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REVIEW ON EXPERIMENTAL STUDY ON USE OF NANO TITANIUM DIOXIDE IN CONCRETE

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ABSTRACT :

Numerous reinforced concrete structures particularly those exposed to coastal and marine conditions, are corroded by reinforcement corrosion. In a chloride-prone environment, diurnal and seasonal temperature and humidity fluctuations initiate cycles of expansion-contraction and hydration-dehydration, resulting in the initiation and propagation of reinforcement corrosion and subsequent cracking, spalling, and loss of load-bearing capacity of reinforced concrete structures. Recently, nanotechnology has garnered considerable scientific attention owing to its novel applications in particles on the nanometer (10-9 m), as nanoscale particles exhibit significantly improved properties compared to materials with predictable grain sizes and the same chemical composition.

This article examines the optimal concentration of nano-TiO2 in cementitious materials. Furthermore, the cost-effectiveness of using nano-titania in cementitious composites has been examined. Nano titania diminishes the workability and setting duration of cementitious materials. It may significantly enhance the mechanical capabilities, durability, and microstructural characteristics of cementitious composites.

Keyword - Compressive Strength, Flexural Strength, Nano Titanium Dioxide, Nano Concrete. Nano titanium dioxide (TIO2)

1. 1 Introduction :

Nanomaterials are materials with at least one dimension less than 100 nanometers. When introduced into concrete, they can significantly enhance the material's properties due to their unique physical and chemical characteristics. Here's an overview of their introduction in concrete:

Types of Nanomaterials Used in Concrete:

- Nano-Silica (SiO2): Improves the hydration process of cement, leading to increased strength and durability.
- Carbon Nanotubes (CNTs): Enhances mechanical properties like tensile strength, ductility, and impact resistance.
- Nano-TiO2 (Titanium Dioxide): Provides self-cleaning properties and reduces pollution through photocatalytic activity.
- Nano-Alumina (AlO2): Increases compressive strength and durability.
- Nano-clay: Improves workability and reduces permeability.
- Graphene Oxide: Enhances mechanical properties and offers potential for smart concrete applications.

2. Literature survey & background :

The incorporation of nanomaterials in concrete has emerged as a promising area of research within the field of construction materials. Among these nanomaterials, nano-titanium dioxide (Nano-TiO2) has garnered significant attention due to its unique photocatalytic properties, which impart self-cleaning, pollution-reducing, and durability-enhancing characteristics to concrete. This literature review provides a comprehensive overview of the research conducted on the application of Nano-TiO in concrete, focusing on its effects on the mechanical properties, durability, environmental impact, and potential challenges.

Jay Sorathiya, Dr. Siddharth Shah, Mr. Smit Kacha, (2017) research includes an attempt to understand the outcome of Anatase Nano Titanium Dioxide (TiO2) on Conventional Concrete (CC) of M20 grade with various proportions and concluded that the nano-TiO2 particles added concrete had appreciably higher compressive strength comparable to that of the normal concrete. It is found that the cement could be gainfully added with nano- TiO2 particle up to maximum limit of 1.0% with average particle sizes of 15 nm. (Jay Sorathiya, 2017)

Iyappan. A.P, Srikanthan.L, Felix Franklin.S, Bhuvaneswari.J, Preethika.A, 2017, studied the use of Nano Titanium Dioxide (anatase based TiO2) of size 15 nanometer (nm) to advance the compressive strength and tensile strength of concrete. An experimental study had been carried out by replacing the cement with nano titanium dioxide. The maximum compressive strength and split tensile strength is attained for 1.5% of Titanium Dioxide (TiO2) with replacement of cement (by weight of cement). (Iyappan. A.P, 2017)

Saloma, Amrinsyah Nasution, Iswandi Imran and Mikrajuddin Abdullah. (2013), in this research Nano Fe2O3 & Al2O3 (15nm), Nano TiO2 (15nm) and Nano silica (10-140 nm) were added up to 2.0 % by weight of cement in concrete. It is derived that the Compressive strength splitting tensile test and Modulus of elasticity of concrete can be considerable. After 3, 7, and 28 days compressive strength and Splitting tensile strength increases considerably. (Saloma, June 2013.)

