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Study of Different Nanomaterials Used in Concrete: A Review

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Abstract

This review paper discussed the nanomaterials used in concrete and focus on the effects on concrete resists by impact loading at elevated temperatures. Basically, the use of nanomaterials is to increase the performance of concrete, so its use is increasing in the field of concrete technology drastically. Numerous studies found that the use of nanomaterials in concrete improves the strength, durability, and other mechanical properties. The nanomaterials are beneficial to improvements in strength characteristics of the concrete. The studies found that different nanomaterials used in different amounts in concrete and kept at a temperature of 1200^{0}C then concrete tolerate high temperatures up to 400^{0}C. The nanomaterials possess the tendency to accelerate the hydration reaction and fill the micropores, so they create the dense microstructural concrete. More the denser concrete more its strength. By doing comparative studies on nanomaterials found that some nanomaterials have unique property such as nano-zinc oxide act as a corrosion inhibitor and nano-alumina controls the setting time. All these aspects make nanomaterials added concrete essentials and sustainable materials for construction purposes.

Keywords: Nano materials, Compressive strength, Impact Strength, Durability, Elevated Temperature.

1. INTRODUCTION

Concrete is a fused and versatile material containing of cement, fine aggregates, coarse aggregates and water. Nowadays, some chemical and natural admixtures are used to make the concrete stronger. "Nanomaterials are the materials used in concrete whose particle size ranges from 1nm to 100nm" [8]. The usage of ultra-fine particles in concrete surges the surface area of the concrete to some extent so that the concrete can withstand any loading. Since the particle size of nanomaterials is ultra-fine, the concrete hardens and hence the concrete becomes stronger. "The application of nanoparticles has beneficial in concrete to fill the cement matrix, gelatinize the structure which results in enhancing the strength and rapid chemical reactions like hydration reactions due to their high reactivity" [10]. "The concrete was subjected to high temperature loses its integrity, results in spalling and weight loss of the concrete" [6,2].

2.NANOMATERIALS

Fig.1 shows the graphical representation of different nanomaterials as follows below.

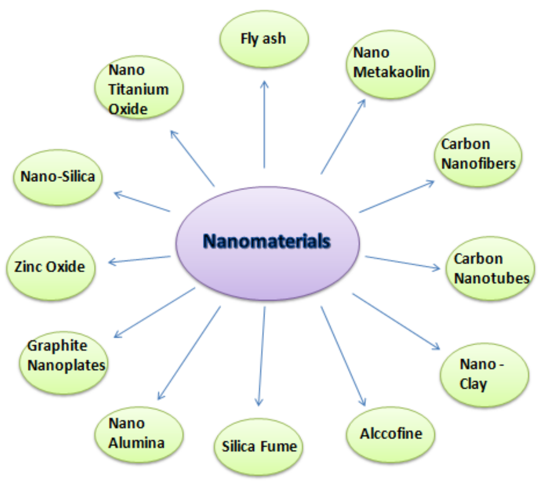

Fig.1. Graphical representation of different nanomaterials

2.1 NANOSILICA

Nanosilica is formed from silica powder and silica powder is made from silicon. Nano-silica plays a very important role in concrete and its use has taken the concrete industry to a whole new level. "Nano-Silica is a highly reactive material and reacts with $Ca(OH)_2$, called a pozzolanic reaction that generates C-S-H gel" [8].

"Several studies and experiments were conducted with varying percentages of Nano-silica, ranging from 1% to 4%" [2,5]. "Some studies have shown that Nano-silica replaces cement by 4%, followed by an increase in the ductility index" [10].

"A range of 5-80 nm particle size of Nano-silica was utilized in disparate studies with almost 99.9% purity" [16, 5]. "The use of Nano-silica in concrete increases the workability of concrete, as the shape of the nanoparticles is round, so their bonding with the cement particles is more" [20].

