dioxide

- **Photocatalytic Mechanism:** TiO_2 acts as a photocatalyst, breaking down air pollutants under UV light. When exposed to sunlight, TiO_2 generates reactive oxygen species (ROS) such as hydroxyl radicals (OH) and superoxide anions (O_2), which oxidize harmful pollutants into harmless byproducts.
- Nitrogen Oxide (NOX) Reduction: TiO_2 effectively reduces NOX gases, converting them into nitrates (NO_3^-), which can be washed away by rain, significantly improving air quality. Studies show that concrete with 1.0% to 2.0% TiO_2 can reduce NOX levels by 20% to 60% depending on environmental conditions.
- Decomposition of Volatile Organic Compounds (VOCS): TiO_2 degrades VOCs such as benzene, toluene, and formaldehyde, converting them into CO_2 and H_2O. The efficiency increases with higher surface area and UV exposure.
- Self-Cleaning and Anti-Pollution Surfaces: TiO_2 coatings on concrete and pavements reduce surface contamination, breaking down organic matter, dirt, and microbial growth, leading to low-maintenance, self-cleaning surfaces.

Effect of Foundry Sand on Concrete Properties

Workability

- WFS reduces workability due to its finer particle size, increased water absorption, and irregular shape.
- A 10% to 20% WFS replacement has minimal impact on workability, but beyond 30%, there is a 20% to 80% reduction in slump, requiring additional water or admixtures to maintain flowability.

Strength Characteristics

- Compressive Strength: Incorporation of up to 30% WFS results in strength comparable to conventional concrete (+6.3%). Beyond 30%, compressive strength declines due to poor particle packing and higher water demand.
- Split Tensile Strength: WFS replacement of 10% to 20% improves split tensile strength by 5% to 12%, while beyond 30%, a decline occurs due to weak bonding in the matrix.
- Flexural Strength: A 15% to 25% WFS substitution leads to an increase in flexural strength by 5% to 10%, but higher percentages negatively impact strength due to increased porosity and reduced cohesion.

Durability Characteristics

- **Chloride Penetration Resistance:** The reference mix shows 420 coulombs, while 30% WFS increases this to 621 coulombs at 180 days, which is still within ASTM C1202-97 limits.
- **Water Absorption & Permeability**: Concretes with 20% to 30% WFS exhibit similar water absorption to control mixes, but beyond 50%, permeability increases, leading to higher moisture ingress.
- **Carbonation Resistance**: The carbonation coefficient of WFS concrete remains below 6 mm/month, indicating acceptable performance in carbonation resistance.
- **Sulphate Resistance:** The presence of sulfur in WFS enhances ettringite formation, increasing the risk of sulfate-induced deterioration, particularly in Na_2SO_4 and $MgSO_4$ exposure.

3.1 RESEARCH GAP

- The combination of partial replacement of Titanium dioxide for cement and partial replacement of foundry sand for fine aggregate not done so far
- The enhancement of strength and durability properties for the combination should be investigated
- The amount of reduction of air pollutants should be investigated for the combination

IV. CONCLUSION

The following conclusions can be drawn from the above literature review

- Titanium dioxide (TiO_2) has a excellent photocatalytic properties and a cost-effective material which enhances concrete strength and provides an environmentally beneficial solution by reducing ambient pollutants.
- From the literature review the partial replacement of TiO_2 for various percentage in cement up to 5%. The early strength, initial and final setting time of cement and workability of concrete differs based on the percentage of replacement of TiO_2 for cement.
- The usage of M-sand demand increases for alternate solution the usage of foundry sand which is a waste product from metal casting industry can be used as a partial replacement for fine aggregate to enhances the strength of the concrete
- From the literature review for the higher grade concrete mix required a less percentage of partial replacement of foundry sand.
- Through the literature review an optimum percentage for the partial replacement of Titanium dioxide for cement is 0.5%, 1%, 1.5% and 2% and for foundry sand for fine aggregate is 10% and 15%.

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