A REVIEW OF THE WORKABILITY AND MECHANICAL PROPERTIES OF HIGH-PERFORMANCE CONCRETE WITH SCM's AND NANOMATERIALS

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ABSTRACT

A lot of research has been done on the use of nanomaterial's in high-performance concrete (HPC) because of their huge surface areas, small particle sizes, filling effects, and macro quantum tunneling effects. The addition of nanoparticles to HPC has a significant positive impact on the cementitious matrix's pore size, cement hydration, and matrix density. This paper described recent advances in HPC and examined the effects of various nanomaterial's on HPC properties based on more than 100 recent studies in order to provide a thorough understanding of the viability of HPC reinforced with nanomaterials. The attributes of HPC containing nanoparticles, including their fresh and hardened characteristics are thoroughly examined. Additionally, HPC enhanced with nanomaterials was contrasted with conventional concrete, yielding a wealth of useful information. The findings of the present review show that adding different nanomaterial's enhances HPC's mechanical characteristics while decreasing its workability. The right amount of nanomaterial can, however, help HPC's mechanical properties. In the future, it is anticipated that adding nanomaterial's to HPC will become a common practise to enhance its capabilities. The application of this new HPC in contemporary civil engineering can be encouraged by this literature review in particular along with Supplementary Cementitious Materials (SCM's) like Nano-Silica(NS), GGBS and Alcoffine are presented and reported, which can offer researchers and engineers working on HPC thorough and organised knowledge.

Keywords: Nano-materials, Filling Effects, Alcoffine, Fly Ash, GGBS

1.0 Introduction

High-performance concrete is characterised as having strength and durability that are much higher than those attained using conventional methods. Hence, the qualities of regular concrete that are attainable at a specific time and place determine the qualities necessary for concrete to be categorised as high performance.

Although concrete structure has a more recent development history than masonry and wood structures, it has become increasingly popular worldwide since the middle of the 19th century due to its advantages over other building materials, including their high strength, high elastic modulus, good plasticity and workability, wide availability of raw materials, convenient local resources, and ease of construction. One of the most frequently used and consumed building materials worldwide is concrete material. It has significantly aided in the growth and advancement of human civilization [1]. The basic difference between HPC and HSC(High Strength Concrete) is HPC is defined based on performance parameters, specifically high durability, high strength, and high workability. HSC is characterised based on its compressive strength at a certain age. is Concrete that is strong, stiff, long-lasting, and crack-resistant is increasingly in demand as modern civil engineering projects progress toward towering, long-span bridges and significant water conservation projects. Traditional concrete, however, is unable to satisfy these demands. Due to this problem, high-strength concrete (HSC), a new type of concrete with a load capacity of up to 90 MPa, was created [2-3]. The creation of high-performance concrete (HPC) and then ultrahigh-performance concrete (UHPC) allowed for the building of structures that could withstand the rigorous structural design and durability standards of contemporary construction projects. Due to its superior performance in terms of workability, durability, strength, and volume stability compared to traditional concrete, HPC is now the most complete type of concrete. Additionally, it is getting more attention in civil engineering construction, and it is anticipated that it will eventually become a direction for concrete technology development [4–8]. To ensure outstanding mechanical qualities, durability, and consistent working performance, HPC is made up of more cementing materials, well-graded aggregates, less water, and high-efficiency water-reducing agents. There aren't any traditional concrete preparation materials or techniques [9]. High performance can be achieved by admixing materials such fly ash (FA), silica fume, slag powder, metakaolin, and other volcanic ashes with concrete [10, 11] [12–14]. These mineral powder active ingredients can improve a number of concrete qualities when mixed with HPC. It will primarily replace some cement, which can accomplish waste recycling, lower carbon dioxide emissions, and safeguard the environment [15]. Silica fume(SF), which has a large specific surface area and a quick pozzolanic reaction speed compared to other pozzolans, can successfully substitute cement and increase the strength of concrete [16–20]. Additionally, fly ash is a popular mineral admixture. It mostly consists of tiny, aluminate glass beads with smooth surfaces. FA can operate as a ball bearing when added to concrete, reducing the amount of water needed for the cement slurry while improving the workability of fresh concrete and increasing the compactness of hardened concrete [21–24].

