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# A comprehensive review on the application of nano materials in concrete

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## ABSTRACT

This review paper discusses the use of nano materials in concrete. In recent years, the application of nano materials has received considerable attention for enhancing the properties of conventional concrete. The primary purpose of incorporating nano materials into concrete is to improve its strength and durability. A nano material is defined as a material containing particles smaller than 200 nm. However, for concrete studies, the effective particle size is typically up to 500 nm. The addition of ultrafine nano materials can reduce cement consumption by partially replacing cement on a weight basis, thereby improving the binding effect. These ultrafine particles also act as fillers, reducing the formation of micro pores and producing a denser concrete matrix, which in turn minimizes the growth of micro cracks in ultra-high-performance concrete (UHPC) structures.

**Keywords**— Nano materials, Nano silica, Nano alumina, Nano clay, Nano kaolin

## 1. INTRODUCTION

The evolution of concrete began with normal-grade concrete, typically ranging from Grade 5 to Grade 45 [1,2]. These grades were widely used during the early 1900s for construction purposes and provided adequate strength for general applications. To achieve the desired design strength, normal-grade concrete generally contained less than 380 kg/m<sup>3</sup> of cement, granite-type coarse aggregates, a moderate water requirement, and a small dosage of super plasticizer [3]. By the 1960s, as more complex structural designs emerged and structures began to carry loads exceeding 50 MPa—up to 95 MPa [4,5]—a new generation of concrete technology was developed, known as High-Strength Concrete (HSC). HSC typically exhibits compressive strengths between 50 MPa and 90 MPa [6,7]. It became widely used in high-rise buildings, bridges, and heavy-load-bearing structures. In terms of mix proportion, HSC requires a higher cement content, a greater number of fine aggregates, reduced water content, and an adequate quantity of super plasticizer. To achieve these properties, various additives and supplementary cementitious materials such as silica fume, fly ash (FA), and metakaolin (MK) have been

incorporated [8–10]. Silica fume gained popularity in HSC mixtures due to its ability to significantly increase strength when used at an optimal percentage of cement replacement [10–14]. In contrast, fly ash enhances the flowability of the mix and serves as a natural admixture. It can also act as a cost-effective alternative to super plasticizers when used in higher dosages [15–18]. Metakaolin, a calcined form of kaolin clay, began to be used as a cement replacement material in the early 1990s [19–23]. Its clay-based structure provides the advantage of reducing water permeability in concrete. Table 1 summarizes the differences in mix proportions among normal concrete, high-strength concrete (with silica fume), and ultra-high-performance concrete (UHPC) mixes reported in previous studies. Notably, an increase in cement content is evident across these three types of concrete. Additionally, other parameters such as aggregate content, admixture dosage, water-to-cement ratio, and slump also vary significantly.

## 2. NANO CONCRETE DEVELOPMENT

Nano concrete refers to concrete that incorporates nano materials—particles with sizes smaller than 500 nm [6,26–31]. The inclusion of nano particles in concrete has been found to significantly enhance the strength and performance of conventional concrete. Nano particles improve the bulk properties of concrete through a mechanism known as the packing model, where ultra-fine particles fill voids within the cement matrix. These ultrafine or nanosized particles act as highly effective fillers by refining the interfacial transition zone (ITZ) between cement paste and aggregates, resulting in a denser microstructure. This filler effect leads to improved particle packing, reduced micro voids, and decreased porosity. Consequently, defects commonly observed in traditional concrete microstructures—such as micro voids, high porosity, and deterioration due to alkali-silica reactions—are minimized. Moreover, when nano particles serve as binding agents smaller than cement particles, they enhance the formation and structure of hydration products. This modification results in a more compact and stable calcium-silicate-hydrate (C–S–H) gel,

producing a well-structured and durable concrete matrix. The combination of the filler effect and chemical interactions during hydration gives rise to a new class of materials known as nano concrete, characterized by superior strength and durability [5,32,33]. The implementation of nanotechnology in concrete began in the early 2000s, driven by the growing demand for Ultra-High-Performance Concrete (UHPC). Traditional UHPC mixes that incorporated silica fume showed improved strength and durability. However, due to the limited availability and high cost of silica fume, the application of UHPC technology became less widespread compared to High-Strength Concrete (HSC). Advancements in nanotechnology have since led to the development of alternative materials that replicate the role of silica fume. One of the most significant innovations is nano-silica, which has emerged as an effective substitute for silica fume [34]. Following this breakthrough, various other nano materials have been introduced for use in concrete, including nano-alumina [35], titanium dioxide (TiO<sub>2</sub>) [36], carbon nano tubes (CNTs) [37] and polycarboxylates [38]. The following subsection discusses the production methods and applications of these nano materials in concrete systems.