Abhishek Singh Kushwaha, Rachit Saxena and Shilpa Pal (2015), in this study, M30 grade concrete was cast and cement was partially replaced by titanium dioxide (by weight). The amount of TiO2 was varied from 1% to 3% by weight of cement. TiO2 acts as the Nano particles that fill the Nano-voids in concrete that leads to the increment of compressive strength. The 1% of TiO2 is optimum for compressive strength of concrete. (Abhishek Singh Kushwaha, June 2015.)

Zhen Li, Baoguo Han, Xun Yu, Sufen Dong, Liqing Zhang, Xufeng Dong, Jinping Ou (2017) made an attempt in which Nano TiO2 was added into RPC to develop high performance concrete. The study concluded that the adding of Nano TiO2 can expand the mechanical properties of RPC and decrease the electrical resistivity of Rapid Portland Cement. The composites at curing age of 3 and 28 days had the maximum surges in flexural strength with 52.72% (2.81 MPa) and 47.07% (3.62 MPa) respectively. Further the increases in compressive strength of the composites are also notified. The compactness model demonstrated that Nano TiO2 can progress the compactness and decline the permeability of RPC. (Zhen Li, 2017)

Ali Nazari (2011) made an attempt to explore the effect of Nano-TiO2 particles mixed with concrete on a flexural strength with respected to the conventional concrete and concluded that the cement would be effectually replaced with Nano-TiO2 units up to desire limit of 2.0%. Optimum dose of Nano-TiO2 particles content was achieved with 1.0% by weight of cement for the samples cured in water for 7, 28 and 90 days. (Nazari, 2011)

Figure 2.1 : Nano Titanium Dioxide (TiO2)

Properties of Nano-TiO2

Nano-TiO2 is known for its strong photocatalytic activity, primarily in the anatase crystalline form. When exposed to ultraviolet (UV) light, Nano-TiO2 generates reactive oxygen species (ROS) such as hydroxyl radicals, which can break down organic pollutants and contaminants on the concrete surface (Chen & Poon, 2009). This property makes it an excellent candidate for enhancing the environmental and aesthetic performance of concrete.

2.1 Review paper on Mechanical Properties of Concrete Containing Nano-TiO2

Several studies have investigated the impact of Nano-TiO2 on the mechanical properties of concrete. Generally, the addition of Nano-TiO2 has been found to improve compressive strength and surface hardness. For instance, Zhang et al. (2012) reported that the inclusion of Nano-TiO2 at optimal concentrations could enhance the early-age strength of concrete by refining the pore structure and improving the hydration process of cement. However, the improvements in mechanical properties are highly dependent on the dispersion of Nano-TiO2 within the concrete matrix. Improper dispersion can lead to agglomeration, which may negatively impact the concrete's strength (Sobolev & Gutiérrez, 2005).

Nano-TiO2 enhances the hydration process of cement by providing additional nucleation sites for the formation of calcium silicate hydrate (C-S-H) gel, the primary binding phase in concrete. According to Zhang et al. (2012), the acceleration of the hydration process leads to the earlier formation of a more refined microstructure, which contributes to the improved early-age strength of the concrete. This property is particularly beneficial in applications where rapid strength development is required.

The majority of research indicates that the incorporation of Nano-TiO2 into concrete generally results in an increase in compressive strength. For instance, Li et al. (2013) reported a significant increase in the compressive strength of concrete with the addition of 1% Nano-TiO2 by weight of cement. The improvement is attributed to the refinement of the pore structure and the enhanced hydration process mentioned earlier.

He positive impact on compressive strength, however, is highly dependent on the dosage of Nano-TiO2. Studies have shown that an optimal dosage typically ranges between 0.5% to 2% by weight of cement. Exceeding this optimal range can lead to agglomeration of the nanoparticles, which negatively affects the homogeneity of the concrete and may result in a reduction in compressive strength (Sobolev & Gutiérrez, 2005). This is due to the formation of weak zones within the concrete matrix where the agglomerated nanoparticles are concentrated.

The addition of Nano-TiO2 has been shown to enhance the tensile strength of concrete. Studies such as those by Hanus & Harris (2013) suggest that the increase in tensile strength can be attributed to the improved bonding between the cement paste and the aggregate, as well as the more refined microstructure.

Imilar to tensile strength, flexural strength benefits from the addition of Nano-TiO2. Research by Shaikh et al. (2017) indicates that concrete with Nano-TiO2 exhibits higher flexural strength compared to conventional concrete. This improvement is especially important for structural elements like beams and slabs, where flexural strength is a critical parameter.