2.2NANO FLYASH

Flyash is the by-product of the coal which was burned in thermal power plant to produce electricity. Fly ash is known as cementitious material and is used to enhance the strength of concrete. "Nano Fly ash is deriving from the fly ash, producing from high energy grinding mill instruments" [11, 26]. "The addition of nano fly ash in concrete reduced the carbon footprint, shrinkage, hydration, heat rate and also compressive strength, durability and consistency are increases" [12]. Moreover, nano fly ash added concrete shows better resistance to the impact loading [9, 24]. "An attempt has made by the researchers to reduce the average particle size of fly ash from 60 µm to 148 nm by using high energy ball milling, consequence the fly ash becomes more amorphous and the crystallite size reduces drastically" [22].

2.3SILICA FUME

Silica fume is a non-crystalline form of silicon dioxide and is also a derivative of silicon and ferrosilicon. In high-performance concrete, silica fume acts as a pozzolanic material which triggers the pozzolanic and hydration reaction. The recent studies show that there are confined researches reported on the usage of nano-silica fume in high-performance of concrete. "The applications of silica fume in concrete reduce the spalling and mass loss of the concrete at elevated temperatures"[6]. "Various studies indicates that the use of silica fume in concrete increase the compressive as well as impact strength of concrete at elevated temperatures" [4, 10] "The use of silica fume in the concrete increases the mechanical as well as elastic modulus of concrete and also the toughness of steel fiber concrete is depending on silica fume content, the fiber volume fraction and the fiber aspect ratio" [14].

2.4NANO METAKAOLIN

Metakaolin is the unhydrated calcined form of Kaolinite clay minerals. Metakaolin has similar properties as silica fume called as pozzolanic material. "Nano Metakaolin is produced using either a top-down or bottom-up approach process" [8, 20].

K. Gayathri et.al. [13], has studied the effects of impact loading on nano metakaolin added concrete at elevated temperatures and found that 10% of nano metakaolin in concrete mixture gives maximum impact strength of the concrete at 250^{0}C. "Impact strength of concrete gets enhanced by the addition of nano metakaolin than control concrete" [11, 26]. The metakaolin is used in high-strength concrete, light-weight concrete, precast and poured mold concrete, glass fiber reinforcement, countertops, and sculptures. Besides, the inclusion of 15% metakaolin in concrete shows better corrosion resistance property, water absorption, resistivity and ultra-sonic pulse velocity values with concrete [21].

2.5NANO-TITANIUM OXIDE

Nano-titanium oxide(nano-TiO_2) is produced from titanium oxide itself. Also, nano-titanium oxide is the amorphous form of titanium oxide. Nano-titanium oxide is used as supplements in paints, plastic, cement, etc. Hui Li et.al. [16], "has studied the abrasion resistance of concrete containing nanoparticles. In this study, nano-TiO_2 added concrete shows better resistance to abrasion than concrete containing nano-silica. Also, the addition of nano-TiO_2 in concrete decreases the calcium hydroxide content and increase in C-S-H gel". "Moreover, the addition of TiO_2 in concrete has a great effect on self-cleaning ability and contribute to the application of green material in construction and care must be taken during mixing of TiO_2 in the concrete mixture, because titanium creates an inflammatory effect and causing cancer" [20].

2.6NANO ALUMINA

Nano alumina(Al_2O_3) is made out of alumina itself. The usage of nano alumina in concrete reinforces the mechanical properties of concrete because of its excessive reactivity. "In some studies, 5% of nano alumina added in concrete increases the modulus of elasticity by 143% in 28 days and it acts as a filler in the sand-paste to fill the pores and creates dense interfacial transition zone with less porosity" [8]. "Besides, nano alumina has the ability to manipulate the setting time of concrete mixture and it speeds up the initial setting time of concrete mixture which reduces the segregation and flocculation" [20].

