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A Review on Nano Materials in Cement

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Abstract: ***The research in construction industry nowadays is mainly focusing on the basic science of cement materials at nano level. The research is also continuing to improve the durability and sustainability of concrete and realized significant increase in strength of material by incorporating nanoparticles. The review paper summarises the effect of various nanoparticles addition on the strength material. It provides the current development of application of nano-materials in mortar and concrete. Nano material can assist in intensifying the use of resources and get the required properties by reducing the use of resources. This review paper also addresses the current development regarding use of nanomaterial in construction industry. The paper first presents general information, then focuses on the most effective nano additives such as nano silica, nano-titania dioxide, iron oxides, chromium oxide, nanoclay are summarized. Along with benefits, some health risks are also associated with the use of nanotechnology. The risks are can be remedied so that the nano building products could be fully exploited for the benefits of mankind.***

Keywords: Nanotechnology, nanomaterial, cement, Concrete, Strength, Durability, economic benefits etc.

I. INTRODUCTION

Building materials are an important part in civil engineering. The important building material includes concrete, steel, stones, bricks, plastics, timber, glass and many metals [1]. Stone and timber are considered to be the oldest materials used by the humans to build shelter against the natural calamities. Today we see concrete and steel as the modern giants in construction industry. As the technology grew, newer and smart materials were developed by the engineers and researchers all over the world. Use of nano technology and nano materials in Civil engineering is a recent initiative. The use of this technology solved many problems of the construction industries.

The excursion of nanotechnology starts from the lecture of Nobel Laureate Feynman in 1959 at the California Institutes of Technology said “There is plenty of room at the bottom” [2]. Today, nanotechnology brought revolution in the world. Nanotechnology is the branch of material science dealing with NPs. Nanoparticles is defined as the one that has least one of its dimensions in nanometers or 10^{-9} m. The properties of these particles observed to be drastically changed when they are milled to nano size. [3]. A copper wire bend due to the movement of its atom at about 50 nm scale. Copper particle smaller than 50nm are super hard material that do not display the same malleability and ductility as those above 50 nm [4]. Conceptually nanotechnology may be defined as the ability to create new structure at the smallest scale, using tools and techniques that allows understanding and manipulating matter at nanoscale, generally from 0.1 to 100 nm [5]. In the construction industry the application of nanotechnology is fairly clear relates with concrete production. Concrete is a composite material at macroscale but its properties can also be improved at meso and nano scale. In fact, nanotechnology has a high potential to contribute to the understanding of concrete’s behaviour in order to improve its mechanical properties and reduce ecological and construction material’s costs [6]. The number of published works in the field of concrete nanotechnology increasing from 2000 to 2009 but from 2009 to 2011 it displayed a huge rise due to information media.

Cement: Cement is a major constituent in the concrete. The raw material needed to produce cement is calcium carbonate, silica, aluminium, and iron ore. This cement is made by heating limestone ($CaCO_3$) and clay at 1450^0C in a kiln, in a process called calcination, CO_2 is liberated to form calcium oxide or quick lime which then chemically combines with the other material. Cement is a mixture of calcium oxide (CaO), Silicon dioxide (SiO_2), Aluminium oxide (Al_2O_3), Iron Oxide (Fe_2O_3), H_2O, Sulphate (SO_3). Improvements have been achieved by the addition of NPs in the cement that are Nano silica and Silica Fume, Titanium Dioxide, Iron oxide, Chromium oxide and nano clay.

Nanosilica In construction Field: Cement is the most broadly used building material. It is very critical to learn the structural fundamental of concrete which are efficient at nano range to organize the mechanical and chemical characteristics of cement mortar. Cement mortar is a mixture of cement and fine aggregates linked by interfacial transition zone by addition of water this paste forms a chemical reaction known as hydration of cement to turn rigid in particular time span. The key part of hydration of cement is calcium silicate hydrate known as C-S-H gel, calcium hydroxide monohydrates etc.

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II. LITERATURE REVIEW

Sakshi Gupta [7] (2015) predicted partial replacement of cement with nanosilica it increases durability of material. The main aim of the study is to optimise the contents and reduce the cost and efforts. It can be used to reduce the amount of cement used in mix. It can be used to reduce the amount of cement used in mix.

Ehsan Ghafari *et al.*,[8] (2015) Studied role of nanosilica on the high performance of concrete. The addition of nanosilica decrease the capillary pores and enhance the interface between the aggregate and the binding paste. The compressive strength also increases with the incorporation of nanosilica in especially at the early stages.

