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APPLICATION OF NANOTECHNOLOGY IN IMPROVING THE PERFORMANCE OF CEMENTITIOUS COMPOSITES

SYNOPSIS

In recent years, the world of science has started to produce new materials and to study their properties using nanotechnology. The use of nanotechnology has become wide spread in all branches of science and technology. In this study, the use of nano powders in cement matrix and concrete have been summarized and evaluated. The influence of nano particles such as nano silica fumes and nano fly ash in cement matrix and concrete was studied with reference to normal size particle cement matrix and normal size concrete. The morphology of nano particles was studied using Transmission Scanning Election Microscopy (TEM) and electron microscope. Also, X-ray diffraction (XRD) of all the mineral additions was studied. The results indicated that the addition of nano particles improves the properties of cement matrix and concrete.

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CHAPTER 1

INTRODUCTION

1.1 General

Nanotechnology seems to hold the key that allows construction and building materials to replicate the features of natural systems improved until perfection during millions of years. This project reviews current knowledge about nanotechnology and nanomaterials used by the researchers. It covers the nanoscale analysis of Portland cement hydration products, the use of nanoparticles to increase the strength and durability of cimentitious composites, the photocatalytic capacity of nanomaterials and also nanotoxicity risks.

1.2 Nanotechnology

Nanotechnology was introduced by Nobel laureate Richard P. Feynman during his now famous 1959 lecture ‘‘There’s Plenty of Room at the Bottom,” there have been many revolutionary developments in physics, chemistry, and biology that have demonstrated Feynman’s ideas of manipulating matter at an extremely small scale, the level of molecules and atoms, i.e., the nanoscale. While the meaning of ‘‘nanotechnology” varies from field to field and country to country and is widely used as a ‘‘catch all” description for anything very small. Nanotechnology is commonly defined as the understanding, control, and restructuring of matter on the order of nanometers (i.e., less than 100 nm) to create materials with fundamentally new properties and functions.

Nanotechnology encompasses two main approaches: (i) the ‘‘topdown” approach, in which larger structures are reduced in size to the nanoscale while maintaining their original properties without atomic-level control (e.g., miniaturization in the domain of electronics) or deconstructed from larger structures into their smaller, composite parts and (ii) the ‘‘bottom-up” approach, also called ‘‘molecular nanotechnology” or ‘‘molecular manufacturing,” introduced by Drexler et al., in which materials are engineered from atoms or molecular components through a process of assembly or self-assembly (figure 1). While most contemporary technologies rely on the ‘‘top-down” approach, molecular nanotechnology holds great promise for breakthroughs in materials and manufacturing, electronics, medicine and healthcare, energy, biotechnology, information technology, and national security.

1.3 Application of Nanotechnology in Civil Engineering

Nanotechnology is one of the most active research areas with both novel science and useful applications that has gradually established it in the past two decades. Expenditure on nanotechnology research is significant; however, the research is continuously moving forward motivated by immediate profitable return generated by high value commercial products. The Architecture, Engineering, and Construction (A/E/C) industry might accommodate broad applications of nanotechnology and nanaomaterials. It has been demonstrated that nanotechnology generated products have many unique characteristics, and can significantly fix current construction problems, and may change the requirement and organization of construction process. This project examines and documents applicable nanotechnology based products that can improve the overall competitiveness of the construction industry. The areas of applying nanotechnology in construction will be mainly focused on:

I. Lighter and stronger structural composites
II. Low maintenance coating
III. Better properties of cementitious materials
IV. Reducing the thermal transfer rate of fire retardant and insulation
V. Construction related Nano-sensors.

1.4 Nanotechnology for Cementitious Composites

Cementitious materials are typically characterized as quasi-brittle and susceptible to cracking. As concrete is loaded, initially, short and discontinuous microcracks are created in a distributed manner. These microcracks coalesce to form large macroscopic cracks, known as macrocracks. Fibers are incorporated into cementitious matrices to control cracking by bridging the cracks during loading and transferring the load. Research recently conducted has led to significant improvement of the mechanical properties of cement based materials. However, while microfibers delay the development of formed microcracks, they do not stop their initiation. The development of new nanosized fibers has opened a new field for nanosized reinforcement within concrete. The incorporation of fibers at the nanoscale will allow the control of the matrix cracks at the nanoscale level and essentially create a new generation of a "crack free material". Research on investigating the changes in nanoscale properties with the addition of different nanofibers is in progress. The ultimate goal of this project is to develop nano-engineered materials with improved properties and to investigate the changes in the nanostructure, fracture properties, transport properties and durability of cement based nanocomposites reinforced with highly dispersed nanofibers.

