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EFFECTS AND CHALLENGES OF APPLICATION OF NANO MATERIALS IN CONCRETE: A BRIEF REVIEW

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Abstract— Concrete is a basic and most widely used construction material due to its ease of casting, strength and durability. It also needs up gradation due to new advancement in technologies like Nanotechnology, fiber reinforced concrete etc. In recent years, many researchers also worked for enhancement of properties of concrete by adding different additive Nano materials and found some positive result. But it is still not widely used due to its cost of production, environmental issues and health hazard etc. In this article, a brief report is summarized on production, effects and challenges of use of Nano materials in concrete production.

Keywords— Nano material, Scattered electron microscopy, Interfacial transition Zone, Mechanical Strength, porosity

I. INTRODUCTION

Since Roman time's concrete is used as a building material comprising mainly four ingredients i.e. coarse aggregates, fine aggregates, cement, and water. A large number of different types of structure using concrete are constructed every year in the world. . Due to change in recent trends in construction industry, ordinary concrete cannot give a needful result. For constructing heavy structure like bridges, multi-storeyed building, sea shore structures and many more structure, there is a very high demand of advance concrete, which can fulfil the need of higher strength and ease of construction. The demand of these type of concrete for a better infrastructure are increasing rapidly due to fast growth of urbanization.

Concrete, which is an ideal building material for construction of any type of structure due to its ability to be easily moulded in any shape and its strength and durability and this is the reason, the rate of production of concrete and its constituents are increasing rapidly. Therefore cement had become the source of about 8 % world's Carbon dioxide emission [1]. The need of cement cannot be reduced in this situation, but if the strength and other properties can be improved and its quantity can be reduced. For this purpose, the macrostructure and microstructure of concrete are being studied by different researchers. In ordinary concrete, four ingredients that is cement, sand, gravel and water are used. Here all the ingredients are of minimum size in millimetres. After this, researcher go for high performance concrete in which micro silica are also used other than above ingredients. In recent ultra-high performance concrete came in market where attempt were made to modify the concrete at Nano level. The emergences of Nano technology comes in picture in 1980s.Since then lot of work are carried in this area. Despite of this use of nanotechnology for advancing concrete are not much popular in India.

II. NANO TECHNOLOGY

Nanotechnology is one of the advanced multidisciplinary technology, which are being used in various fields like Nano medicine, (ii) Environment, (iii) Energy (iv) nano batteries, (v) Information and communication (vi) Heavy industry etc. Nanotechnology. One of the most important requirement for the nano material used in concrete should have higher strength and lower density. Properties of the particle changes as they approach the nano size. At nano level the gravity forces become less influential, electrostatic forces become more important and quantum effect rises as particle becomes nano sized, the proportion of atoms on the surfaces increases relative to those inside which causes nano effects .It is believed that finer particles i.e particle of micro size or nano size have large surface area per unit volume which is important for cement and concrete. Large surface area of binder results in high early strength and also helps in increasing ultimate strength due to faster and more effective hydration reaction

Various nano materials, which are being used in construction industry or on which various researches are going on, are Nano Silica, Nano titania, Carbon Nanotubes, Carbon nano fiber, Nano Alumina, Nano $ZrCO_2$, Nano $CaCO_3$, Nano clay, Nano Fe_2O_3, Nano CuO etc.

III. APPLICATION OF NANO PARTICLES

A. *Nano SiO_2 (Nano Silica)*

Silica fume or micro silica is an industrial by-product from electric arc furnace. Many researches shows that if silica fumes is added in concrete, it increases the density, compressive strength, tensile strength, abrasion resistance and also resistance against chemical attack. These effects on concrete is caused due to the ability of silica fume to fill voids and improve interfacial transition zone. While its particle size is in range of 100-200 nm and surface area $20m^2/g$. similarly Nano-Silica, which is finer than silica fume, can show a better result in the enhancement of the properties of concrete.

Using reaction of nano silica with concrete ingredients, one can set the example for utility of nanomaterial in nano concrete. Following pozzolonic reaction take place in concrete using nano silica.
The addition of nano silica particles in concrete mix converts the weak Ca(OH)2 into strong CSH gel. Hence it can be said that nano particles fills the void at nano level and form extra more solidify CSH gel.