P.Di Mida *et al.,[9]* (2015) Effect of powdered and colloidal nanosilica on the properties of cement mortar. Approximately 27 to 37 % enhancement in the compressive strength was observed using nanosilica and 19% increase in the compressive strength when powdered silica was used.

Rashad [10] (2014) presented an extensive overview on the effect of nanosilica on the properties of traditional cementitious material and alkali – activated fly ash. Using NS in concrete improves strength, workability and setting time, heat of hydration, fire and abrasion resistance or leaching.

Ehsan Mohseni *et al.*,[11] (2015) analysed the effect of NS (5 - 70 nm) on the physical properties of cement. From the study of cement mortar with nanosilica an increase in the flexural and compressive strength was obtained. The addition of NS resulted in overall enhancement of cement mortar.

Shakhmenko *et al.*, [12] (2013) tested the effect on cement's paste by adding SF and NS demonstrated higher values of compressive strength (more than 3 times higher at early ages and approximate15% at 28 days) and long term hardening effect compared to cement paste.

Hou *et al., [13]* (2013) tested different samples of cement pastes with colloidal NS. The result suggested that the addition of NS increased both the hydration peak temperature and the rate.

Bahadori and Hosseini [14] (2012), Berra *et al.*, (2012) and Qing *et al.*, (2006) obtained a remarkable reduction of the mixers workability when NS were used.

Li *et al.*, [15] (2006), Nazari and Riahi [16] (2011 a),have been performed to study the abrasion of concrete mixes modified with NS. This property plays a key role when concrete is used in pavements.

Meral and Remzi [17] (2011) studied the combined as well as individual effect of three NP's namely SiO_2, nano Al_2O_3 and nano Fe_2O_3 on the permeability and compressive strength of cement mixes containing silica fumes and Compressive strength was calculated for different days.

V. Ershadi *et al.*, [18] (2011) studied the effect of nanosilica on permeability of oil well. NS has been used to improve impermeability and physical properties of the hardened material with addition of NS with very fine particles in the matrix the permeability was considerably reduced and compressive strength was increased from 1486 psi to 3801 psi.

Belkowitz [19] (2009) studied the effect of nanosilica on hydration of cement by adding NS. It enhances the strength of the cement. Author concluded that due to the addition of NS in the cement mortar many properties of cement begins to improve because silica decreases in size and increase in size distribution.

N. Guskos, *et al.*, [20] (2008) examined the influence of NS and micro silica concludes that with 7% nanosilica has better microstructure. The properties were considerably improved. Author advised to study the specific samples.

A. Nano Titanium Dioxide

Is a naturally occurring oxide of titanium having chemical formula TiO2. Titanium dioxide has excellent ultraviolet (UV) resistant qualities [21]. Since the past decade nano titania particles are being produced in abundance. Nano titania are found to be stable, anticorrosive and possess photo catalytic properties [22]. Apart from paints nano titania have also been used in concrete [23]. The manufactured concrete is named as self cleaning concrete or photocatalytic concrete or smog eating concrete or green concrete. Application of this concrete also includes environmental pollution cleaning and self disinfecting [24]. Photo catalytic concrete made headlines for the first time in 2007, when an Italian company Italcementi made photocatalytic concrete at commercial scale[25]. Therefore the application of TiO_2 NPs in cementitious material is justified because it is eco-friendly and good in an emerging need for environmental regulation to the development of new strategies to reduce the polluting agents [26].A self cleaning effect that is the removal of inorganic substances dirt on surfaces due to rain water soaking between this absorbed substances and the TiO_2 surface is obtained by the photo-induced hydrophilicity of the catalyst surface [27]

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TiO_2 NPs has great potential in concrete. TiO_2 powder in cement based materials without additional treatments due to the porous structure of the hardened cement paste or mortar [28]. It is also demonstrated that TiO_2 was inert and stable during cement hydration process. Thus, the use of those NPs has important on the total porosity and pore size distribution of the cement paste.
Nazari and Riahi [29], [30] (2011 b, 2011 c) stated that TiO_2 NPs could improve the pore structure of concrete and change the pores size distribution to harmless or slightly harmful pores. Nazari and Riahi [29] (2011 b) also stated that TiO_2 NPs as a partial replacement of cement up to 3 weight% may accelerate C-S-H gel formation. This resulted in an improvement up to 45% of the compressive strength of concrete. Similarly these NPs improves the resistance to water permeability of concrete when it is mixed in cement paste. It also helps to decrease setting time.