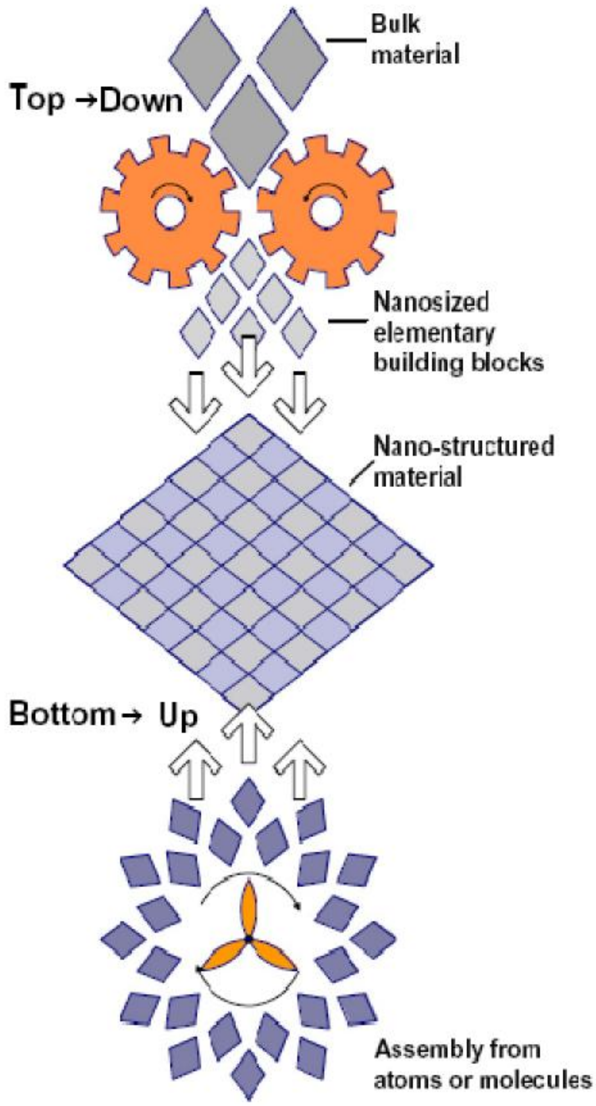


Fig. 1. Illustration of the ''top-down" and ''bottom-up" approaches in nanotechnology ***(*****Sanchez et al., 2010*****)***

1.5 Objective of the Study

Concrete is one of the most common and widely used construction materials. Typical reinforcement of concrete is usually provided at the macro and micro scale using macrofibers and microfibers, respectively. Although cementitious construction materials are primarily used in a large scale basis and in enormous quantities, fundamental properties of these materials such as strength, ductility, early age rheology, creep and shrinkage, fracture behaviour, durability depend to a great extent on structural elements and phenomena which are effective at micro- but most important at nanoscale. Cementitious materials are typically characterized as quasi-brittle and susceptible to cracking. As concrete is loaded, initially, short and discontinuous microcracks are created in a distributed manner. These microcracks coalesce to form large macroscopic cracks, known as macrocracks. Fibers are incorporated into cementitious matrices to control cracking by bridging the cracks during loading and transferring the load. Research recently conducted has led to significant improvement of the mechanical properties of cement based materials. However, while microfibers delay the development of formed microcracks, they do not stop their initiation. The development of new nanosized fibers has opened a new field for nanosized reinforcement within concrete. The incorporation of fibers at the nanoscale will allow the control of the matrix cracks at the nanoscale level and essentially create a new generation of a "crack free material".

Research on investigating the changes in nanoscale properties with the addition of different nanofibers is in progress. The ultimate goal of this project is to develop nano-engineered materials with improved properties and to investigate the changes in the nanostructure, fracture properties, transport properties and durability of cement based nanocomposites reinforced with highly dispersed nanofibers. The project results will find wide applications for highway structures, bridges, pavements, runways for airports, and in general in all applications of conventional and high strength concrete, as well as in manufactured precast elements for residential and commercial buildings.

1.6 Scope of the Study

This project reviews the state of the field of nanotechnology in cement and concrete. The impact of recent advances in materials science and their use in cement and concrete research is discussed. Recent progress in nano-engineering and nanomodification of cement-based materials is presented.

To date, nanotechnology applications and advances in the construction and building materials fields have been uneven. Exploitation of nanotechnology in concrete on a commercial scale remains limited with few results successfully converted into marketable products. The main advances have been in the nanoscience of cementitious materials with an increase in the knowledge and understanding of basic phenomena in cement at the nanoscale (e.g., structure and mechanical properties of the main hydrate phases, origins of cement cohesion, cement hydration, interfaces in concrete, and mechanisms of degradation). Recent strides in instrumentation for observation and measurement at the nanoscale are providing a wealth of new and unprecedented information about concrete, some of which is confounding previous conventional thinking.

