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Utilisation of nano materials(Al2O3 ,TiO2) in concrete to enhance multipurpose properties of concrete.

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Abstract: This review paper examines the roles of titanium dioxide (TiO_2) and aluminium oxide (Al_2O_3) when incorporated into Portland cement concrete. Both oxides, particularly in nano- and micro scale forms, have been reported to influence fresh and hardened properties of concrete, affecting hydration kinetics, microstructure refinement, mechanical strength, durability, and functional performance such as photocatalytic self-cleaning and air purification. This paper synthesizes findings from experimental studies and meta-analyses, assesses mechanisms of action, evaluates practical considerations (dosage, dispersion, compatibility), and outlines future research directions and potential applications. The review aims to provide a consolidated resource for researchers and practitioners interested in advanced functional concretes and sustainable infrastructure.

Keywords: *Titanium dioxide, Aluminium oxide, Nanoparticles, Concrete, Photocatalysis, Durability*

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I.INTRODUCTION:

Concrete is the most consumed engineered material in the world and the backbone of modern infrastructure. Despite its ubiquity, conventional concrete has inherent limitations including relatively low tensile strength, susceptibility to cracking, permeability to aggressive agents, and a significant carbon footprint associated with Portland cement production. To address these issues, researchers have pursued material modifications at multiple scales. Recent decades have seen a surge of interest in incorporating functional additives—particularly nanoscale oxides—into cementitious matrices to tailor properties and add new functionalities. Titanium dioxide (TiO_2) and aluminium oxide (Al_2O_3) represent two oxides with distinct, but complementary roles when used as concrete additives. TiO_2 is widely recognized for its photocatalytic properties under ultraviolet (and with certain dopants, visible) light; it enables degradation of organic pollutants and imparts self-cleaning surfaces. Al_2O_3 (commonly in nano- or micro-powder forms such as nano-alumina or calcined alumina) is prized for mechanical reinforcement, pore refinement, and improved abrasion resistance. The following sections explore the chemistry, mechanisms, experimental observations, and engineering implications of adding TiO_2 and Al_2O_3 to concrete.

Titanium Dioxide (TiO_2) TiO_2 exists primarily in anatase and rutile crystal forms; anatase is typically more photocatalytically active due to favorable band-gap and surface characteristics. Photocatalysis proceeds when photons with energy greater than the band-gap promote electrons from the valence band to the conduction band, generating electron–hole pairs that react with adsorbed oxygen and water to produce reactive oxygen species (ROS). These ROS oxidize organic compounds and reduce nitrogen oxides, conferring air-purifying and self-cleaning properties to treated surfaces. In cementitious matrices, TiO_2 may also act as a fine filler and participate in pozzolanic-like interactions depending on particle size and surface treatment.

Aluminium Oxide (Al_2O_3) Al O (alumina) is chemically stable, hard, and highly refractory. Nano-alumina has a high specific surface area which can accelerate cement hydration by acting as nucleation sites for calcium–silicate–hydrate (C–S–H) formation. The filler effect reduces porosity and refines pore size distribution leading to increased strength and reduced permeability. Additionally, Al_2O_3 may contribute to abrasion resistance and thermal stability in specialized concretes

II.LITERATURE REVIEW

2.1 **Mahmud Sami Döndüren and Mohammed Gamal Al-Hagri (2022)**

presented a comprehensive review titled “A review of the effect and optimization of use of nano-TiO_2 in cementitious composites.” They summarized that the addition of nano-TiO_2 enhances compressive strength, reduces porosity, accelerates hydration, and refines the microstructure of concrete. They noted that nano-TiO_2 acts mainly through the **filler effect** and **nucleation effect**, producing more C–S–H gel and a denser interfacial transition zone (ITZ). The authors reported optimum dosages in the range of **0.5 %–2 %** by the weight of cement, beyond which agglomeration and loss of workability can reduce performance.

2.2 Hala N. Elia, Anindya Ghosh, Amin K. Akhnoukh and Zeid A. Nima (2018)

explored the environmental benefits of nano-TiO_2 in their paper “Using nano- and micro-titanium dioxide in concrete to reduce air pollution.” They demonstrated that TiO_2 incorporated concrete can degrade nitrogen oxides and other organic pollutants under sunlight, thereby improving air quality around concrete structures.

2.3 **Raeid Kadhium Mohammed, Alaa Aladdin Abdel-Hamead and Farhad Mohammed Othman (2018)**

studied the microstructure and mechanical properties of recycled concrete containing nano-Al_2O_3. They reported that 0.5–2.5 % nano-Al_2O_3 improved compressive strength and reduced calcium hydroxide formation, leading to a denser C–S–H gel and enhanced bonding between the old and new cement paste.