Nano-TiO-modified concrete has shown improved resistance to environmental degradation, including resistance to freeze-thaw cycles, chemical attacks, and UV radiation. This enhanced durability is largely due to the reduced porosity and the denser microstructure, which limit the ingress of harmful substances such as water, chlorides, and sulfates (Sanchez & Sobolev, 2010).

Achieving a uniform dispersion of Nano-TiO2 within the concrete matrix is critical for realizing its mechanical benefits. Poor dispersion can lead to agglomeration, which creates weak spots in the concrete and negates the potential advantages. This challenge requires the use of advanced mixing techniques and possibly the incorporation of dispersing agents to ensure even distribution (Sikora et al., 2015).

The cost of Nano-TiO2 remains a significant barrier to its widespread adoption in the construction industry. Although the material cost is decreasing with technological advancements, it is still higher than that of traditional additives. This cost factor limits its use to high-performance and specialized applications where the enhanced mechanical properties justify the expense (Xu et al., 2019).

Chen et al. [46] reported the compressive strength at 3, 7 and 28 days of mortars modified two kinds of nano titanium dioxide, P25 (75 % anatase and 25 % rutile) and anatase (99 % anatase) were used. The NT was added to the cement at proportions of 0 %, 5 %, and 10 % by weight.

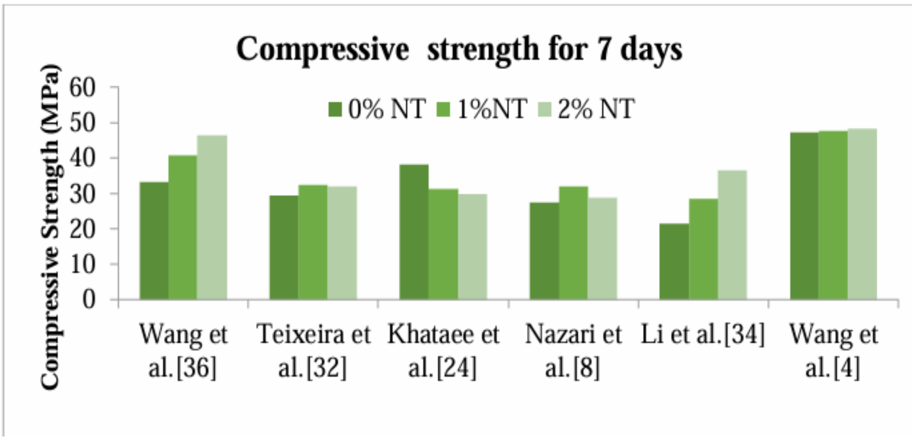

Figure 2.2

The effect of NT on the 7 days compressive strength of plain and blended concrete.