### 3. NANO MATERIALS PRODUCTION

Since the emergence of nanotechnology in the late 1960s, the concept and process of producing nano materials have continuously evolved. Due to their extremely small particle size, nano particles exhibit a much greater filler effect compared to micro-scale materials. According to Guterrez [39], virtually all materials can be transformed into nano particles. The successful formation of nanoparticles depends on maintaining the purity and basic chemical composition of the parent material during processing. Two primary approaches are used in the production of nano materials: the top-down approach [40] and the bottom-up approach [41]. The selection between these methods depends on factors such as cost, material characteristics, and available expertise in handling nano materials [2,24,25].

#### 3.1. Top-Down Approach

The top-down approach involves breaking down bulk materials into nano scale particles while preserving their original chemical composition and structural integrity at the atomic level [1,42]. In this method, larger particles are mechanically reduced in size through processes such as milling, etching, and mechanical attrition. Milling is the most widely used technique due to its practicality, cost-effectiveness, and ease of maintenance, as it primarily relies on mechanical operations rather than chemical or electronic processes. However, this method often produces nano particles with non-uniform size and inconsistent quality. The efficiency and final product quality of milling depend on several parameters, including the number and type of balls, milling speed, and type of milling jar used [40,43,44]. High-energy ball milling is particularly effective in synthesizing various nano structured materials such as nano materials, nano grains, nano alloys, nano composites, and nano-quasi crystalline materials. The technique was pioneered by John Benjamin in the 1970s, who used to mill to produce oxide particles in nickel super alloys for high-temperature

structural applications [45]. During milling, key processes such as plastic deformation, cold welding, and fracture contribute to the transformation of materials into the desired nanostructures. In addition to reducing particle size, milling can blend materials and induce new material phases. Typically, the final products of milling appear as flakes, although refinement is possible depending on milling conditions.

#### 3.2. Bottom-up approach

In contrast, the bottom-up approach fabricates nano materials by assembling atoms or molecules into nano scale structures through chemical synthesis or self-assembly processes [24]. This approach is also known as molecular nanotechnology or molecular manufacturing. The bottom-up method allows precise control over the size, shape, and morphology of nano particles, resulting in highly uniform and crystalline structures. Nano particles produced using this method often exhibit superior properties due to their orderly atomic arrangement. The approach involves techniques related to electronic conductivity, optical absorption, and chemical reactivity [25,46]. Furthermore, it enhances surface characteristics by improving surface energy, morphology, and reactivity, enabling broad applications in areas such as catalysis, sensor development, self-cleaning coatings, and smart materials. Despite its advantages, the bottom-up approach is generally more expensive, requires specialized chemical expertise, and is mostly limited to laboratory-scale production [39,47,48]. Nevertheless, it is the preferred technique for producing advanced nano materials used in electronics, biotechnology, and high-performance concrete systems such as UHPC.

### 4. UHPC APPLICATION OF NANOMATERIALS

Since the breakthrough of nanotechnology in the field of construction, various nano materials have been incorporated into concrete. As discussed in earlier sections, the use of nano materials significantly enhances the performance and durability of concrete. This subsection further elaborates on the types of nano materials reported by previous researchers and their specific applications in Ultra-High-Performance Concrete (UHPC).

TABLE 1: SUMMARY OF KEY PROPERTIES OF DIFFERENT TYPES OF CONCRETE AS REPORTED IN PREVIOUS STUDIES

	Compressive strength	Flexural strength	Porosity in %	Water absorption in %	Remark
Concrete (normal)	10-40	1 - 10	<30	<30	Mehta and Monteiro [3]
Concrete (High Performance)	41–100	11-20	12 - 25	12-25	Hamid, Yusof [49], [50,51]
Concrete (Ultra High Performance)	100	20-30	<10	<12	Hartmann [52], [53,54]
Nanomaterial infused Concrete	70	12-20	<10	<12	Aïtcin [26], Chong [28]