2.7ALCCOFINE

Alccofine is an ultrafine additional cementitious material ground granulated blast furnace slag. Alccofine has tendency which triggers both pozzolanic as well as hydration reaction. Alccofine conjointly consumes the CH from the hydration of cement to make an extra C-S-H gel, almost like pozzolana. Actually, alccofine is a cementitious material obtained from Ambuja cement Ltd, manufacturer of assorted cement in India.

K.Thangapandi et.al.[28], "have studied the performance of hardened concrete with nanomaterials and found that the use of 10% of alccofine in concrete improves the compressive, flexural and split-tensile strength of concrete. Also, the alccofine added concrete shows better resistance to water permeability as well as chloride permeability". "Furthermore, the alccofine in concrete helps to set concrete quickly than that of control concrete and improves workability" [25].

2.8 Zinc Oxide

Nano-zinc oxide was produced from zinc oxide itself. As the particles size of zinc oxide is very small it has a large specific surface area. Nano-zinc oxide absorbs the ultraviolet rays and it has used in sunscreen to protect the human body from ultraviolet rays. Since nano-zinc oxide is new material in the construction field its hazardous effect are not well known. Care should be taken to handling it at the time of mixing it in the concrete mixture.

"Zinc oxide acts as a corrosion inhibitor in concrete and 0.5% of zinc oxide increases the strength and durability properties of the concrete" [28]. "Moreover, zinc oxide increases the distribution of the pore diameter and creates a dense microstructure in the cement paste increases the strength of the cement paste at 28 days" [18].

2.9GRAPHITE NANOPLATELETS

Graphite nanoplatelets (GnPs) are a new type of nanoparticles made from graphite. Graphite nanoplatelets possess the lightweight, electric and thermal conductance property. Also, graphite nanoplatelets are used as different material such as polymeric materials, natural or artificial rubber, elastomers, greases, paints, films, thermoplastic and thermoset composite materials.

Peyvandi et.al. [23], "had studied the evaluation of the reinforcement efficiency with low-cost graphite nanomaterial in high-performance concrete. The addition of graphite nanoplatelets in concrete improves the compressive, flexural and impact strength. Also, the graphite nanoplatelets added concrete provides excellent resistance to moisture sorption".

2.10 CARBON NANOTUBES (CNTS) AND CARBON NANOFIBERS (CNFS)

Carbon nanotubes are of two kinds such as Single-walled nanotubes and multi-walled nanotubes. In single-walled nanotubes, there is just one coat of graphene and multi-walled nanotubes consist of two coats of graphene. "Carbon nanotubes in ultra-high-performance concrete provide flexibility to the concrete and improve the compressive and tensile strength of the concrete" [20]. "Numerous studies, the addition of carbon nanotubes in concrete reduces the shrinkage about 25%, also capillary stresses and porosity reduced" [27].

Carbon nanofibers (CNFs) are the cylindrical-shape type nanostructures which contain a coat of graphene and organized as accumulated cones, cups or plates. In carbon nanotubes, graphene layers are covered as hollow cylinders whereas, in carbon nanofibers the graphene layers are usually accumulated as platelet, ribbon-like or fabric structure. "The carbon nanofibers improve the compressive, flexural and impact strength of the concrete and also provides resistance to moisture sorption" [23].

2.11NANO CLAY

Nano-clay has produced from naturally occurring clay. "Nano clays are classified into montmorillonite, bentonite, kaolinite, hectorite and halloysite depending on the chemical composition and nanoparticle morphology" (Norhasri et.al., 2016). "Various studies have shown that nano clay is composed of two layers and the transport of water molecules is restricted by the sheet and low permeability of cement mortar can be achieved" [27].

Langaroudi et.al.[15], "studied the effect of nano clay on workability, mechanical, and durability properties of self-consolidating concrete and they found that 3% of nano clay in blended self-consolidating concrete enhances the mechanical and durability properties significantly".

3. PROPERTIES OF NANOMATERIALS ADDED IN CONCRETE

Out of the characteristics, the impact of nanomaterials on the physical characteristics in the fresh and hardened state, mechanical characteristics and durability characteristics are explained in detail.