1.7 Concluding Remarks

In recent years, the world of science has started to produce new materials with new researches aim at exploring modified properties using nanotechnology. The use of nanotechnology has become wide spread in all branches of science. So, studies of nano-scale should be increased for concrete technology. The main developments in the field of nanotechnology and nanoscience research in cement and concrete have been thoghroghly reviewed and investigations have been undertaken to explore application of nanotechnology in improving the performance of cementitious composites.

CHAPTER 2

LITERATURE REVIEW

2.1 General

During the period of the second half of the previous century, the terms "nano-science" and "nonotechnology" were not yet familiarly used as today, however they were really practiced and successfully applied to the progress in the field of material science and technology. Concrete performance is strongly dependent on nano-size dimensions of solid material such as C-S-H particles or voids such as the gel porosity in the cement matrix and the transition zone at the interface of cement paste with aggregate or steel reinforcement, typical properties affected by nano-sized particles are strength, durability, shrinkage and steel-bond. The word nano means anything of size 10^{-9}, nano particles is a solid particle of having size in the range 1 to 100 nm. The purpose of the present work is to study a new material in the dimension range between "micron " and " nano " size , this material is nano silica (Nano-$Si0_2$) which added to new super plasticizer (polycarboxylic ether polymerd based PCE Sky) to improve workability , strength and durability of high-performance and selfcompacted concrete. There are few studies on the application of nano-technology in concrete production summarized below: Collepardi S. et al., studied the influence of nano-sized mineral additions on performance of self-compacted concrete and found that Poly-functional super plasticizers are able to keep the initial slump for at least 1.0 hour without any retarding effect on the early strength and also reduce drying shrinkage. Soblev K. et al. used polycarboxylic ether polymer based PCE Sky mixed with nano $Si0_2$ to improve workability and strength of high-performance and self-compacted concrete. Ferrada M.G. Studied the use of commercial nano admixture for concrete called Gaia to substitute for silica fume at ready-mixed and achieved two fold increase in concrete compressive strength at the age of 7 and 28-days, he used cement content 460 kg/m^3 at ambient temperature 20ºC.

Sobolev K. and Ferrada M.G., studied the application of Gaia super plasticizer containing nano-$Si0_2$ particles at a dosage of 1.3% by weight of cementitious materials and found that there is an increase in concrete compressive strength (100-150) % at the age of 7 and 28 days when used the above superplasticizer mixed with nano $Si0_2$ and this was dependent on w/c ratio. Remzi S. and Meral O., made a literature review on the researches studied the effect of nano powders on cement paste, mortar and concrete and found that the use of nano powders in concrete technology affects the cement kinetics and accelerates hydration significantly due to larger surface area, stronger electrostatic forces of nano powders, and due to improvement in the microstructures of concrete having nano powders. Li G. studied the properties of high volume fly ash concrete incorporating nano-$Si0_2$ and found that the addition of nano-$Si0_2$ can activates fly ash, leads to an increase of both short-term and long term strength, and acts as an accelerating additive leading to more compact structure even at short curing times. Zhang G. studied the effect of blending CPE (carboxylic polymer ether) to nano-$Si0_2$ and found that the addition of nano-$Si0_2$ to CPE polymer increases strength, flexibility and aging resistance since nano-$Si0_2$ interpenetrates polymer networks. Hui Li studied the flexural fatigue performance of concrete containing nano- particles (nano-$Si0_2$ and nano-$Ti0_2$) for pavements and found that the fatigue of concretes containing nano - particles follows the double – parameter weibull distribution , the flexural fatigue performance of concretes containing nano-particles is improved significantly especially when contained nano-$Ti0_2$ in the amount of 1% by weight of binder, which is much better than that of concrete containing polypropylene fibers (PP) which has been extensively used to improve fatigue performance of concrete pavements.

Sobolev K. carried out an investigation study nano materials and nanotechnology for high-performance cement composites and found that the major problem of nano-$Si0_2$ application is strength loss at later ages due to the agglomeration of nano particles (30-100 nm) at the final drying stage of sol-gel method which can be solved using acrylic polymer based super plasticizer called Gaia at a dosage of 1.3% by weight of cementitious materials , also Sobolev K. found that high-temperature treatment at (400ºc or more) of nano-$Si0_2$ concrete affects the performance of these additives and must be avoided. Jorge IV carried out an investigation about Portland cement blended with nano particles and found that nanotechnology is a new topic in cement industry to produce high performance concretes , since there is mineralogy modifications of cement paste and mortars occurred due to the incorporation of nano particles like nano-$Si0_2$, nano-$Ti0_2$. R. Abbas carried out an investigation to study the influence of Nano-Silica addition on properties of conventional and ultra-high performance concretes and found that nano- Silica (NS) concretes requires additional amount of water to maintain the same workability, also nano-silica addition resulted in significant early increase in compressive, splitting and flexural strengths of concrete in case of high cement content and low w/c ratio . Also, addition of 5% nano-silica leads to an increase 50% in 7-day compressive strength and 40% in 28-day compressive strength when compared with the same concrete without nano-silica.