## 5. NANO SILICA

Nano-silica represents a significant breakthrough in the application of nano materials for Ultra-High-Performance Concrete (UHPC). It is generally produced from micro-based silica through controlled size reduction processes. The chemical and physical reactions induced by nano-silica in UHPC are comparable to those of silica fume or micro-silica, particularly in enhancing mechanical strength and durability [55–57]. Studies by Qing and Zenan [56] revealed that concrete incorporating nano-silica achieves higher early-age strength than that containing silica fume. Moreover, the inclusion of nano-silica improves the workability of concrete even when only a minimal dosage of super plasticizer is used. This improvement is attributed to the spherical morphology of nano-silica particles, which act as *ball bearings* within the cement matrix, facilitating particle dispersion and reducing internal friction. Due to its ultrafine particle size, nano-silica acts as an excellent filler, refining and densifying the concrete microstructure by minimizing micro voids and pores [58,59]. Other notable advantages include improved control of the water-to-cement ratio and the ability to achieve desired target strengths through precise dosage adjustments. According to Quercia and Hüsken [60],

nano-silica not only enhances the strength of High-Strength Concrete (HSC) but can also serve as a partial cement replacement material. Their study reported that up to 20–30% of cement could be replaced with nano-silica without compromising mechanical or durability performance, making it a promising alternative binder. However, the primary limitation of nano-silica is its high production cost and limited availability. In many regions, nano-silica must be imported for use in the concrete industry, which can restrict its large-scale adoption [4].

## 6. NANO ALUMINA

Silica and alumina are two major chemical components involved in the cement hydration process. While silica primarily contributes to the strength development of cement, alumina plays a key role in controlling its setting time. Nano-alumina, derived from alumina itself, has recently gained attention for its potential role in improving the performance of Ultra-High-Performance Concrete (UHPC). Although research on the use of nano-alumina in concrete is still limited, existing studies indicate that its incorporation can significantly influence the fresh and hardened properties of UHPC [61–64]. The primary function of nano-alumina is to accelerate the initial setting time, thereby minimizing issues such as segregation and flocculation during mixing. This ensures a more homogeneous distribution of cement particles within the matrix, improving overall performance. In UHPC, nano-alumina acts as a dispersion agent that enhances the distribution of cement grains. Due to its nanoscale size, it also functions as a microstructure refiner, filling voids within the hydration gel and densifying the cementitious matrix. Given the high cement content in UHPC, proper dispersion of cement particles must occur in conjunction with the hydration reactions of silica. Without the refining influence of nano-alumina, the hydration process may proceed more slowly because silica particles are unable to effectively penetrate the internal structure of the hydration gel. The addition of nano-alumina creates pathways within the gel structure, allowing silica and other binding materials to infiltrate more efficiently, thus promoting a faster and more complete hydration process [27,62,65].

## 7. CARBON NANO TUBES

Carbon Nanotubes (CNTs) are allotropes of carbon characterized by their cylindrical nanostructure. They possess an exceptionally high length-to-diameter ratio—reported to reach up to 132,000,000:1—which far exceeds that of any other known material. These cylindrical carbon molecules exhibit remarkable mechanical, electrical, and thermal properties, making them highly valuable in nanotechnology, electronics, optics, and various fields of materials science and engineering [1,39,66]. CNTs belong to the fullerene structural family, and their name derives from their long, hollow, tube-like geometry. The walls of a nanotube consist of one-atom-thick sheets of carbon atoms arranged in a graphene lattice. These graphene sheets are rolled into tubes at specific angles, with the rolling angle and tube radius determining the nanotube's unique properties [37]. Based on their structure, CNTs are generally classified as Single-Walled Nanotubes (SWNTs) or Multi-Walled Nanotubes (MWNTs). Individual nanotubes tend to

align naturally into bundles or “ropes”, held together by van der Waals forces—specifically  $\pi$ -stacking interactions [67,68]. The chemical bonding within CNTs is similar to that of graphite, consisting of strong  $sp^2$  carbon-carbon bonds, which are stronger than those found in alkanes or even diamond. This bonding structure contributes to their exceptional tensile strength and stiffness. In the context of Ultra-High-Performance Concrete (UHPC), the incorporation of CNTs offers several advantages. One of the key benefits is their flexibility, which allows UHPC designs to be tailored for both rigid and ductile structural applications. The inclusion of CNTs enhances both the tensile and compressive strength of UHPC, making it one of the most effective nanomaterials for simultaneously improving strength and flexibility [37]. Additionally, the small size and low dosage requirement of CNTs provide efficient reinforcement without significantly increasing the overall material volume. The integration of CNTs into UHPC can potentially reduce or replace conventional steel reinforcement, thereby enabling the design of lightweight, high-strength structures capable of withstanding greater loads [69]. This substitution also offers potential benefits in terms of reducing construction time and overall costs. However, despite their outstanding properties, the widespread use of CNTs in UHPC remains limited due to several challenges. The high cost of production, limited availability, lack of standardized guidelines, and need for specialized expertise in dispersion and handling make CNTs less feasible for large scale concrete applications at present.

