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Influence of Nano Materials in Concrete

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Abstract— *The strength of the concrete can be increased in various ways. We can add some kind of additives or some innovative materials to increase the strength of the concrete. Nano materials are one such material that can be added to the concrete mix to increase its strength. Molecular materials are poured into the concrete to add strength to the concrete during the concrete mix. Some of the nano-concrete mixtures are comprised of polyethylene or ethylene particles. Other nano-concrete uses the silicates from finely grounded clay. Another way to strengthen the concrete is to incorporate steel into the mix. It does not use fine particles. In this the concrete is poured over steel bars or cables that are woven into a mesh. The mesh is completely encapsulated into the concrete. Fibers can also be applied to the concrete during the mixing stage. Steel, polypropylene and other polymers are mixed into the concrete to reinforce it after drying.*

Keywords: *Strength of concrete, nano concrete, steel fiber reinforced concrete, silica fume, various fibers*

1. INTRODUCTION

Concrete has an extensive role to play in the construction and improvement of our civil engineering and infrastructure development. Its great strength, durability and veracity are the properties that are utilized in construction of Roads, Bridges, Airports, Railways, and Tunnels, Port, Harbours, and many other infrastructural projects. Concrete is used in infrastructure and in buildings. It is composed of granular materials of different sizes and the size range of the composed solid mix covers wide intervals. The overall grading of the mix, containing particles from 300 nm to 32 mm determines the mix properties of the concrete. The properties in fresh state (flow properties and workability) are for instance governed by the particle size distribution (PSD), but also the properties of the concrete in hardened state, such as strength and durability, are affected by the mix grading and resulting particle packing.

Concrete, the most popular construction material, second highest consumed material after food is very strong in compression. It has some limited properties, low tensile strength, low ductility, low energy absorption, and shrinkage, cracking associated with hardening and curing. Out of all these drawbacks low tensile strength is the important one and to counteract this problem some fiber like material can be added to concrete to increase its tensile strength. Some type of admixtures and some materials can affect the strength of the concrete in one way or the other. These materials can be added to the concrete to gain more strength.

2. USE OF NANO CONCRETE

The most active research areas dealing with cement and concrete are: understanding of the hydration of cement particles and the use of nano-size ingredients such as alumina and silica particles. There are also a limited number of investigations dealing with the manufacture of nano-cement. If cement with nano-size particles can be manufactured and processed, it will open up a large number of opportunities in the fields of ceramics, high strength composites and electronic applications. Nanotechnology is a very active research field and has applications in a number of areas. Nanotechnology deals with the production and application of physical, chemical, and biological systems at scales ranging from few nanometers to submicron dimensions, as well as the integration of the resulting nanostructures into larger systems. Nanotechnology also involves the investigation of matter at the level down to individual atoms. Fig.1 shows new nanomaterials based on metal and oxides of silicon and germanium demonstrate superplastic behaviour, undergoing elongations from 100 to 1000 % before failure.

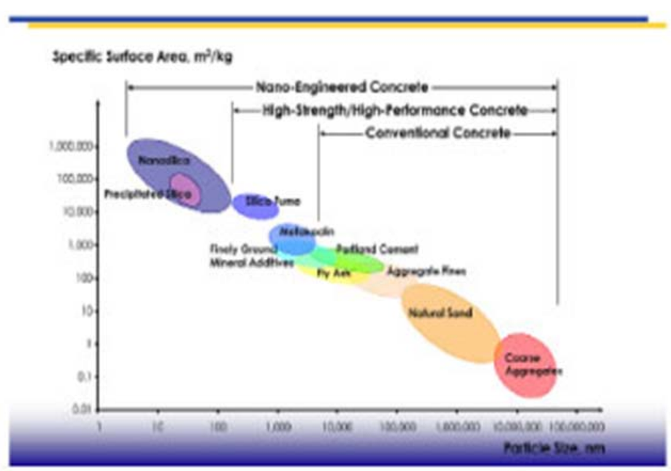

Fig. 1: The particle size and specific surface area scale related to concrete materials [9]