B. Iron III oxide

The structural safety of building service is an important vector in the construction industry. In this issue, Iron III oxide plays a key role. This is an oxide of iron. Iron has two oxidation state and to denote which kind of iron forms on dissociation iron is named as Iron II or Iron III. Fe_2O_3 has three iron ions, thus it is called as Iron III oxide. The addition of Fe_2O_3 NPs may play an important role due to its electrical properties. [31] tested different samples of cement mortar and addition of nano Iron III oxides is able to sense its own compressive stress in the elastic and inelastic regimes thanks to their ability to change the volume electric resistance as the applied load changes. Moreover it has been shown that NF particles do not decrease the resistivity of cement mortar, which is beneficial for the durability of reinforced concrete structure. More tests are needed to clarify NF also plays an important role in the production of the called heavy weights concrete. This type of concrete is widely used for radiation shielding of nuclear reactors and other structures that requires radiation impermeability.
Gencel *et al.*, [32] (2010) investigated the physical and mechanical properties of concrete with hematite materials with focus on workability and durability. Regarding the mechanical properties, it was found that there was only a minor effect of hematite added to concrete on its essential properties, namely the compressive strength which did not differ from that of plain concrete.
Nazari and Riahi [33] (2010 b) tested the compressive strength and workability of concrete with addition of NF with average diameter of 15 nm. Different contents were used 0.5 %, 1.01 %, 1.5 %, and 2.0 % by weights. The results showed an increase of 15 % in the ultimate strength of concrete for a maximum replacement level of 1.0 %. Self monitoring and self sensing seems to be the property with the best potential advantages concerning the use of NF on concrete structures.

C. Chromium III Oxides

It is the inorganic compound and principal oxides of chromium and is used as a pigment. Use of Cr_2O_3 NPs is less in comparison with SiO_2 and TiO_2. Nevertheless, there are several reports on the incorporation of these NPs in concrete.
Nazari and Riahi [34] (2011 d) tested some samples of concrete with NCr and their results that these specimens have higher strength than those without these NPs at every curing ages. The replacement of cement with NCr with average size of 15 nm up to a maximum limit of 2.0 % improved mechanical properties of concrete. These NPs improves both flexural strength and splitting tensile strength. A reduction of water absorption was also observed in the samples with those NPs. The pore structures of self compacting concrete containing NCr is improved also increasing the content of all meso pores and macro pores.
Assem and Zhu [35] (2007) have justified its decreasing use for pigments and paints because chromium leaching is known to be a problematic issue. Similarly to TiO_2 NPs, the incorporation of NCr in the cement matrix improves a reduction of water absorption and this reduction is due to reduction of the amount of pores when NCr is added to the cement matrix.

D. Nanoclay

Addition of small amount of nanoclay enhance the mechanical properties of concrete. Many studies have targeted the application of clay in the cement composites and several enhancements on concrete properties were achieved. Clay belongs to a wider group of minerals and described as hydrous silicates [36]. Clay minerals are characterised by their fine grained natural structures with sheet like geometry. Natural clay particles are micron and submicron in size and composed of crystalline layers of aluminium phyllosilicates. Clay minerals are divided into four major groups which includes the kaolinite, montmorillonite, the illite and the chlorite group [37]. Out of these Kaoline and montmorillionite /smectite group are widely referred when use filler in concrete production is studied [38], [39], [40]. In presence of silica and aluminium, clay particles may act as ‘nuclei’ of hydration and increasing overall concrete performance [41], [42], [43]. The large surface area of these NPs and their abundance because of their small size can facilitate the chemical reaction to produce a dense cement matrix with more calcium silicate hydrate (C-S-H) and less calcium hydroxide.

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Morsy *et al*., [44] (2010) studied the effect of NCl on the mechanical properties of Portland cement. The result showed that the compressive and tensile strength of the cement mortars was higher than that of the plain cement mortar.

Chang *et al*., [45] (2007) studied the compressive strength and permeability of the cement paste when nano – montmorillonite is used. Result indicated that after 28 days, the optimal amounts of nano montmorillonite were found by weight of cement, where cement paste composites had highest compressive strength and the lowest permeability coefficient at 28 days. Denser and more stable bonding structure were also found.

Farzadnia *et al*., [46] (2013) studied the mechanical properties, flowability, thermal behaviour and durability of mortars containing halloysite nanoclay. Results from its use in mortars showed that the compressive strength and gas permeability of samples improved up to 24 % and 56 % from this results, NCl particles have potentials improve mechanical performances, reducing permeability and shrinkage of concrete. The potential of these NPs in addition to a relatively low cost may justify further developments in this area.

Risks of Nanoparticles- Nano particles are of very fine size, hence they are highly airborne and waterborne. The situation can become serious when such NPs are also of toxic nature [47], [48]. Similarly as discussed above nano titania particles might be of toxic nature as reprted by USA health department. It is necessary to address the health issues related to nano technology before application because every engineering technology is meant for the benefit of the human society.