2.2 Nanotechnology and Concrete

2.2.1 Concrete

Concrete, the most ubiquitous material in the world, is a nanostructured, multi-phase, composite material that ages over time. It is composed of an amorphous phase, nanometer to micrometer size crystals, and bound water. The properties of concrete exist in, and the degradation mechanisms occur across, multiple length scales (nano to micro to macro) where the properties of each scale derive from those of the next smaller scale [Sanchez F et al., 2009]. The amorphous phase, calcium–silicate–hydrate (C–S–H) is the ‘‘glue” that holds concrete together and is itself a nanomaterial. Viewed from the bottom-up, concrete at the nanoscale is a composite of molecular assemblages, surfaces (aggregates, fibers), and chemical bonds that interact through local chemical reactions, intermolecular forces, and intraphase diffusion. Properties characterizing this scale are molecular structure; surface functional groups; and bond length, strength (energy), and density. The structure of the amorphous and crystalline phases and of the interphase boundaries originates from this scale. The properties and processes at the nanoscale define the interactions that occur between particles and phases at the microscale and the effects of working loads and the surrounding environment at the macroscale. Processes occurring at the nanoscale ultimately affect the engineering properties and performance of the bulk material. [Garboczi EJ, 1996; Garboczi EJ, 1998; Xi Y et al., 2000]

2.2.2 Use of Nanotechnology in Concrete

The nanoscience and nano-engineering, sometimes called nanomodification, of concrete are terms that have come into common usage and describe two main avenues of application of nanotechnology in concrete research [Scrivener KL. et al., 2009;

Raki L et al., 2009]. Nanoscience deals with the measurement and characterization of the nano and microscale structure of cement-based materials to better understand how this structure affects macroscale properties and performance through the use of advanced characterization techniques and atomistic or molecular level modeling. Nano-engineering encompasses the techniques of manipulation of the structure at the nanometer scale to develop a new generation of tailored, multifunctional, cementitious composites with superior mechanical performance and durability potentially having a range of novel properties such as: low electrical resistivity, self-sensing capabilities, self-cleaning, selfhealing, high ductility, and self-control of cracks. Concrete can be nano-engineered by the incorporation of nanosized building blocks or objects (e.g., nanoparticles) to control material behavior and add novel properties, or by the grafting of molecules onto cement particles, cement phases, aggregates, and additives (including nanosized additives) to provide surface functionality, which can be adjusted to promote specific interfacial interactions.

2.3 Nano- Engineering of Cement Based Materials

Nano-engineering, or nanomodification, of cement is a quickly emerging field. Synthesis and assembly of materials in the nanometer scale range offer the possibility for the development of new cement additives such as novel superplasticizers, nanoparticles, or nanoreinforcements. Methodologies for hybridization and grafting of molecules allow for the direct manipulation of the fundamental structure of cement phases. These techniques can be used effectively in a bottom-up approach to control concrete properties, performance, and degradation processes for a superior concrete and to provide the material with new functions and smart properties not currently available. Engineering concrete at the nanoscale can take place in one or more of three locations in the solid phases, in the liquid phase, and at interfaces, including liquid–solid and solid–solid interfaces. While nano-engineering of cement-based materials is seen as having tremendous potential, nonetheless, several challenges will need to be solved to realize its full potential, including the proper dispersion of the nanoscale additives, scale-up of laboratory results and implementation on larger scale, and a lowering of the cost benefit ratio. The following summarizes the effects of the addition of nanoparticles and nanoreinforcements to cement and the recent developments in hybridization of hydrated cement phases. [Scrivener KL et al., 2008]

2.3.1 Addition of Nanosized Materials

For millennia, nanoparticles have been added to the production of ceramics; however, it is their conscious, scientific utilization that constitutes nanotechnology. Nanosized particles have a high surface area to volume ratio (Fig. 2.1), providing the potential for tremendous chemical reactivity. Much of the work to date with nanoparticles has been with nano-silica (nano-Si02) and nano-titanium oxide (nano-TiO2) [Bjornstrom J, 2004; Li H, 2004; Qing Y, 2007; Lin DF, 2008]. There are a few studies on incorporating nano-iron (nano-Fe2O3), nano-alumina (nano-Al2O3), and nanoclay particles. Additionally, a limited number of investigations are dealing with the manufacture of nanosized cement particles and the development of nanobinders. Nanoparticles can act as nuclei for cement phases, further promoting cement hydration due to their high reactivity, as nanoreinforcement, and as filler, densifying the microstructure and thereby, leading to a reduced porosity. The most significant issue for all nanoparticles is that of effective dispersion. Though it is particularly significant at high loadings, even low loadings experience problems with self-aggregation, which reduces the benefits of their small size and creates unreacted pockets leading to a potential for concentration of stresses in the material.