The details as to "bottom-up" synthesis of nano-SiO_2 (nano-Silicon Dioxide) particles and the effect of this material on the performance of cement systems were reported [9]. The nanoparticles of SiO_2 (with the size range of 10-100 nm) were synthesized using sol-gel method. Tetraethoxysilane (98% TEOS, supplied by Aldrich) was used as a precursor and the reaction was realized in an acidic (nitric acid solution at pH = 2) or base (ammonia solution at pH = 9) reaction media with ammonia as catalyst. The specimens of nano-SiO_2 were obtained at different experimental conditions (i.e. water-to-TEOS and ethanol-to-TEOS ratios)

Ultra-fine amorphous colloidal silica was found to be much more efficient than micron sized silica for improving the performance such as permeability, and subsequently, durability. In addition, reduced amount of about 15 to 20 kg of nano-silica was found to provide same strength as 60 kg of regular or micro silica. The increase of SiO_2 dosage improves the strength of the mortar.

Alkali Silica Reaction (ASR) results in the formation of alkali/silica gel, which expands and causes significant material damage. The gel is formed due to the reaction between cement alkalis and a reactive form of silica from aggregates or supplementary additions. Federal Highway Administration (FHWA) researchers are using neutron scattering and positron annihilation spectroscopy to measure nano-scale changes in gel microstructure as a function of gel chemistry, temperature and relative humidity.

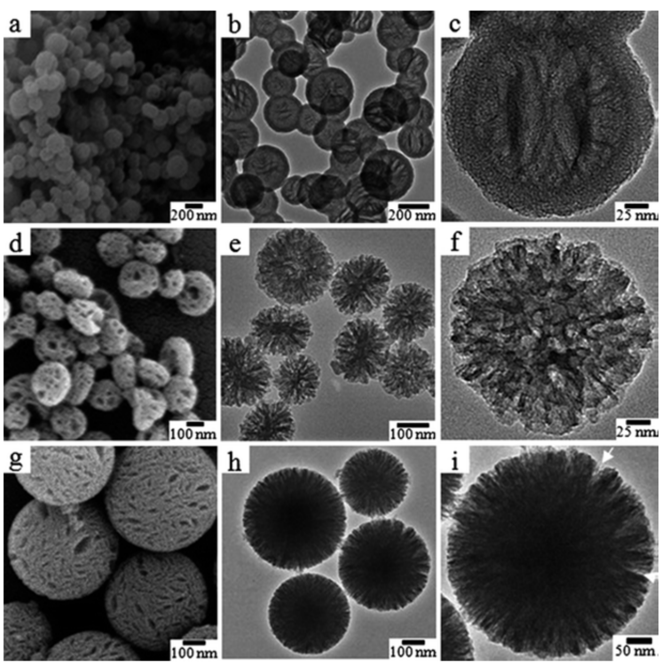

Fig. 2: Scanning Electron Microscope (SEM) (a,d,g) and Transmission Electron Microscope (TEM) (b,c,e,f,h,i) images of the fabricated hollow mesoporous silica nanoparticles (a–c) and nanoparticles with hierarchical pores[10]