A.M. Said et al. (2012) investigated the mechanical strength, hydration time, temperature and Back scattered electron microscopy test on concrete sample containing 3% and 6% Nano silica with and without fly ash and found 18% increment in compressive strength, 25% increment in tensile strength and 55% reduction in chloride penetration. Hydration time also reduced and temperature on hydration increased, which showed the early strength gaining property. BSEM showed higher degree of hydration on 28^{th} days. As per the experimental work of Gengying Li(2004), it was found that Addition of nano-SiO2 to high-strength concrete also leads to an increase in both short term strength as well as long-term strength up to 10%. Mostafa Khanzadi et al. (2010) and Tao Ji (2005), Both has reported the concrete incorporating Nano silica has better permeability resistance and less water absorption capacity than the normal concretes. The microstructure of the Nano silica concrete is more uniform and denser than that of plain concrete.Nano-SiO2 reacts quickly with Ca(OH)2 crystal and produce C–S–H gel. This leads to absorption of Ca(OH)2 crystal and reduction of calcium hydroxide crystals. Now C–S–H gel can fill the voids to improve the density of the interfacial transition zone (ITZ) and the binding paste matrix.

$$C_3S+H_2O \longrightarrow CSH+ Ca(OH)_2+Heat\ Exhausted$$

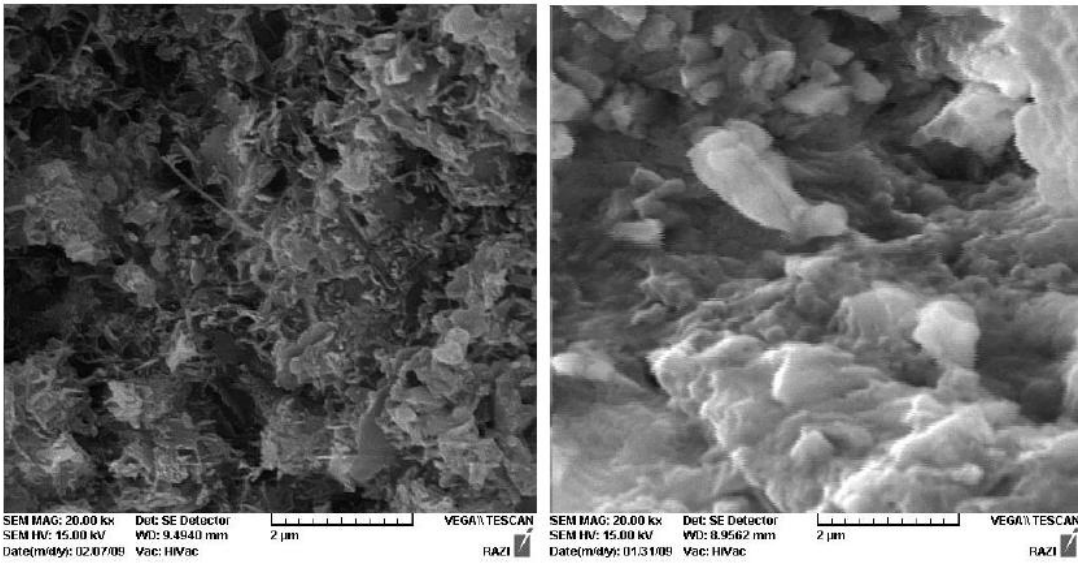

Fig.1:SEM of OPC Concrete & SEM of Nano Silica Concrete (Source: Mostafa.Khanzadi et al.(2010))

Steel fiber is also one of the additive material used for increment of strength and toughness parameter of concrete, but it increases the voids in concrete. Peng Zhang et al (2014) mixed 5% Nano silica with 2% steel fiber, which showed a better performance in both toughness and strength parameter without increasing voids.

B. ***Nano-TiO_2 (Nano Titanium Oxide)***

TiO2 Converts toxic (NOx) i.e. oxide of nitrogen into Nitrogen and oxygen. It is also called self-cleaning compound or photo catalytic concrete. It disintegrates organic pollutants into harmless CO_2 and water in presence of light. Products of reaction can be easily removed by water and thus also help in preventing deterring colour of the building.