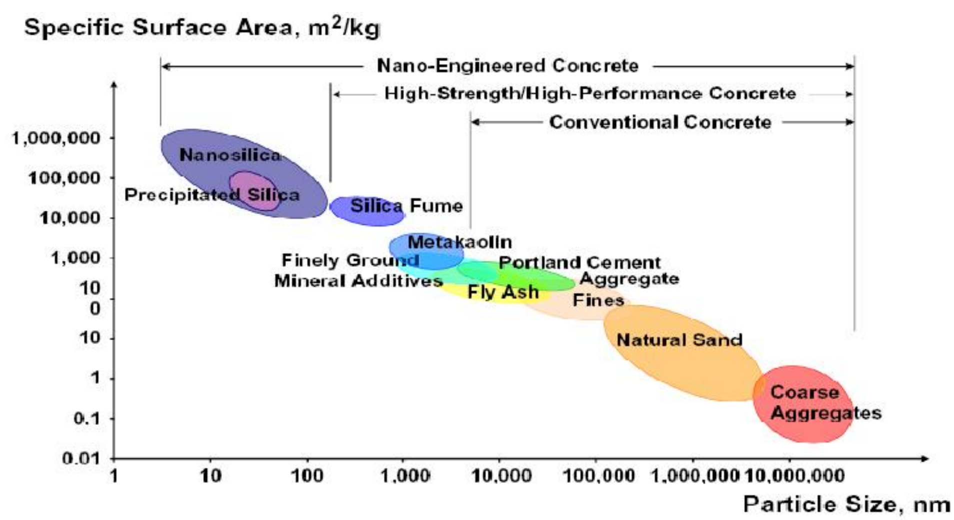


Figure2.1 Particle size and specific surface area related to concrete materials. ((*Sobolev et al., 2010.)*

Nano-Si02 has been found to improve concrete workability and strength, to increase resistance to water penetration, and to help control the leaching of calcium, which is closely associated with various types of concrete degradation. Nano-Si02, additionally, was shown to accelerate the hydration reactions of both C3S and an ash–cement mortar as a result of the large and highly reactive surface of the nanoparticles. Nano-Si02 was found to be more efficient in enhancing strength than silica fume. Addition of 10% nano-Si02 with dispersing agents was observed to increase the compressive strength of cement mortars at 28 days by as much as 26%, compared to only a 10% increase with the addition of 15% silica fume (Fig. 2.2) [Bjornstrom J et al., 2004; Lin KL et al, 2008]. Even the addition of small amounts (0.25%) of nano-Si02 was observed to increase the strength, improving the 28 day compressive strength by 10% and flexural strength by 25%. It was noted that the results obtained depended on the production route and conditions of synthesis of the nano-Si02 (e.g., molar ratios of the reagents, type of reaction media, and duration of the reaction for the sol–gel method) and that dispersion of the nano-Si02 in the paste plays an important role. Nano-Si02 not only behaved as a filler to improve the microstructure but also as an activator to promote pozzolanic reactions.

Nano-TiO2 has proven very effective for the self-cleaning of concrete and provides the additional benefit of helping to clean the environment. Nano-TiO2 containing concrete acts by triggering a photocatalytic degradation of pollutants, such as NOx, carbon monoxide, chlorophenols, and aldehydes from vehicle and industrial emissions. A detailed discussion of the mechanisms of TiO2-based photocatalysis can be found in. ‘‘Self-cleaning” and ‘‘de-polluting” concrete products are already being produced by several companies for use in the facades of buildings and in paving materials for roads and have been used in Europe and Japan (e.g., the Jubilee Church in Rome, Italy; a 230-m long stretch of road surfaces outside of Milan, Italy). In addition to imparting self-cleaning properties, a few studies have shown that nano-TiO2 can accelerate the early-age hydration of portland cement, improve compressive and flexural strengths, and enhance the abrasion resistance of concrete. However, it was also found that aging due to carbonation may result in loss in catalytic efficiency. [Vallee F et al., 2004; Murata Y et al, 2009; Lackhoff M et al., 2003].