The influence of nano-titania on the compressive strength of concrete and mortar has been studied by some researchers. The results have shown that NT can have a very good effect on the compressive of such materials. Nazari et al. [72] conducted an experimental study on nano-titania effect on the compressive strength of plain concrete. Their results demonstrated that NT had a good effect on the compressive strength of concrete. Maximum enhancement of around 18% in strength was observed with 1.0 wt% nano-TiO2. Nazari et al. reported that the effect of NT on compressive strength got reduced with higher content, however, NT up to 2.0 wt% still had better performance than that of the plain concrete. These findings are consistent with what Zhang and Li [73] reported. However, Zhang and Li studied contents of NT up to 5.0 wt% and reported that such content didn't show any remarkable influence on the strength compared to the plain concrete. On the other hand, the findings of Behfarnia et al. [67] contradict the above findings. They stated that incorporation of NT into plain concrete led to reduction in the strength of plain concrete compared to mixes without NT. Their results showed that the least reduction in 28-day compressive strength was -16% and was observed in samples incorporating 3.0 wt% nano-TiO2, while the maximum reduction was around -27% and was observed for 2.0 wt% nano-TiO2. They ascribed this to the negative effect of titania nanoparticles on dicalcium silicate (C2S) hydration which contributes to properties of hydrated concrete at later ages. Some other scholars have investigated NT effect on the compressive strength of SCC. Jalal et al. [34] found that the use of NT increased the compressive strength of SCC at all studied ages and for all investigated contents of NT. The maximum enhancement in the compressive strength was observed for 4.0 wt% NT content. This content led to an increase of 22.5%, 22% and 26.9% in the 7, 28 and 90-day compressive strength, respectively. NT effect on the compressive strength of mortar has been also investigated by some researchers. Chen et al. [74] reported that higher content of NT (10 wt%) led to negligibly higher performance compared to lower content (5.0 wt%). On the other hand, [5,20,65,66,75] reported small content of NT (≤5.0 wt%) to be the optimum content. This content was observed to improve the strength by more than 15%. Mohseni et al. [66], who conducted an experimental study on the effect NT on the compressive strength of self compacting mortar incorporating a constant amount of fly ash (FA), demonstrated that NT increased the strength at all ages and for all studied replacement percentages. The best results were observed with 5.0 wt% replacement percentage, which caused an improvement of about 28%, 16% and 23% in the compressive strength in the 7th, 28th and 90th curing days, respectively. As stated before, enhancement in strength in this case could be attributed to the fact that titania nanoparticles enhance the microstructure properties by improving the homogeneity, enhancing the compaction, reducing the pore volume and size of cement based materials. It might also be related to the hydration acceleration effect of NT through increasing the surface area for product nucleation [20,31,32,35,40,44,52,56,60,63,72,81]. It has to be noted that while some papers, such as [31,32,72] stated that TiO2 nanoparticles lead to more formation of hydrated products, some others, such as [19,40,45,63,67,74,79,82] stated that NT is chemically inert and hence does not increase the amount of hydration products. On the other hand, the observed reduction in the compressive strength by increasing the content of nano-TiO2 more than the optimum content may be related to the agglomeration and bad dispersion of nanoparticles that lead to weak zones [31,34,44,55,72,78,81]. Trying to find the optimum content of NT in cementitious materials to improve their mechanical properties is hard, due to the lack of information related to its effect. However, to have an idea about the range of the optimum content of NT in concrete and mortar to improve their mechanical properties, we can compare the collected data from different publications, regardless of the different characteristics found in each one of them. Since the most investigated mechanical property is the compressive strength and to make the comparison much easier, the authors presented the data related to the compressive strength graphically in Fig. 1. Comparing the results presented in Table 1 and Fig. 1, we can roughly say that the optimum content of NT to enhance the mechanical properties of mortar and concrete is 1.0-5.0 wt%.

The results indicated a gain in the compressive strength at all ages with the addition of NT. Khataee et al. [79] investigated the compressive strength of pastes modified with NT at ages of 1, 3, 7, 14 and 28 days. Cement was admixed with NT at levels of 0 %, 5 % and 10 % by weight. The results indicated an increment in the compressive strength of 1, 3 and 7 days with the addition of 5 % NT, while a reduction in the compressive strength at 28 days was found. The increment was obtained in the 1 and 7 days compressive strength with the addition of 10 % NT, while a loss in compressive strength was obtained at the remaining ages. Li et al. [92] observed an increase in the compressive strength by addition 5 % and 10 % NT in calcium phosphate cement. Meng et al. [102] investigated the compressive strength of mortars admixed with NT at ages of 1, 3, 7 and 28 days.

2.2 Durability and Long-Term Performance

The addition of Nano-TiO2 to concrete has been shown to improve its durability, particularly in terms of resistance to environmental degradation. According to Li et al. (2013), concrete containing Nano-TiO2 exhibited superior resistance to UV radiation, reducing the rate of surface weathering and maintaining its structural integrity over time. Moreover, the photocatalytic activity of Nano-TiO2 contributes to the breakdown of organic materials that could otherwise accelerate concrete deterioration. This aspect is particularly valuable in urban environments, where concrete structures are exposed to pollutants and harsh weather conditions (Parkin & Palgrave, 2005).

Reports on the effect of NT on the durability of cementitious materials have revealed that NT importantly improves the durability of cement-based materials. Use of nanoparticle has been found to lead to a denser and mor homogenous microstructure due to their role as nano fillers and as nucleation sites due to their high surface area. This leads to smaller pore sizes and as a result to a lower permeability and a higher durability However, higher content of NT has been reported to lead to a reverse effect on the durability [85,86]. In this section, the effect of NT on durability is evaluated using some of the commonly investigated durability parameters; namely, permeability, ultrasonic pulse velocity, electrical resistivity, carbonation resistance, freeze and thaw resistance and sulfate attack resistance.