Nanomaterials are a relatively recent class of material, with variations in Size, shape, specific surface area, aspect ratio,Agglomeration/aggregation state, Size distribution., Surface morphology/topography.Structure, including crystallinity and defect structure and Solubility. having been created in the early 1980s. Ultra-fine materials having particle sizes on the order of nanometers are referred to as nanomaterials (1–100 nm). They frequently exist in the zone between atomic clusters and macroscopic objects, and they can be made of a range of granular materials, including organic, inorganic, and biological ones [25]. Nanomaterials are materials with at least one dimension in the nanoscale range, typically between 1 to 100 nanometers (nm). This means they have unique physical and chemical properties that differ from their bulk counterparts. These materials may be made up of a variety of substances including metals, ceramics, polymers, or composites, and they can take on a range of shapes including nanoparticles, nanowires, and nanotubes. Due to their small size and unique properties, nanomaterials have many potential applications in fields such as electronics, medicine, energy, and environmental remediation. Nanomaterials are made of tiny particles with a lot of distinct surfaces. When the particle size is as small as 10 nm, the surface atom proportion is 20%, and the number of atoms scattered on the particle surface dramatically rises as the particle size decreases. When the particle size is as small as 10 nm, the percentage of surface atoms is 20%, and as the particle size decreases, the number of atoms scattered on the surface of the particles rises dramatically. The surface effect, volume effect, filling effect, and other unique qualities of nanomaterials are produced when the particle size is 1 nm, when practically all of the atoms are concentrated on the surface of the particles. In contrast to conventional granular materials, ultrafine powder possesses a variety of peculiar mechanical, electrical, magnetic, catalytic, and optical properties. Nanomaterials have demonstrated impressive application potential as a novel material in fine ceramics, microelectronics, bioengineering, light industries, and medicine importance. The continuous filler of the cementitious material composition, is primarily responsible for the high performance of ultrafine particles in concrete [26]. Due of its finer granularity and high activity, silica fume gives UHPC superior strength and durability [17]. However, it produces little and costs a lot. In general, silica fume is not taken into account when the strength of the concrete is less than 80 MPa. Nanotechnology has created nanomaterials to replace silica fume due to the rising need for HPC. In large part because of their unique nanoeffects, nanomaterials are used in concrete.

The results indicate that the use of nanoparticles has improved the workability, mechanical characteristics, durability, and microstructure of concrete [27]. The comparison results for the capabilities of conventional concrete, HPC, UHPC, and nanoconcrete are shown in Table 1.

Table 1: A summary of findings regarding the performance of various types of concrete

Type of Concrete	Compressive strength (MPa)	Flexural Strength (MPa)	References
Normal Concrete	10-40	1-10	29
HPC	40-100	11-20	28
UHPC	100	20-30	31
Nano concrete mix	70	12-20	30

Several nanomaterials, including carbon nanotubes (CNTs) [40], nanometakaolin (NMK) [41], nano-SiO2 (NS) [32], nano-CaCO3 [33], nano-Al2O3 (NA) [34], nano-Fe3O4 (NF) [35], nano-TiO2 (NT), nano-ZnO2 [36], nano-limestone [38], and nano-FA [37-39], are utilised to use in concrete. With its high pozzolanic activity, NS, one of many nanomaterials, has effectively replaced the conventional silica fume, making it widely suitable in HPC. The calcium-silicate-hydrate (C-S-H) gel formed by the reaction of calcium hydroxide crystals distributed between the cement-based material matrix and aggregate can heighten the strength of the hardened cement stone matrix due to the high activity of NS, which is one of the important reasons why NS can significantly improve the mechanical strength of concrete [42].

Table 2: Physical characteristics of Nano Particles

Physical Property	**Description**
Size and surface area	Nanomaterials have at least one dimension in the nanoscale range (typically between 1 and 100 nanometers), which gives them a high surface area-to-volume ratio. This can lead to increased reactivity and surface energy.
Optical properties	Many nanomaterials exhibit unique optical properties due to their size and shape, such as fluorescence, plasmon resonance, and quantum confinement effects.
Mechanical properties	Nanomaterials can exhibit improved mechanical properties such as strength, stiffness, and ductility compared to bulk materials due to their small size and high surface area.
Chemical reactivity	The high surface area of nanomaterials makes them highly reactive and enables them to have unique chemical properties. They can act as catalysts for chemical reactions.