3.1.FRESH STATE PROPERTIES

Workability is simply depends on water content, aggregates, cementitious materials and level of hydration. The workability is usually measured by the slump test. "Nano-silica is highly reactive material which triggers hydration of cement quickly, it reduces the water content in the concrete mixture, and so more water requires to maintain the workability" [6]. "Some water reducing agents are was used to adjust the workability of the concrete mixture" [2]. "The large specific area of nano-silica absorbs the water from the concrete mixture and decreases the workability of the concrete mixture" [5]. "Satisfactory workability can be achieved by the addition of a nano-clay of 3% into the concrete mixture" [15]. "Various studies have shown that silica fume is added in mixture along with steel fiber so better workability can be achieved" [14].

The initial and final setting time is affected by the fineness of cement, the presence of salt in the sand and atmospheric condition factors. "Due to the highly reactive nanomaterials, hydration reaction gets accelerated and the initial setting time is not advantageous" [5]. "Some nanomaterials like nano-zinc oxide are insoluble in water which reduces the setting time of concrete mixtures" [28].

3.2MECHANICAL PROPERTIES

3.2.1COMPRESSIVE STRENGTH

High-strength concrete is tested to determine the compressive strength of the concrete specimens. Bastami et.al. [6], "was studied the performance of high-strength concrete with nano-silica. Six sample cylinders with a size of 150x300 mm were cast with varying amounts of nano-silica were used in them, two samples were made nano-silica free and tested for the desired number of days of curing. In this study they found that the compressive strength of high strength concrete containing nano-silica is increased as compared to concrete without nano-silica". "In numerous studies, the compressive strength of the concrete increases with the addition of 10% of alccofine and 0.5% of zinc oxide in concrete and also found that decrease in compressive strength felt beyond 0.5% addition of zinc oxide in concrete" [28]. "The addition of graphite nanoplatelets and carbon nanofibers in high-performance concrete is beneficial to increase the compressive strength of the high-performance concrete" [23]. "Also, the nanomaterials such as nano-cement and nano-cement kiln dust included in concrete increase the compressive strength significantly" [1,9]. "Additionally, 5% of nano-silica increases the early age compressive strength of the concrete" [5, 7, 12]."The combination of alccofine and ground granulated blast furnace slag in concrete shows a decrease in the compressive strength of the concrete" [25]."But in the case of silica fume and steel fibers combination improves the compressive strength of the concrete" [14].

3.2.2.Flexural strength and Tensile strength

"The flexural strength of concrete increases drastically when the nano-zinc oxide replaces cement with 0.5% by weight" [28]."The addition of graphite nanoplatelets and carbon nanofibers in concrete improves the flexural strength of the concrete" [23]."Numerous studies show that the enhancement in flexural strength of the concrete occurs with the inclusion of 3% of nano-silica" [7]. "0.2 weight per cent of nano-zinc oxide in concrete elevates the flexural strength of the concrete" [18].

"At high temperature, nano-silica is more effective than silica fume in increasing the tensile strength of the high-strength concrete" [6]. "The act as a nucleation site for pozzolanic effect and hydration of cement as a result, increasing in hydration products in voids and form the dense, homogenous and compact microstructure which leads to improving the tensile strength of the concrete" [7]. "In the various study, it is found that the tensile strength of concrete is increased desperately by using nanomaterials such as Alccofine, Zinc oxide and silica flour into the concrete with varying proportions" [28, 4]. "Nano-clay material possesses the tendency to increase the split-tensile strength of the concrete, so the addition of 3% nano-clay increases the tensile strength of the concrete" [15].

3.2.3.IMPACT STRENGTH

Impact strength of concrete means the resistance provided by the concrete to the sudden applied loads or shocks. "The addition of graphite nanoplatelets and carbon nanofibers in high-performance concrete increases the impact resistance" [23].