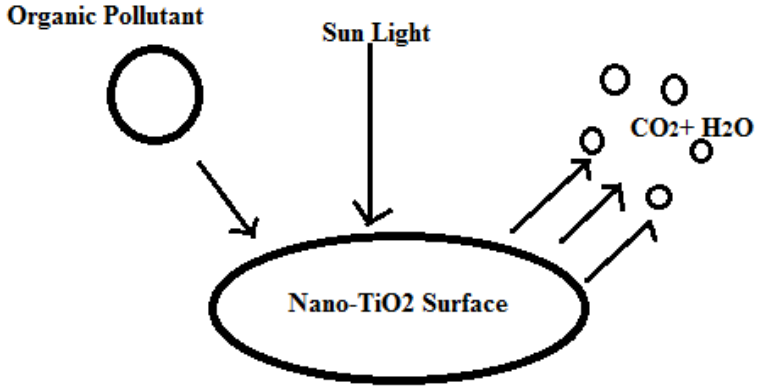

Fig2: Photo catalytic phenomena at Nano TiO_2 Surface

Baoguo Ma et al.(2015) discovered that addition of 3%Nano TiO_2 significantly increase the tensile strength (65.6%), flexural strength (61.9%), reduction in total pore volume and the harmful pores by 48.2% and 34.6%, respectively and reduction of water absorption ratio by 40–65%. Effect of Nano TiO_2 can be easily seen in SEM images. As per T. Maggos et al. (2008) Cementitious materials mixed with nano-TiO_2 shows the ability of air purification, T. Yuranova (2007) shows ability of self-cleaning and disinfection characteristics checked by C. A. Linkous(2000).

As per comparative study of Hui Li et al.(2006), between Polypropylene fiber, Nano Silica and Nano titanium, Polypropylene showed maximum increment in flexural and compressive strength, while Nano titanium showed better strength result of 10.28% increment in flexural strength and 18% increment in compressive strength at 1% addition. Best abrasion resistance result was also found by Nano titanium. Hui Li et al.(2007) further studied the flexural fatigue strength and got better result by Nano titanium.

C. ***Carbon Nano Tubes*** **(CNT)**

Carbon nanotubes are allotropes of carbon in a cylindrical tube shaped geometry, which diameter ranges from 1 to 100 nm and lengths varies up to a few millimeters. It can have a single layer of graphene rolled in a cylindrical shape or more than one layer. It's Young's modulus is 5 times, strength is 8 times more than steel, while density is 1/6th times. As per the study of li Geng et al. (2005), CNT increases higher bond strength due to a better interfacial interactions between carbon nanotubes and cement hydrates. It also help to bridges the cracks and voids during load-transfer in tension.

D. ***Carbon nano fiber (CNF)***

Carbon nanofibers are graphene layers, which is arranged as stacked cones, cups or plates not in cylindrical tubular form like nanotubes.Carbon Nanofibers (CNF) have an average diameter of 70 -200 nano meters (nm) and an average length of 50- 200 microns. It is considered superior as Carbon nanotubes. It is easier to produce and less in cost also.

Nur Yazdani et al. (2014) done comparative study and found the increment of 54% and 14% in compressive and flexural strength of cement composite by adding CNT 0.1 %, while increment of 67% and 8% compressive and flexural strengths of cement composite with addition of 0.1% CNF. But there was only issue of proper dispersion of nano material in cement matrix. But, Joshua Hogancamp et al.(2017) successfully dispersed CNF 5%(by wt of cement) by alcohol/sonication/distillation technique. CNF and CNT both are also called smart material due to its electrical and heat conductivity. These materials can be used for structural health monitoring because it helps to measure strains and temperature also.

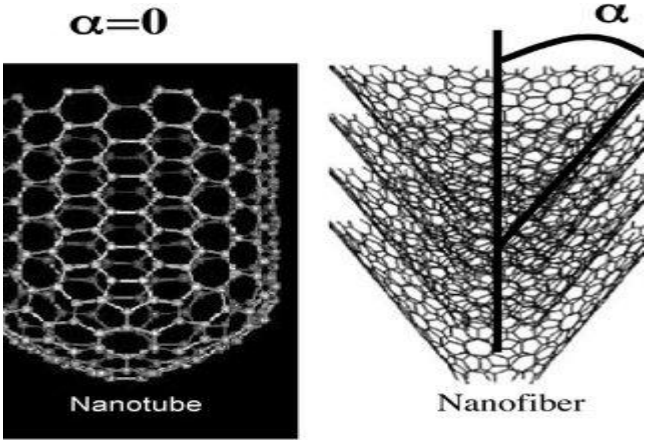

Fig3: Carbon Nano tube & Carbon Nano fiber [Source: Quoc Ngo et al. (2007)]