III. CONCLUSION

A. Nanotechnology has potential in construction industry.

B. In the important development made in cement are ultrahigh strength, photo catalytic, self heating, bendable etc.

C. Incorporation of nano silica results in higher initial and final compressive strengths, higher workability and lower permeability. Additional higher tensile strength and segregation resistance are also achieved.

D. Utilization of nano TiO_2 on UV radiation can be used as an effective way to reduce the contaminants and enhance environmental safety.

E. Serious health issues related to the use of nano materials must be well understood and remedies are mandatory.

F. Applications of nanotechnology to build up novel building materials with various economic benefits to the construction industry.

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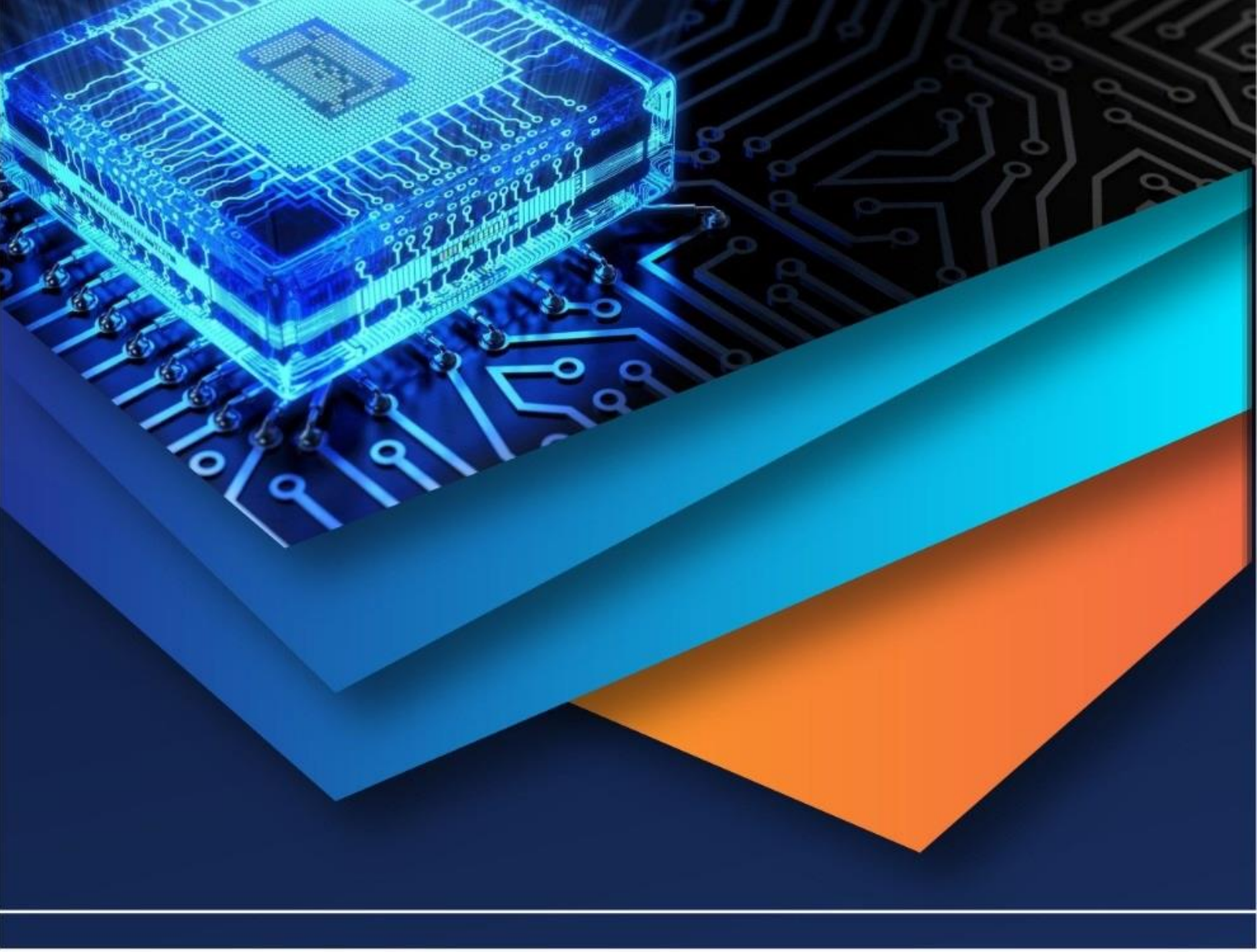

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