A. Effect of nano-Silica (nS) addition in concrete and mortars

In concrete, the micro-silica works on two levels. The first one is the chemical effect: the pozzolanic reaction of silica with calcium hydroxide forms more Calcium Silicate Hydrate gel (CSH-gel) at final stages. The second function is physical one, because micro-silica is about 100 times smaller than cement. Micro-silica can fill the remaining voids in the young and partially hydrated cement paste, increasing its final density. Some researchers found that the addition of 1 kg of micro-silica permits a reduction of about 4 kg of cement, and this can be higher if nS is used. Another possibility is to maintain the cement content at a constant level but optimizing particle packing by using stone waste material to obtain a broad Particle Size Distribution (PSD). Optimizing the PSD will increase the properties (strength, durability) of the concrete due to the acceleration effect of nS in cement paste. Nano-silica addition in cement paste and concrete can result in different effects. The main mechanism of this working principle is related to the high surface area of nS, because it works as nucleation site for the precipitation of CSHgel. However, according to Bjornstrom et al. it has not yet been determined whether the more rapid hydration of cement in the presence of nS is due to its chemical reactivity upon dissolution (pozzolanic activity) or to their considerable surface activity. Also the accelerating effect of nS addition was established indirectly by measuring the viscosity change (rheology) of cement paste and mortars. The most reported effect of nS addition is the impact on the *mechanical properties of concrete and mortars* as the nS addition increases density, reduces porosity, and improves the bond between cement matrix and aggregates. The application of these concretes can be anywhere, both in infrastructure and in buildings. Nano-silica is applied in *HPC and SCC concrete* mainly as an anti-bleeding agent. It is also added to increase the cohesiveness of concrete and to reduce the segregation tendency. Some researchers found that the addition of colloidal nS (range 0 to 2% bwoc) causes a slight reduction in the strength development of concretes with ground limestone, but does not affect the compressive strength of mixtures with fly ash or ground fly ash (GFA).

B. Synthesis of Cement Using Nano-Particles

In a project supported by National Science Foundation, it has been synthesized the components of portland cement Type I using nano-particles and compared their properties with that of commercial cement. Scanning electron microscope (SEM) and X ray diffraction (XRD) equipment were used to evaluate the morphology and structure of synthesized tricalcium silicate (C_3S) components. Conglomerated nano-particles with crystalline structures containing quantities of tri- and di-calcium silicate compounds as well as copper oxide were found to be present in the synthesized cement. Hydration tests indicated that the nano-cement had a more rapid hydration rate than portland cement Types I and III. Compressive strength of the cement synthesized using nano-particles was found to be less than that of ordinary portland cement. The authors attributed this reduction to a number of factors including: particle aggregation, rapid hydration, a high water to cement ratio, and the lack of gypsum.

C. Carbon nano tubes

The most popular nano-tubes are carbon nano-tubes, discovered by the Japanese Scientist Sumio Iijima in 1991. The first nano-tubes discovered were multi-walled tubes. Transmission electron microscopy studies indicate that these tubes look like nested shells with an interlayer spacing of about 0.34 nm. The equivalent diameter of the tubes is in the range of 10 to 50 nm. The typical length varies from 100 to 1000nm. Single layer tube has a much smaller diameter (1 to 3 nm) and length (about 300 nm). The single layer tubes are often manufactured in “rope” or “bundled” form, where many individual tubes are closepacked in parallel.

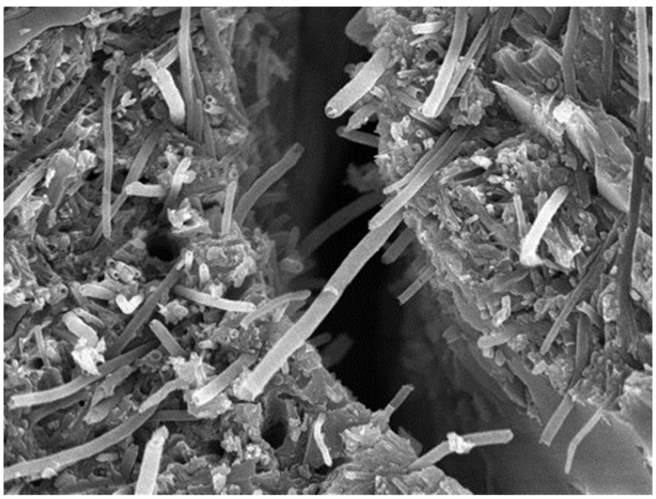

Fig. 3: Electron microscope scan of carbon nanofibers bridging crack in a cementitious composite [11]

3. STEEL FIBER REINFORCED CONCRETE

Fiber reinforced concrete (FRC) may be defined as a composite materials made with Portland cement, aggregate, and incorporating discrete discontinuous fibers. When the fiber reinforcement is in the form of short discrete fibers, they act effectively as rigid inclusions in the concrete matrix. Physically, they have thus the same order of magnitude as aggregate inclusions; steel fiber reinforcement cannot therefore be regarded as a direct replacement of longitudinal reinforcement in reinforced and prestressed structural members. However, because of the inherent material properties of fiber concrete, the presence of fibers in the body of the concrete or the provision of a tensile skin of fiber concrete can be expected to improve the resistance of conventionally reinforced structural members to cracking, deflection and other serviceability conditions.