E. ***Nano-Al_2O_3(Nano Alumina)***

Nano-Al2O3 is also that type of nano particle, which efficiently fill the voids of cement matrix and therefore it is capable to increase the modulus of elasticity by 143% at 28 days by incorporation of 5% nano- Al2O3 (~ 150 nm particle size) [Zhenhua Li et al. 2006]. A proper mixing procedure was selected in order to ensure adherence of nano- Al2O3 particles on the sand surfaces. It is believed that during cement hydration, these nano-alumina particles were available to fill the pores at the sand-paste interfaces and created a dense ITZ with less porosity.

F. ***Nano ZrO_2 (Nano Zicronium oxide)***

It also helps in Reduction of porosity and permeability in concreter as well as enhancement of compressive strength and improvement in microstructure of cement matrix. A. Nazari et al.(2010) reported that addition of ZrO2 nanoparticles 2.0% by weight can increase the compressive, flexural and split tensile strength of concrete but also decreases the setting time and workability.

G. ***Nano Clay***

Organo-modified montmorillonites is generally used in polymer/clay nano-composites as fillers and reinforcements in cement mortars. Nano clay particles have also shown enhancement in the mechanical performance, the resistance to chloride penetration, self-compacting properties of concrete and reduction in permeability and shrinkage.

H. ***Other Nano materials***

Similarly other material in nano size shows same effects at different extent and addition with their special effects like nano-$CaCO_3$ accelerate heat of hydration and impact resistance, Fe_2O_3 nanoparticles decreases setting time and workability, nano-ZnO_2 reduces the demerits of superplastisizers. silver nanoparticles as an additive in paints can kill pathogenic microorganisms.

LIMITATION

Utilization of Nano particles in concrete or mortar enhances the properties of cement composites, but at some extent only. There are also some limitations in its application, which are following:

1. These should be used in optimal amount to get positive effects.
2. It has also some other effects like reduction in workability or change in setting time. Therefore, these materials should be added in concrete by considering all these effects.
3. Since these particles have size range in nano meters, therefore its surface area becomes very high, which increases the water demand to make concrete workable.
4. The process of mixing of nano materials in concrete requires skill to proper dispersion of nano materials in concrete.
5. These materials are not naturally occurring materials, therefore it requires a dedicated manufacturing plant and a well-defined manufacturing processes.
6. Production cost of Nano materials is generally high.
7. Exposure of nano material in environment can leads to serious environmental pollution. Due to its very small size and highly reactive in nature, it can harm human as well as other living creature. Carbon nanotubes can exert damage the lungs and the cell membrane. It can slow down the respiratory functions and harm the mitochondrial deoxyribonucleic acid (DNA).
8. Nano-silica is carcinogenic also.
9. Nano TiO_2 can damage DNA and cause cytotoxicity and inflammation in mammals.

CONCLUSION

The present study of inclusion of Nano materials in concrete showed a lots of benefits of nano technology in concrete with some limitation. Therefore, following conclusion can be drawn by this study.

1. Addition of nano materials can increase density, mechanical strength, impact resistance, abrasion resistance and also long term strength and durability also due to its size in nanometers.
2. Its chemical composition can affect other properties also like Nano Silica can convert Ca(OH)2 into useful C-S-H gel. Nano Alumina can increase the rate of hydration, while Nano Fe_2O_3 can decrease setting time. These materials can be used as per requirements.
3. Nano-TiO_2 can be utilized in paints and plastering of building. Wich can help to reduce indoor and outdoor pollution.
4. Carbon Nano tubes or Carbon Nano fibers can increase strength as well as can help in real time health monitoring of a structure.
5. Construction with nano materials requires skill and care. Because it is health hazardous also.

FUTURE SCOPE

As Nobel Laureate Richard Feyman in1959 said at the California Institute of Technology, “There is plenty of room at the bottom”. There is really a lots of scope in advancement of concrete with nano technology for efficient, smart and sustainable structures. Like- Nano material can be manufactured from natural process and natural occurring materials like rice husk ash etc. Effect of nano particles with fibers should be studied and this technology should be made more easy and eco-friendly.s

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