Electronic properties	The electronic properties of nanomaterials can differ from bulk materials, and they can exhibit unique electrical conductivity, dielectric properties, and energy band gaps.
Magnetic properties	Some nanomaterials can exhibit magnetic properties, and their magnetic properties can vary depending on their size and shape.
Thermal properties	Nanomaterials can have different thermal properties from bulk materials due to their size, shape, and high surface area. They can have high thermal conductivity or low thermal expansion, depending on the specific material

The characteristics of different nano materials that are studied are furnished here with

Table 3: Physical properties of different nano materials

Physical Property	**Nano Silica**	**Carbon Nanotubes**	**Nano Metakaolin**	**Nano Aluminium Oxide**	**Nano Fly Ash**
Particle size	1-100 nm	1-100 nm	10-100 nm	10-50 nm	1-100 nm
Aspect ratio	N/A	High aspect ratio (length to diameter)	N/A	N/A	N/A
Density	Low	Low	High	High	Variable
Electrical conductivity	Low	Excellent	Low	Low	Variable
Thermal conductivity	Low	High	Low	High	Variable
Tensile strength	N/A	Very high	N/A	N/A	N/A
Elastic modulus	N/A	Very high	N/A	Very high	N/A
Chemical stability	Chemically stable	Chemically stable	Chemically stable	Chemically stable	Chemically stable
Surface area	High surface area per unit volume	High surface area per unit volume	High surface area per unit volume	High surface area per unit volume	High surface area per unit volume

Numerous studies have discovered that nanomaterials are highly successful as cementing materials in improving the characteristics of concrete in recent years as a result of substantial study being undertaken on the performance of nano modified concrete. They greatly contribute to improving the performance of conventional concrete because they may both significantly lower the amount of cement and fill up material gaps. Therefore, the primary goal of this paper is to evaluate and summarise the most recent developments in the study of various nanoparticles in regular concrete and HPC. The workability, compressive strength, and tensile strength of nanoparticles in HPC under single or mixed conditions are also examined.

2.0 Workability

Workability is a broad technical attribute that is utilised to ensure that every building process runs smoothly and to get stable performance out of new concrete. A slump height of roughly 650 mm is considered appropriate for freshly laid concrete and a measure of adequate strength for high-quality concrete, according to earlier experimental study. In fact, within a particular range, the greater the slump, the better the workability, suggesting that concrete can flow readily without segregation. Due to its capacity to self-compact, fresh concrete needs to be sufficiently workable to provide maximum strength; for this reason, managing the workability of concrete is important. Important parameters for assessing high-performance concrete include slump and slump flow are described [43-44].

2.1 Impact of SCM's on Fresh Properties

A slump is thought to be a good measure of how fluid new concrete is. Numerous investigations have demonstrated that SCM's affects concrete slump [45]. At ideal replacement rates of 2% and 40%, respectively, Aydn et al. [46] evaluated the impact of changes in NS and FA on the slump flow of fresh concrete. Their analysis showed that NS significantly enhanced the performance of fresh concrete and removed the segregation of 40% FA while mixing. According to Hani et al. [47], self-compacting concrete with four NS components can affect slump at various water-binder ratios. The three series under consideration had water-binder ratios of 0.41, 0.45, and 0.5. Additionally, it is intended to substitute NS for 0%, 0.25%, 0.5%, and 0.75% of the cement in each series. The study's most crucial conclusion is that all NS combinations have decreased fluidity. Additionally, among the three water-cement ratios, the addition of 0.75% NS reduces the slump by 15.2%, 15.5%, and 14.1%, respectively. Slump loss and slump flow loss of concrete mixes with various water-binder ratios are decreased by NS, and these losses rise as the amount of nanoparticles in the mixture increases. This is because of the water demand by the nano particles since with the decrease in the size of the particle, the amount of water demand by the particles increases. It was discovered by Naji Givi et al. [48] that limited workability may be related to an increase in the mixture's surface area following the inclusion of nanoparticles, necessitating the use of additional cement slurry to encase the NS. Further evidence that the presence of NS has a noticeable effect on the flow ability of fresh concrete was acquired through a slump test to support these findings. Under a water-binder ratio of 0.4, all mixes including NS had less slump than the control group. Additionally, ASTM C143 (2015) notes that slump loss is typically utilised to find the impact of NS on the fresh property of concrete. According to Supit and Shaikh [49], adding 2%–4% NS to concrete can significantly lower slump loss, which can approach 60%. Meanwhile, Bahadori and Hosseini [50] studied the mechanical and durability index characteristics of green concrete (GC) and normal concrete (NM) of grade M30 (GC). The experimental studies proven that using alccofine had enabled concrete to reach higher strengths at earlier ages. In comparison to all other mixes, the mechanical and durability index values of the green concrete mix with 20% alcofine substitution of cement were greater Results showed that compared to regular UHPC, UHPC mixtures combined with alccofine produced higher mechanical performance. [51–57].