Steel Fiber Reinforced Concrete (SFRC) can be produced using conventional concrete practices. The performance of the hardened concrete is enhanced more by fibers with a higher aspect ratio, since this improves the fiber-matrix bond. On the other hand, a high aspect ratio adversely affects the workability of the fresh mix. When using a transit mix truck or revolving drum mixer, the fibers should be added last to the wet concrete. The concrete alone, typically, should have a slump of 50-75 mm greater than the desired slump of the SFRC. Of course, the fibers should be added free of clumps, usually by first passing them through an appropriate screen. Once the fibers are all in the mixer, about 30-40 revolutions at mixing speed should properly disperse the fibers.

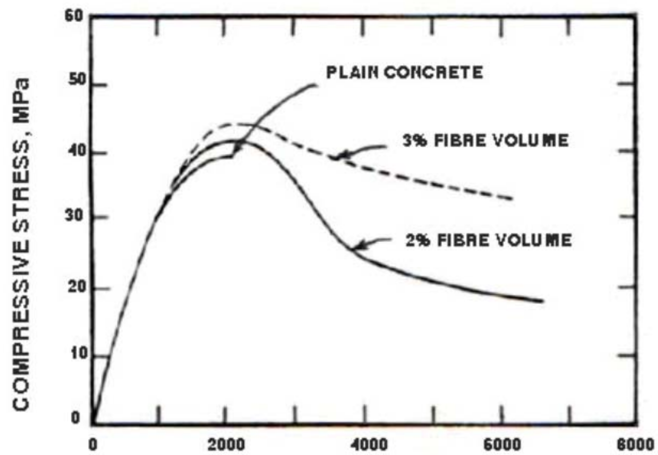

Fig. 4: Stress Strain curve in compression for SRFC [12]

A. Compressive strength

Fibers do little to enhance the static compressive strength of concrete, with increases in strength ranging from essentially nil to perhaps 25%. Even in members who contain conventional reinforcement in addition to the steel fibers, the fibers have little effect on compressive strength. However, the fibers do substantially increase the post-cracking ductility, or energy absorption of the material

B. Tensile Strength

Fibers aligned in the direction of the tensile stress may bring about very large increases in direct tensile strength, as high as 133% for 5% of smooth, straight steel fibers. However, for more or less randomly distributed fibers, the increase in strength is much smaller, ranging from as little as no increase in some instances to perhaps 60%.

C. Flexural Strength

Steel fibers are generally found to have aggregate much greater effect on the flexural strength of SFRC than on either the compressive or tensile strength, with increases of more than 100% having been reported. The increases in flexural strength are particularly sensitive, not only to the fiber volume, but also to the aspect ratio of the fibers, with higher aspect ratio leading to larger strength increases.

As recommended by American Concrete Institute (ACI) Committee 544 [13], 'when used in structural applications, steel fiber reinforced concrete should only be used in a supplementary role to inhibit cracking, to improve resistance to impact or dynamic loading, and to resist material disintegration. In structural members where flexural or tensile loads will occur, the reinforcing steel must be capable of supporting the total tensile load. Thus, while there are a number of techniques for predicting the strength of beams reinforced only with steel fibers, there are no predictive equations for large SFRC beams, since these would be expected to contain conventional reinforcing bars as well.