## 8. POLYCARBOXYLATES

Polycarboxylates (PCE) represent one of the most widely utilized nanomaterials in modern concrete technology [70]. In general, PCE is a polymer-based compound composed of a methoxy-polyethylene glycol copolymer, which functions as a side-chain component, and a methacrylic acid copolymer, which forms the main backbone. The carboxylate groups within the polymer structure contain water molecules that impart a negative charge along the PCE backbone, while the polyethylene oxide side chains exhibit a non-uniform electron cloud distribution, introducing chemical polarity into the molecule. The length and number of side chains in the polymer structure are flexible and can be easily adjusted to tune the performance of PCE. However, excessive side-chain branching or high electron unit density can lower the molar mass and alter the polymer density, resulting in reduced performance in cement suspensions. Optimal performance is achieved when long side chains and high charge density are properly balanced, allowing effective interaction and pairing between polymer chains. In concrete applications, polycarboxylates are primarily used as high-range water reducers (HRWRs). The inclusion of PCE enables precise control of workability even at low water-to-cement ratios, a key requirement for Ultra-High-Performance Concrete (UHPC). The performance of PCE, however, is highly dosage-dependent; excessive amounts may lead to false setting or inhibited cement hydration [71]. At appropriate dosages, PCE can facilitate the production of Self-Compacting Concrete (SCC), which exhibits superior flowability and ease of placement, especially in densely reinforced or complex formworks.

Another major advantage of PCE-modified concrete is its applicability in marine and aggressive environments. The ability of PCE to reduce air bubbles and refine the pore structure enhances the density and impermeability of UHPC. Consequently, this minimizes the ingress of chlorides and sulphates, thus improving resistance to seawater-induced deterioration. Moreover, PCE offers a more environmentally friendly alternative to traditional materials such as silica fume for refining UHPC micro structure. Studies by Sobolev (2005) demonstrated that the use of PCE in High-Strength Concrete (HSC) significantly enhances workability and mechanical performance compared to mixes containing silica fume. Similarly, research by Crainic (2002) reported that incorporating PCE at approximately 2.5% of cement weight led to a rapid increase in early-age strength, with compressive strengths rising from 40 MPa to 80 MPa on the first day and reaching 70–100 MPa at 28 days, even at lower dosages. These findings confirm that PCE can serve as an effective alternative admixture for enhancing the strength, durability, and workability of UHPC. Due to its ease of use, minimal handling requirements, and consistent performance, PCE has become one of the most popular and practical nano materials for UHPC applications.

## 9. TITANIUM DIOXIDE

Titanium dioxide ( $TiO_2$ ), also known as titania, is the naturally occurring oxide of titanium. When used as a pigment, it is commonly referred to as titanium white.  $TiO_2$  is primarily derived from minerals such as ilmenite, rutile, and anatase, and is widely used across various industries including paints, coatings, sunscreens, and food coloring. In nature, titanium dioxide exists mainly in three mineral forms—rutile, anatase, and brookite—while two additional high-pressure polymorphs, a monoclinic baddeleyite-like form and an orthorhombic form, have been identified at the Ries crater in Bavaria [67,72]. Among its sources, ilmenite ore is the most abundant, whereas rutile ore, containing up to 98%  $TiO_2$ , is the richest in titanium content. The metastable forms anatase and brookite transform into the stable rutile phase when heated to temperatures between 600°C and 800°C [25,73]. The incorporation of  $TiO_2$  nanoparticles in Ultra-High-Performance Concrete (UHPC) and conventional concrete has shown significant benefits, particularly in enhancing self-cleaning properties and promoting sustainable construction practices [74]. The photocatalytic activity of  $TiO_2$  enables it to break down organic pollutants and surface contaminants upon exposure to ultraviolet light, resulting in a self-cleaning effect. This property has been successfully utilized in various applications such as building facades, pavements, and architectural finishes, notably demonstrated in the Jubilee Church (Rome, Italy) [25]. Beyond its self-cleaning capability,  $TiO_2$  also contributes to early-age strength development, improved abrasion resistance, and overall durability enhancement of concrete [75]. These effects are attributed to the ability of  $TiO_2$  to form a thin glass-like or pigment layer around cement particles, which interacts with the hydration products during mixing. This layer acts as a protective and reactive coating, refining the microstructure and imparting self-cleaning characteristics to the concrete surface. Additionally,  $TiO_2$  nanoparticles can reinforce the