Nano-Fe2O3 has been found to provide concrete with self-sensing capabilities as well as to improve its compressive (Fig. 2.2) and flexural strengths. The volume electric resistance of cement mortar with nano-Fe2O3 was found to change with the applied load, demonstrating that mortar with nano-Fe2O3 could sense its own compressive stress. Such sensing capabilities are invaluable for real-time, structural health monitoring and for the construction of smart structures as they do not involve the use of embedded or attached sensors. Nano-Al2O3 has been shown to significantly increase the modulus of elasticity but to have a limited effect on the compressive strength, and no novel properties have been reported. [Li Z et al., 2006]

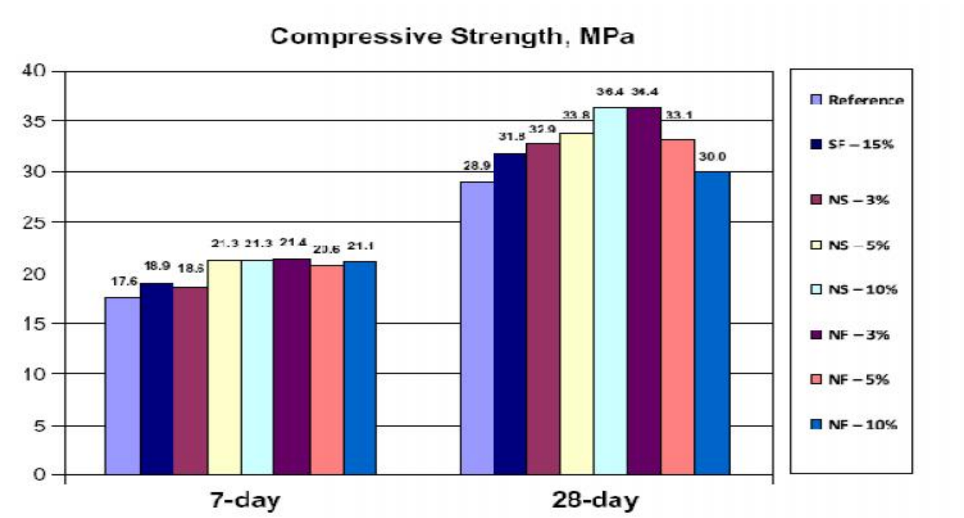


Figure 2.2 Compressive strengths of cement mortars with different dosage of nano-Si02 (NS) and nano-Fe2O3 (NF) vs. reference portland cement and silica fume (SF) mortars.
(Li H et al., 2004.)

2.3.2 Addition of Nano-Structured Materials

Nanosized cement particles and nanobinders have been proposed as a way to improve cement performance while reducing carbon emissions. Two avenues have been reported for creating nanosized cement particles: (i) high energy milling of conventional Portland cement clinker (top-down approach) and (ii) chemical synthesis (bottom-up approach). Cement pastes made with nanosized cement particles have shown faster setting times and an increase in early compressive strength compared to pastes prepared with common, commercially available cement.

Recently, the concept of a nanobinder has been proposed. This concept involves mechano-chemical activation that is obtained by inter-grinding cement with dry mineral additives in a ball mill. Mechano-chemical modification of cement with high volumes of blast furnace slag has been shown to increase the compressive strength by up to 62%. [Sobolev K et al., 2005; Sobolev K et al., 2009; Sobolev K et al., 2005].

Nanoclay particles have shown promise in enhancing the mechanical performance, the resistance to chloride penetration, and the self-compacting properties of concrete and in reducing permeability and shrinkage. Clay and the properties of clay that are important as admixtures to cement exist on the nanoscale. Individual, natural clay particles are micron and sub-micron in size, and the base structure of clay is composed of crystalline layers of aluminum phyllosilicates with thicknesses on the order of 1 nm. Exfoliated layers are true nanoparticles. The effect of clay in cement is not a new subject and most applications utilize calcined clay (metakaolin). There has been a recent resurgence, however, focused on the possibilities of the nanoengineering of clays. Much of this work is looking at natural (non-calcined) clays. Because clay particles are typically highly hydrophilic, the control of water requirements in clay–cement composites is important. A reduction in the amount of water needed can be achieved by organic cation exchange modification, where organic cations replace sodium or calcium in the interlayer, reducing the hydrophilicity. Chemical binding of PVA (polyvinyl alcohol) to exfoliated clay particles recently has been proposed to create linked clay particle chains that, when incorporated in cement, were shown to improve the post-failure properties of the material. Additionally, non-modified, nanosized smectite clays were observed to act as nucleation agents for C–S–H and to modify the structure of C–S–H. [Lindgreen H et al., 2008; Kroyer H et al., 2003].