4. INFLUENCE OF SILICA FUME IN CONCRETE

The silica fume is a better replacement of cement. The rate of strength gain in silica fume concrete is high. With the increase in w/cm ratio strength of concrete decreases. The optimum value of compressive strength can be achieved in 10% replacement of silica fume. As strength of 15% replacement of cement by silica fume is more than normal concrete. The optimum silica fume replacement percentage is varies from 10 % to 15 % replacement level. Workability of concrete decreases as increase with % of silica fume. Compressive strength decreases when the cement replacement is above 15% of silica fume.

5. FIBER REINFORCED POLYMERS

Fiber Reinforced Polymers (FRPs) are made of long and continuous fibers (e.g. glass, carbon, etc.) bonded together with a resin matrix. The fibers provide the composites with their unique structural properties. The resin serves as the bonding agent to protect the fibers and to distribute the load among them. The most common type resins are polyesters, vinyl esters and epoxies. Anisotropy is a major advantage of FRPs; depending on the type of application, the fibers can be oriented in a multitude of directions to enhance the mechanical properties of the composite in the desired direction. A variety of fabric geometry and strength can be produced. The more common ones are unidirectional fabrics where all fibers are aligned in a single direction or biaxial fabrics where the fibers are placed in orthogonal directions. The fabric thickness is typically less than 2 mm and the addition of the resin matrix adds very little to the overall thickness. Depending on the required strength enhancement, two or more layers of fabric can be applied.

FRPs generally behave linearly elastic to failure. Carbon fibers, for example, have a tensile strength of over 2700 MPa and a modulus of elasticity of about 120 GPa. However, due to the progressive fracture of fibers, it is very difficult to achieve such high stresses in sections consisting of a large number of fibers. Furthermore, in most cases, the fibers account for 60% to 70% of the volume of the composite, with resins making up the balance. Due to the limited contribution of resin to the strength and stiffness, carbon FRPs have tensile strength in the range of 700 to 1000 MPa and modulus of elasticity of about 70 GPa.

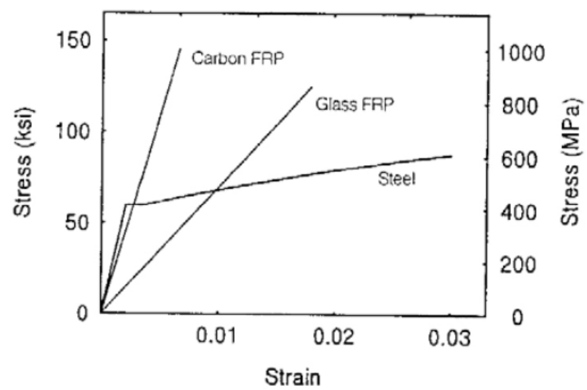

Fig. 5: Stress Vs Strain behavior of Steel and FRP's [14]

A. Construction Procedure

Strengthening of structures with FRPs consists of a number of steps. First, the substrate surface that is to receive the FRP must be cleaned of any paint or other coating; this is usually achieved with sandblasting or water-blasting the surface. Next, a very thin layer of primer is applied to the cleaned surface; the primer is very low in viscosity and can be sprayed or brushed like paint. In the third stage, a layer of tack coat, about 1mm thick is applied; the tack coat is a high-viscosity epoxy with superior structural properties and is one of the most critical components of the system. The tack coat has a relatively long pot life and will remain tacky for two to three hours. The fourth stage involves bonding of the saturated fabric to the tack coat; this can be best achieved by running the fabric through an impregnator machine to ensure uniform saturation.

The impregnator machine consists of two large rollers between which the fabric is passed while the saturating resin is introduced. The saturated fabric coming out of these rollers is wrapped around a removable mandrel (e.g. pipe). The fabric is applied to the tack coat and is pressed on to ensure complete bond and removal of any air bubbles. The flexibility of the fabric allows it to be passed through narrow openings and locations where access is limited. If required, additional layers of saturated fabric can be applied. The system will dry in ambient temperature within a few hours and it will fully cure in five to seven days.

FRPs can be employed in many applications as a substitute for steel that has been traditionally used for its high tensile strength. These include strengthening for flexure, shear, and confinement.