cement matrix by acting as nano-fibers, similar to the effect of glass fibers, leading to a denser microstructure and improved mechanical performance [76]. However, health and safety concerns associated with TiO<sub>2</sub> remain a significant issue. Although environmental pollution due to TiO<sub>2</sub> has not been widely reported, inhalation of fine TiO<sub>2</sub> dust particles during manufacturing and handling poses potential respiratory and carcinogenic risks to factory workers [75]. Consequently, strict safety measures should be implemented during the production, packaging, and mixing processes to mitigate these risks.

## 10. NANO KAOLIN

Nano kaolin is a derivative of kaolin, also known by its chemical name kaolinite, which is a clay mineral belonging to the family of industrial minerals with the chemical composition Al<sub>2</sub>Si<sub>2</sub>O<sub>5</sub>(OH)<sub>4</sub>. Kaolinite is a layered silicate mineral, consisting of one tetrahedral silica sheet linked through oxygen atoms to one octahedral alumina sheet [77,78]. Rocks rich in kaolinite are commonly referred to as kaolin or china clay [79]. It is a white dioctahedral phyllosilicate clay mineral, typically formed through the chemical weathering of aluminum silicate minerals such as feldspar [77,80]. In mineralogy, the chemical formula of kaolinite is represented as Al<sub>2</sub>Si<sub>2</sub>O<sub>5</sub>(OH)<sub>4</sub>, while in ceramic applications, it is often expressed in terms of oxides. Upon heat treatment (endothermic dehydration), kaolin transforms from a crystalline to an amorphous phase, producing a new form of clay known as metakaolin [81]. Metakaolin comprises amorphous silica and alumina arranged in hexagonal layers, and it is widely recognized as a highly reactive pozzolanic material [79,82]. Compared to silica fume, metakaolin offers several advantages, including improved strength and durability, refined microstructure, enhanced resistance to water penetration, and cost-effectiveness [19,20,83–85]. Nano kaolin can be synthesized using either the top-down or bottom-up approach, and the choice of method significantly influences its final morphology. The formation process primarily involves the layering or stacking of flaky particles. Although kaolin and nano kaolin share a similar particle structure, the reduction in size from micro to nano scale greatly increases the specific surface area of the particles, enhancing their reactivity. For application in concrete, nano kaolin typically undergoes further treatment to form nano metakaolin, which is a more reactive and stable compound. Although the use of nano metakaolin in concrete is relatively recent, studies have reported encouraging results. According to Morsy et al. [86], the incorporation of nano metakaolin in mortar resulted in approximately 8–10% improvement in compressive strength, while tensile and flexural strengths increased by 10–15% compared to ordinary Portland cement (OPC) mixes [86,87]. These enhancements are attributed to the filler effect, pore refinement, and improved interfacial bonding between the cement matrix and aggregates. Despite its potential benefits, the application of nano metakaolin in UHPC remains limited due to scarcity of raw kaolin resources in some regions and the lack of standardized production guidelines. To maximize its potential as an alternative nanomaterial for concrete, further research and development are required to establish commercial

production methods and optimize its mix design compatibility.