2.2 Impact of nano materials on fresh properties

Titanium oxide, sometimes referred to as titanium dioxide (TiO_2), is a substance that naturally occurs in the metal. Concrete's performance will vary when TiO_2 is added. The amount of high-range water-reducing admixture (HRWRA) needed for each mixture to produce a slump of 65025 mm was determined by Joshaghani et al. [58]. They found that the inclusion of 5% TiO_2 resulted in a high demand for HRWRA under various water-binder ratios, with the major cause of the surface sinking of self-compacting concrete being a solidification delay produced by a high HRWRA dose.Additionally, 5% of nano-Fe_2O_3 and nano-Al_2O_3 added to concrete caused a significant increase in demand for HRWRA. The test results from the study indicate the link between the content of nano-TiO_2 and the slump of the mixture when the water-binder ratio is 0.40. The large surface area of the nanoparticles led to more water being absorbed on their surfaces, increasing the mixture's water demand. They came to the conclusion that all the combinations treated with nano-TiO_2 showed lesser slump in a short dose range when compared to the mixture without nano-TiO_2 [59].

3.0 Mechanical Properties

One of the most promising research areas for the use of nanomaterials in concrete is the use of different nanoparticles to change the concrete matrix and produce concrete with outstanding mechanical characteristics. The mechanical characteristics of nanoconcrete, such as its compressive strength, elastic tensile strength, and flexural strength, have been investigated through a number of tests. A kind of nanomaterial called NS is frequently utilised to alter HPC. It serves as a cement alternative and gives cement particles a ball bearing function. Additionally, due to the particle size of NS, which makes the structure of concrete denser and enhances concrete performance, NS is employed as a super filler in concrete.

3.1 Compressive Strength

Compressive Power According to several research, NS-modified concrete has significantly increased compressive strength. Numerous studies have shown that, within a particular dose range, introducing SCM's can increase the compressive strength of cementitious materials. The ideal doping level has also been taken into consideration. If the dose is increased beyond the recommended level, the strength will decrease primarily because a significant proportion of NS will clump and become poorly dispersed in the combination [47, 74, 76, 77]. Amin and Abuel Hassan [81] looked at how basalt fibre content and NS content, which ranged from 0% to 1.8%, affected compressive strength and tensile strength. More investigation found that when NS concentration rises, a significant amount of C-S-H gels as well as alumina, ferric oxide, and trisulphide crystals would form. The most C-S-H gel is present when the dose is 1.2%, which results in denser concrete. These outcomes are in line with what was shown in the compressive strength test.

The Li et al. study [38] revealed that the optimal dose for enhancing concrete performance is 2%. The ideal content of NS, according to Sadrmomtazi et al. [83], is between 5% and 7%. Even if the optimum content is surpassed, the compressive strength will still be better than the control mixture. The maximal strength however still happens at the ideal content. The Alccofine material can reduce the consumption of cement and C02 emissions in the atmosphere.Despite the fact that the IS 10262-2019 code expressly discourages using Alccofine to replace some of the cement in concrete mix proportions, the recommended guidelines are the same for other Supplementary cementitious materials, such as GGBS and FA, which are also used in Alccofine replacement concrete mixes[39]. A study [72] also shown that, in terms of increasing strength, a mortar combined with NS after curing for 7 or 28 days outperforms a mortar mixed with silica fume. In this investigation, NS with contents of 5%, 10%, and 15% was used in place of cement. The impact of partially substituting NS for cement on the compressive strength of HVFA. The compressive strength of the mortar was evaluated after 7 and 28 days of curing, while the compressive strength of the concrete was evaluated after 3, 7, 28, 56, and 90 days of curing. The findings indicate that when the concentration of NS is 2%, the compressive strength of cement mortar in 7 and 28 days achieves its maximum. Moreover, after 7 days of curing with the addition of 2% slag micro powder, the compressive strength of the mortar mixed with 40% and 50% FA rises by 5% and 7%, respectively. However, no discernible improvement is shown when the FA concentration in regular mortar approaches 50%. The 28-day compressive strength of all HVFA mortars, however, is increased by adding 2% NS, with mortars with FA contents exceeding 50% experiencing the most benefit. The addition of 2% NS to HVFA concrete improves the compressive strength at the early stage (3 days)[60-84][reference studies].