2.4 Concluding Remarks

The present chapter reviews the current state of the field of nanotechnology in concrete and recent key advances. The potential of nanotechnology to improve the performance of concrete and to lead to the development of novel, sustainable, advanced cement based composites with unique mechanical, thermal, and electrical properties is promising and many new opportunities are expected to arise in the coming years. The advances in instrumentation and computational science are enabling scientists and engineers to obtain unprecedented information about concrete, from the atomic through the continuum scale, and the role of nanoscale structures on performance and durability. This information is crucial for predicting the service life of concrete and for providing new insights on how it can be improved. New developments have taken place in the nano-engineering and nanomodification of concrete; however, current challenges need to be solved before the full potential of nanotechnology can be realized in concrete applications, including proper dispersion; compatibility of the nanomaterials in cement; processing, manufacturing, safety, and handling issues; scale-up; and cost. Additionally, introduction of these novel materials into the public sphere through civil infrastructure will necessitate an evaluation and understanding of the impact they may have on the environment and human health. Nanotechnology is changing the way scientists and engineers look at one of the world's oldest man-made materials, concrete.

CHAPTER 3

EXPERIMENTAL PROGRAMME

3.1 General

In order to access the effect of nanotechnology on cement matrix several tests were carried out which are discussed in details in this chapter. Construction materials namely cement, fine aggregate, coarse aggregate, silica fumes, fly ash and acetone were collected from different sources. Tests were conducted as per the recommendation of the relevant Indian Standard Code of Practices. To complete the project we divide the entire work in four different stages. Test results tabulated and presented in this chapter.

3.2 Stage I- Test on particle sizes of Constituents

Samples of Cement, Fly ash and Silica Fume were collected from different sources and studied under Scanning Electron Microscope (SEM).

3.2.1 Cement

The sample of cement was taken and kept under Scanning Electron Microscope (SEM). Shree Ultra 43 grade ordinary portland cement was used. Figure 3.1 briefly describes the particle size of the cement.

3.2.2 Silica Fumes

Silica Fume was collected from the industry and then kept under Scanning Electron Microscope (SEM). Figure 3.3 describe the particle size of silica fumes.

3.2.3 Fly ash

Fly ash was collected from the thermal power plant and kept under Scanning Electron Microscope (SEM). Figure 3.5 shows the particle size of fly ash.

3.2.4 Conversion of the Constituent to nano scale

Conversion of the constituent particles to nano scale was carried out with the help of Ball Mill Machine (Figure 3.7 & 3.8). Conversion to nano scale in the machine can be carried out in two ways:

1. Dry Grinding
2. Wet Grinding

In this entire project we conducted the dry grinding of the constituent particles. However we also conducted wet grinding but only in the case of cement (Figure 3.9). Acetone was used for wet grinding of cement in the ball mill machine. Cement, Fly ash and silica fumes were converted into nano scale using ball mill machine and were again kept under SEM for determination of particle size to assure the nano size of these particles size. Figure 3.2, 3.4 and 3.6 give assurance of the nano size of the cement, fly ash and silica fumes respectively.

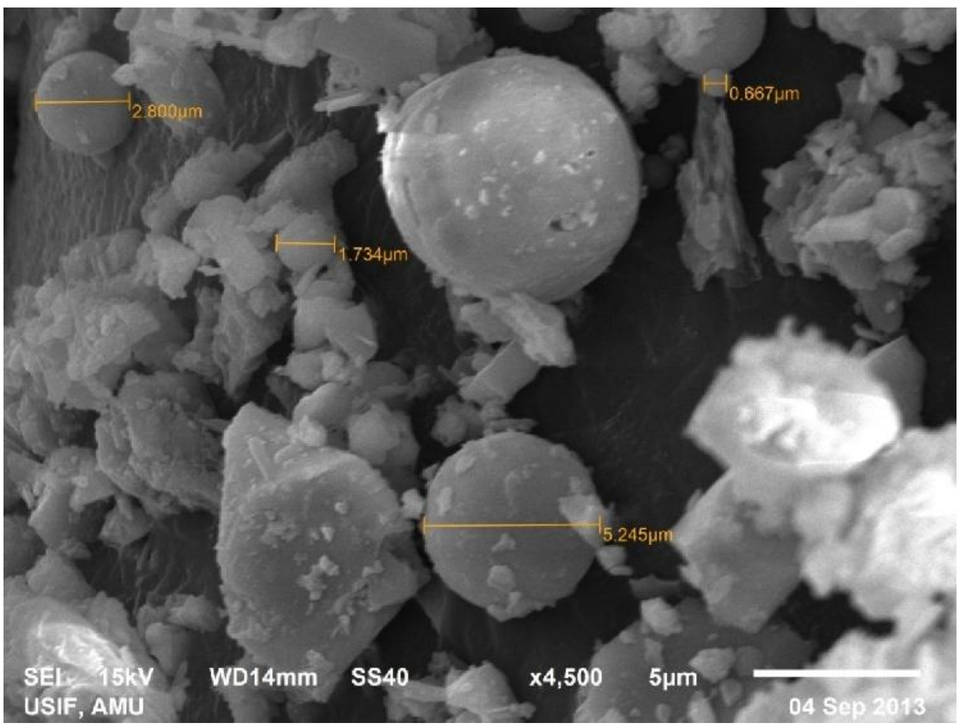


Figure 3.1 SEM picture showing particle size of Shree Ultra 43 grade cement.