Reddy et.al. [26], "has studied the impact strength of concrete containing nano-silica, nano flyash, and, nano metakaolin in concrete. The addition of nanomaterials as 10% by the weight of cement shows an increase in the impact strength of concrete". "The impact strength of concrete increases with the addition of 30% of flyash and 1.5% of steel fibers into the concrete" [24]. "Numerous studies, the nanomaterials (nano-cement, nano flyash, nano-silica and nano-metakaolin) in concrete shows effective resistance to the impact loading". "According to numerous studies, nanomaterials (nano-cement, nano-fly, ash, nano-silica and nano-metakaolin) in concrete show better resistance to impact loads" [10, 11, 13].

3.3DURABILITY PROPERTIES

The essential durability properties of concrete are water absorption and permeability, chloride permeability, carbonation depth and dry shrinkage.

3.3.1.WATER ABSORPTION AND PERMEABILITY

"With the addition of nano-silica ranges from 0-4% into the concrete, the water permeability decreases by 20% from range 17.6 mm to 14.1 mm" [2]. "The increment of zinc oxide into the concrete leads to a decreasing in water permeability and an increase in durability of concrete" [28]."Moreover, the use of nanomaterials (Graphite nanoplatelets, Carbon nanofibers, Nano-silica) in the concrete decreases the water absorption in concrete which also reduces capillary pores and shows greater resistance to water permeability" [23, 5,12]."The concrete containing nanomaterials such as nano-cement and nano clay opposes to the water absorption and water permeability" [9, 15].

3.3.2.CHLORIDE PERMEABILITY AND CARBONATION DEPTH

"The use of nano-silica content 4% in the concrete mixture reduces the carbonation depth and increases in dry shrinkage strain of 90 days of high-performance concrete" [2]. "The inclusion of 10% alccofine and 1% zinc oxide into the concrete shows resistance to chloride permeability of the concrete" [28]. "The nanomaterials (nano-silica and nano-clay) added concrete possesses better chloride permeability resistance compared to conventional concrete" [5, 15]. "Additionally, the nanomaterials(nano-silica, nano-titanium oxide, graphite nanoplatelets, carbon nanofibers, and nano-clay) used in concrete shows better resistance to abrasion, corrosion initiation and surface attack" [5,15,16, 23].

4.ELEVATED TEMPERATURE

The concrete tends to lose integrity and increased the spalling effect, because of the dehydration and loss of pore water in cement paste at high temperature. Bastami et.al.[6], "studied the effects of elevated temperatures on high-performance concrete with nano-silica and found that there are no visible cracks were observed on the surface of the concrete at 400^{0}C. But at 600^{0}C temperature, large cracks and partial spalling observed". "At temperature beyond 500^{0}C, the volume of the capillary pore increase drastically and dehydration of hydration product caused micro cracking in the microstructure" [29]. "The relative strength of concrete reduces with an increase in the temperature" [3]. "Numerous studies show that at 250^{0}C temperature, the impact strength of the concrete has increased" [11,13,26]. "At 100^{0}C to 400^{0}C temperature, the pozzolanic reaction is accelerated along with a steep decrease in $Ca(OH)_2$ content" [19].

5. Conclusion

While studying the existing literature, it is understandable that the different nanomaterials are used to replace the cement with varying percentages. Nanomaterials act as a catalyst to accelerate hydration reaction and fill the microstructural pores. An increase in nanomaterials content increases the compressive, tensile, flexural, and impact strength of the concrete. The interfacial transition zone improves by the use of nanomaterials, thus making the denser concrete and increases the durability properties of concrete. The presence of nanomaterials provides resistance to temperatures up to 400C. The impact testing on high-strength concrete with nanomaterials at elevated temperatures has been not done yet till now. This is the reason for pursuing further study and investigations. Also, the use of nano-clay in high-strength concrete at elevated temperatures has been not revealed.

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