2.4 **Jenima, Priya Dharshini, Ajin, Jebeen Moses, Krishna Priya Retnam, Krishna Prakash Arunachalam, Siva Avudaiappan and Ramon Francisco Arrue Muñoz (2024)**

carried out an extensive study titled *"A comprehensive review of titanium dioxide nanoparticles in cementitious composites."* They emphasized that nano-TiO_2 not only improves the mechanical and durability properties but also imparts **photocatalytic and self-cleaning properties**, helping to reduce environmental pollution. They found that anatase-phase TiO_2 under UV light decomposes organic pollutants, leading to self-cleaning and air-purifying concrete surfaces. However, they also highlighted the challenge of dispersing nano-TiO_2 uniformly in the cement matrix.

2.5 **Wioleta Iskra-Kozak and Janusz Konkol (2021)**

examined the *"Impact of nano-Al_2O_3 on the physical and strength properties as well as on the morphology of cement composite crack surfaces."* They tested dosages from 1 % to 4 % by cement weight and found that 1 % nano-Al_2O_3 increased compressive strength by approximately **20 %** compared to control mixes. The authors attributed the improvement to nano-Al_2O_3's ability to accelerate cement hydration and refine the pore structure. However, they observed that workability decreased as nano-Al_2O_3 content increased.

Summary of Literature & Identified Gaps

In terms of **durability**, TiO_2-modified concrete shows improved resistance to **chloride and sulfate attack**, **carbonation**, and **freeze–thaw cycles**, as noted by **Jenima et al. (2024)** and **Narreddy et al. (2024)**. However, increased water demand and reduced workability are common side effects, necessitating the use of superplasticizers or improved dispersion techniques.

For **nano-Al_2O_3**, researchers such as **Iskra-Kozak and Konkol (2021)** and **Kadhium et al. (2018)** found that small additions (around **1 %**) significantly increase **compressive and flexural strength** by densifying the matrix and accelerating hydration. The particles serve as micro-fillers and nucleation sites, leading to a refined pore structure and better interfacial transition zones. Studies by **Agarkar and Joshi** and **Tara Alaa Jalil (2025)** also confirmed similar trends—strength and durability improvements at low dosages, followed by deterioration at higher concentrations due to particle agglomeration.

In hybrid systems, **Srivastava, Mishra, and Singh (2025)** and **Orakzai (2020)** found synergistic effects when TiO_2 and Al_2O_3 were used together, improving compressive and tensile strength simultaneously while reducing porosity. These findings suggest that multi-nanoparticle systems could offer enhanced mechanical and durability properties compared to single-nanoparticle mixes.

Overall, the consensus across the literature is that TiO_2 and Al_2O_3 nanoparticles can substantially enhance concrete's **mechanical strength, microstructural density, durability, and—in TiO_2's case—functional behaviour** such as self-cleaning and pollution mitigation. The improvements depend heavily on the nanoparticle dosage, dispersion quality, and compatibility with mix components.

III.CONCLUSION

The incorporation of nanomaterials, particularly **titanium dioxide (TiO_2)** and **aluminium oxide (Al_2O_3)**, represents a significant advancement in the development of high-performance and multifunctional concrete. Based on the reviewed literature, both nanoparticles have demonstrated strong potential to improve the **mechanical strength, durability, and microstructural integrity** of cementitious materials when used in optimum proportions.

Nano-TiO_2 enhances compressive and flexural strength through its nucleation and filler effects, leading to a denser and more refined microstructure. In addition, it imparts **photocatalytic and self-cleaning properties**, enabling concrete to degrade environmental pollutants such as NO_x and organic compounds under sunlight. This makes TiO_2-modified concrete not only structurally superior but also environmentally beneficial, contributing to sustainable and smart infrastructure development.

Nano-Al_2O_3, on the other hand, primarily improves the **hydration kinetics, bonding strength, and pore structure** of concrete. When added in small dosages (typically 0.5–2 % by weight of cement), it accelerates the formation of C–S–H gel, increases compressive and tensile strength, and reduces permeability. Its micro-filling ability also helps strengthen the interfacial transition zone between cement paste and aggregates.

IV.FUTURE SCOPE

Although numerous studies have demonstrated the promising effects of nano-titanium dioxide (TiO_2) and nano-aluminium oxide (Al_2O_3) in enhancing the mechanical and functional properties of concrete, several areas remain open for further exploration. Future research should focus on developing standardized guidelines for nanoparticle dosage, dispersion techniques, and mix design to ensure uniform performance at both laboratory and field scales.

There is a strong need for long-term field studies to evaluate the durability, weathering behavior, and photocatalytic efficiency of nano-modified concretes under real environmental conditions. Research should also emphasize cost reduction and large-scale production methods to make nano-concrete economically viable for commercial construction projects.

Moreover, the combination of TiO_2 and Al_2O_3 with other nanomaterials—such as nano-silica, graphene oxide, or carbon nanotubes—could be explored to achieve synergistic improvements in strength, self-sensing, and self-healing properties. Investigations into the safety, health, and environmental impacts of nanomaterial use in construction are equally important to ensure sustainable and responsible implementation.

Finally, future work should integrate life-cycle assessment (LCA) and techno-economic analysis to evaluate the environmental and financial benefits of nano-enhanced concrete, thereby supporting its adoption in modern green and smart infrastructure systems

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