2.3 Environmental and Aesthetic Benefits

One of the most notable benefits of incorporating Nano-TiO2 in concrete is its ability to reduce air pollution. Research by Ballari et al. (2010) demonstrated that concrete surfaces treated with Nano-TiO2 could significantly reduce the concentration of nitrogen oxides (NOx) in the surrounding air, contributing to improved air quality in urban areas. Additionally, Nano-TiO2 imparts self-cleaning properties to concrete surfaces, as explored by Pacheco-Torgal et al. (2014), reducing the need for chemical cleaners and maintenance.
In terms of aesthetics, Nano-TiO2 helps maintain the whiteness and brightness of concrete, preventing discoloration caused by environmental pollutants. This property is particularly valued in architectural and decorative concrete applications, where visual appeal is critical (Hong et al., 2012).

2.4 Challenges and Limitations

Despite the advantages, the use of Nano-TiO2 in concrete is not without challenges. The high cost of Nano-TiO2 compared to traditional concrete additives is a significant barrier to its widespread adoption (Sanchez & Sobolev, 2010). Additionally, concerns about the potential toxicity and environmental impact of Nano-TiO2 particles persist, particularly regarding their long-term behavior in the environment and the potential health risks associated with nanoparticle exposure during manufacturing and application (Meng et al., 2016).
Another challenge is achieving uniform dispersion of Nano-TiO2 in the concrete matrix. As noted by Sikora et al. (2015), effective dispersion is crucial for realizing the full benefits of Nano-TiO2, yet it requires specialized mixing equipment and techniques, which can complicate the construction process.
Future research on Nano-TiO2 in concrete should focus on addressing the current challenges, particularly in terms of cost reduction and environmental impact assessment. Exploring the use of alternative, more cost-effective synthesis methods for Nano-TiO2 could make its application more economically

viable (Xu et al., 2019). Additionally, more comprehensive studies are needed to evaluate the long-term environmental impact of Nano-TiO2, including its potential to accumulate in ecosystems and its effects on human health.

Further research is also required to improve the dispersion techniques for Nano-TiO2 in concrete, ensuring that the material's benefits are consistently realized in practical applications. The development of hybrid nanomaterials, combining Nano-TiO2 with other nanomaterials, could open new avenues for enhancing the multifunctionality of concrete, potentially leading to smarter and more sustainable construction materials (Lu et al., 2018).Gailius et al. investigated the ongoing behaviour of fly ash-containing concretes under a chloride exposure regime. Chloride penetration was simulated by subjecting materials to repeated salt solution loading, drying, or freeze-thaw cycles in the presence of salt chloride. Rapid test results for concrete resistance to chloride penetration were compared with those obtained from the long-term monitoring of electrical resistivity changes (RCMT). The resistivity was monitored over a 12-month period, and after 28, 90 and 180 d of curing, a quick test was used to assess the resistance to chloride penetration

1.3 Conclusion :

NT may significantly enhance the resistance of mortar and concrete against water, chloride, and gas infiltration. This pertains to the function of nano-TiO2 in enhancing the microstructural characteristics of mortar and concrete, as shown by the SEM studies.

Substituting cement with a suitable proportion of NT may enhance the UPV, electrical sensitivity, and resistance to sulphate attack in cementitious composites. Nonetheless, NT may result in a diminished resistance of cementitious materials to carbonation. Nano-titania enhances the sustainability and longevity of buildings while decreasing maintenance and repair expenses by optimising the performance of cement-based materials. The inclusion of a large proportion of nanoparticles may adversely affect the characteristics of cementitious composites owing to inadequate dispersion and agglomeration. Identifying an optimal composition for the integration of nano-titania into cement-based products is very challenging. This is due to a significant lack of knowledge on the impact of NT on various characteristics of cementitious composites. Furthermore, some conflicting evidence has been identified in the literature. The optimal NT content is 1.0-5.0 wt%. Further study in this area is of significant relevance. Future study is advocated to identify answers for issues associated with the use of NT, including possible effects on human well-being, elevated costs, and nanoparticle agglomeration. Further study is necessary to enhance our understanding of the impact of NT on the characteristics of cementitious composites. Further study is necessary to investigate the impact of NT on freeze-thaw resistance and carbonation resistance. Furthermore, the durability and long-term cost efficiency of using NT in cement-based products need examination. Further investigation on the impact of NT on the dynamic characteristics of cementitious materials is necessary. Further study is required to develop equations that depict the correlation between the characteristics of cementitious composites and the concentration of NT. Research analogous to the present study including different nano-additives may serve as subjects for future investigations.

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