## 11. NANO CLAY

Nano clay refers to nanoparticles derived from layered silicate minerals. Depending on their chemical composition and nanoparticle morphology, nanoclays are classified into several types, including montmorillonite, bentonite, kaolinite, hectorite, and halloysite. Among these, montmorillonite-based nanoclay is the most widely studied and economically viable, offering promising results in both polymeric and cementitious systems. Nanoclay typically possesses a platelet-like structure, with an average thickness of about 1 nm and a lateral dimension ranging from 70 to 150 nm. This unique layered morphology provides several advantageous properties such as high surface area, interlayer spacing, excellent swelling and hydration capacity, and strong chemical reactivity, all of which make it suitable for nano technological manipulation. Characterization of nanoclays and their organically modified derivatives can be performed using a combination of traditional and advanced analytical techniques, including gravimetric analysis, inductively coupled plasma (ICP), X-ray fluorescence (XRF), cation exchange capacity (CEC) determination (typically using the ammonium acetate method), surface area analysis, Fourier Transform Infrared Spectroscopy (FTIR), and Powdered X-ray Diffraction (PXRD) [58,88–90]. The purity and cation exchange capacity of clays are critical factors influencing the performance of the resulting nanocomposites. Therefore, it is important to minimize impurities such as crystalline silica (quartz), amorphous silica, calcite, and kaolin [77,88]. Common purification techniques include hydrocycloning, centrifugation, sedimentation, and chemical treatment [78,82]. From an economic perspective, clay is an inexpensive and widely available material, making nanoclay a cost-effective option for use in concrete. However, despite its abundance, standardized methods and guidelines for converting clay into nanoclay suitable for construction applications remain underdeveloped. Further research is required to fully explore the advantages and limitations of nanoclay in cementitious materials. In polymeric systems, nanoclays have already demonstrated significant improvements in stiffness, thermal stability, and barrier properties. In the context of concrete, nanoclay is primarily used as an additive to enhance mechanical and durability performance. Morsy et al. [86] reported that the inclusion of nanoclay in mortar increased both compressive and tensile strengths, while also improving the thermal behavior of cement paste [91,92]. These enhancements are attributed to the filler effect and pore refinement mechanisms, which lead to a denser and more durable concrete microstructure.

## 12. RESULTS AND DISCUSSIONS

A review of the existing literature indicates that the incorporation of nano materials in concrete generally enhances several technical properties of cement-based materials, although it may also introduce certain drawbacks, such as increased water demand. Studies have reported the use of various nano materials in concrete, including nano-silica, nano-alumina, and nano-titanium oxide, which have been the focus of current research on nano-based concrete

development. The addition of these nano materials produces effects similar to those observed with micro-scale additives such as metakaolin and silica fume—namely, pore refinement and improvements in strength and durability. The primary distinction lies in the particle size, which is reduced to the nano scale. Given that micro-scale materials have been shown to enhance concrete's strength and durability, it is expected that the use of nano particles would lead to further improvement of these properties. However, the application of nano-meta kaolin and nano-meta clay in concrete has not yet been extensively explored, highlighting a need for further investigation. According to existing studies, meta kaolin used as a partial cement replacement in ultra-high-performance concrete (UHPC) provides effects comparable to those of silica fume, contributing to improved concrete performance.



FIGURE-1: KEY INSIGHTS OF USING NANO MATERIALS IN CONCRETE

### 13. CONCLUSION

**1. Improvement of Concrete Properties:** The use of nano materials like nano silica, alumina, and titanium oxide has been shown to improve certain technical properties of cement-based materials. These improvements primarily include enhanced strength and durability.

**2. Similar Effects to Micro Materials:** Nano materials have a similar effect to micro-based materials, such as metakaolin and silica fume, in terms of pore refinement and the enhancement of concrete's strength and durability. The difference lies in the size of the materials—nano materials are smaller in scale, which could offer more refined effects.

**3. Nano Scale vs. Micro Scale:** The key difference between nano materials and their micro counterparts is their size. The smaller size of nano particles means they might penetrate the concrete matrix more effectively, potentially resulting in superior improvements.

**4. Water Demand:** One challenge mentioned is that nano materials might increase water demand in concrete, which is a factor to consider when incorporating them into mixes.

**5. Unexplored Areas:** Despite the known benefits of nano silica and similar materials, the use of nano metakaolin and nano metaclay in concrete has not yet been fully explored. This opens up avenues for further research to evaluate their potential effects.

**6. Metakaolin in UHPC:** Metakaolin, when used as a cement replacement in ultra-high-performance concrete

(UHPC), reportedly has effects similar to those of silica fume in improving concrete properties. This suggests that metakaolin could be an effective material, though the use of its nano version remains unexplored.

This literature review points to the potential of nano materials in concrete (Fig. 1) but also highlights areas that need further research. Investigating the inclusion of nano metakaolin and nano meta clay in concrete mixes could lead to more optimized formulations.

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