3.2 Split-tensile and Flexural Strength

Concrete's tensile strength is modest, often 1/10 to 1/20 of its compressive strength. A HSC with 1.2% NS and 3 kg/m3 basalt fibre may reach the best splitting tensile strength, according to Amin and Abu el-Hassan [81]. Comparing the tensile strength of the concrete to a control mixture, the study found that it could be raised by 17.42%. Jalal et al. [84] noted that after curing for 90 days with 10% FA and 2% NS in various cementitious material contents, the splitting tensile strength of self-compacting concrete may be enhanced by 25, 30, and 35.9%. Fallah and Nematzadeh [85] investigated how strong HPC combined with polymer fibre and NS might be. The tensile strength of cement rose by 12.96%, 7.82%, and 16.10%, respectively, when cement was replaced with 1%, 2%, and 3% NS, according to tests. The enhanced bonding force between the cement base and aggregate is primarily responsible for the improvement in strength. According to Mohamed's research [86], after 90 days of curing, adding 0.75% NS and 3% nano clay (NC) to concrete may boost its flexural strength by 4% and 9%, respectively. They also noted the significant benefits of 3% nanoparticles with 25% NS and 75% NC for enhancing mechanical qualities. Additionally, Amin and Abu el-Hassan [81] reported that the addition of NS and $NiFe_2O_4$ nanoparticles boosted concrete's flexural strength by around 23% when compared to a control group.

4.0 Conclusions

This review study demonstrates the impact of different nanoparticles and SCM's on the mechanical and fresh HPC performance. Nanomaterials being investigated for the creation of nano concrete include NS, nano-CaCO3, NA, and TiO_2. In-depth discussion of the information on the workability, compressive strength, and flexural characteristics of concrete modified with nanoparticles is provided in this paper. The analyses of the existing literature offer significant insights into the contribution of nanomaterials to the performance enhancement of concrete. In order to provide more useful results, this work also aims to contrast the performance of control concrete with concrete enhanced with nanoparticles.

1. Concrete that has been changed by NS has less slump flow. The workability decreases as cement substitution increases. In this situation, a sufficient quantity of a water-reducing agent should be applied to guarantee the functionality of HPC with NS.

2. Mortar and concrete with a high FA content become less workable when alcoffine is added, and the workability gets worse as more cement replacement is added.

3. The workability of HPC is decreased by 15-28% by the inclusion of different nanomaterials, such as TiO_2, Al_2O_3, and metakaolin[61-62]

4. Because NS and alcoffine substitute cement, a significant amount of C-S-H gel is produced, and the microstructure is more compact, the HPC modified by NS and alcoffine has good compressive strength. Therefore, it has to do with the right amount of NS and alcoffine. To maximise NS and alcoffine replacement, many criteria have been suggested by researchers.However, NS and alcoffine replacement rates must not be too high; a value of less than 5% is typically advised. When adding more nanoparticles to the mixture than is necessary, they will aggregate and weaken the combination's compressive strength. The compressive strength of HPC will also be impacted by the kind, dose, and size of NS and alcoffine.

5. With the addition of NS and alcoffine, tensile strength and bending strength development trends are equivalent to those of compressive strength. There is a dosage that works well for the influence trend of NS and alcoffine.

6. The majority of research demonstrate that adding nanomaterials, such as nano-CaCO3, CNTs, TiO2, and Al2O3, to HPC decreases the quantity of cement used while simultaneously promoting the hydration of C3S and improving the mechanical qualities of concrete. The dose affects performance, and going over the recommended amount may decreases the strength.

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