Fig. 6: Impregnator Machine [14]

The initial developments of this concept took place in Germany where thick glass (GFRP) plates were used and in Switzerland where thin sheets of carbon (CFRP) were utilized (Meier 1987). These studies showed the validity of the strain compatibility method in the analysis of cross sections and suggested that inclined cracking may lead to premature failure by peeling-off of the strengthening sheet. Kaiser's study included the development of an analytical model for the composite plate anchoring which is in good agreement with test results (Kaiser 1989). In one of the earliest reported studies on this subject, five beams each having a cross-section of 90 x 153 mm and a length of 1.68 m were constructed. The beams were reinforced with a single 9- mm mild steel bar (Saadatmanesh and Ehsani 1990). Using a different epoxy for each beam, the beams were strengthened by bonding a 6x75 mm GFRP plate to the tension face. It was concluded that the success of this technique is greatly dependent on the use of a suitable epoxy and that the epoxy should have sufficient stiffness, strength and also toughness such as rubber toughened epoxies.

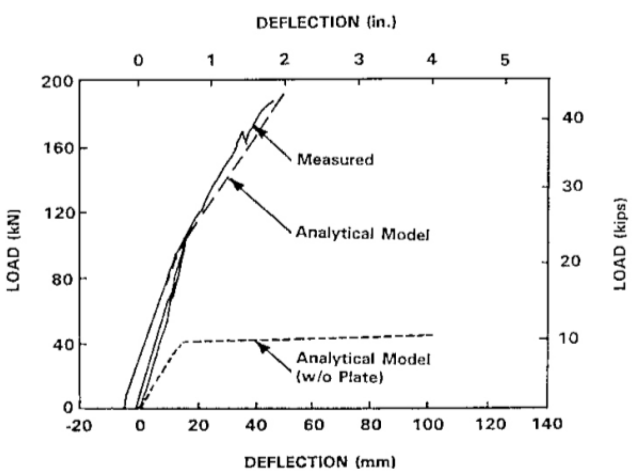

Fig. 7: Load vs. deflection response of beam retrofitted with GFRP [15]

6. ADDITION OF VARIOUS FIBERS

A. Glass Fiber Reinforced Concrete (GFRC)

Glass fiber reinforced concrete has been successfully used since the last 25 years for concrete reinforcement, in addition to steel. GFRC is being manufactured into big panels with a simple configuration or into intricate shapes by using special techniques. Originally, GFRC components were anchored directly with the buildings by the use of metal studs.

B. Steel Fiber Reinforced Concrete (SFRC)

Steel fiber reinforced concrete is a composite material that can be sprayed. It consists of hydraulic cements with steel fibers that are dispersed randomly and possess a rectangular cross-section. The steel fibers reinforce concrete by withstanding tensile cracking. The flexural strength of fiber reinforced concrete is greater than the un-reinforced concrete.

C. Natural fiber reinforced concrete (NFRC)

It consists of cellulose fibers that are processed from pine trees. This category is also producing good results. The recycled carpet waste has been successfully used for concrete reinforcement by using the waste carpet fibers.

D. Polypropylene Fiber Reinforced (PFR) concrete

Polypropylene is a cheap and abundant polymer widely used due to its resistance to forming chemical reactions.

E. Asbestos Fibers

These fibers are cheap and provide the cement with mechanical, chemical and thermal resistance, although the asbestos fiber reinforced concrete appears to have low impact strength.

F. Carbon Fibers

These fibers have been recently used due to their very high modulus of elasticity and flexural strength. Characteristics such as strength and stiffness are better than those of steel fibers, although they are more susceptible to damage.

7. CONCLUSION

Concrete is the material that is used worldwide for construction. From the study conducted on the strengthening of the concrete it was found that Nano- concrete is one of the material that can provide desirable strength to the concrete. Another solution can be done by using Steel fiber reinforced concrete. Silica flumes influence concrete at a higher rate. So silica fumes can also be used for strengthening of concrete. Fiber reinforced polymers are another solution for increasing the strength of the concrete. Addition of various fibers can also increase the strength of the concrete.

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