Particle Size of Cement = 2.6 µm

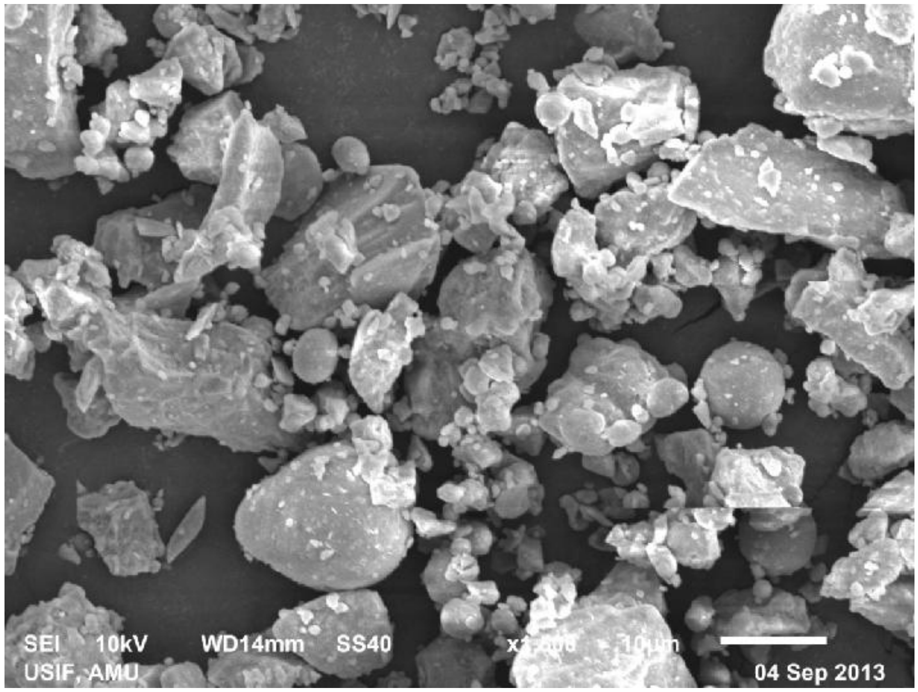


Figure 3.2 SEM picture showing particle size of converted fine cement.

Particle Size of Cement = 5.05 x 10-^{8}

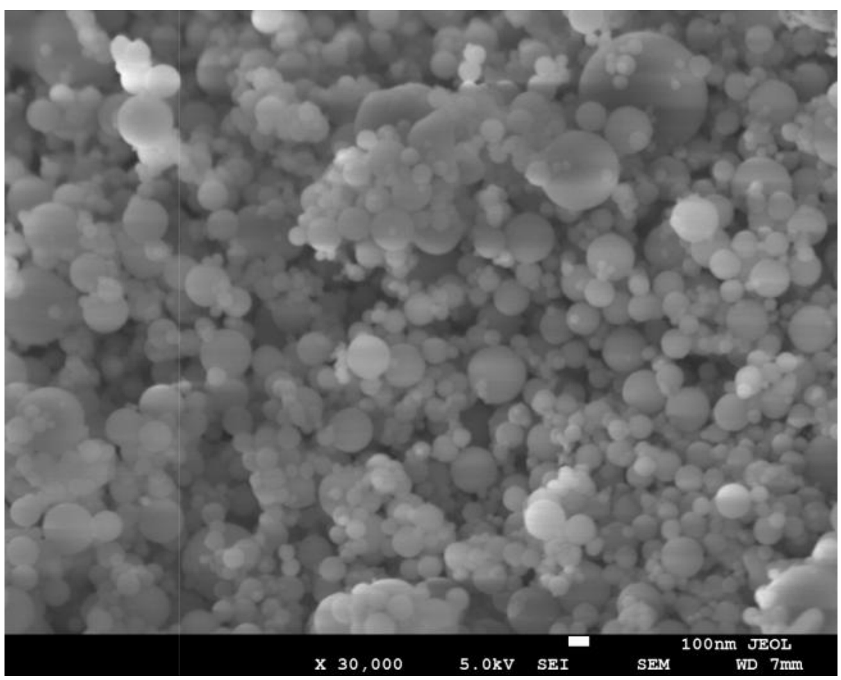


Figure 3.3 SEM picture showing particle size of silica fume.

Particle Size of Silica Fume = 6.09 x 10^{-8}

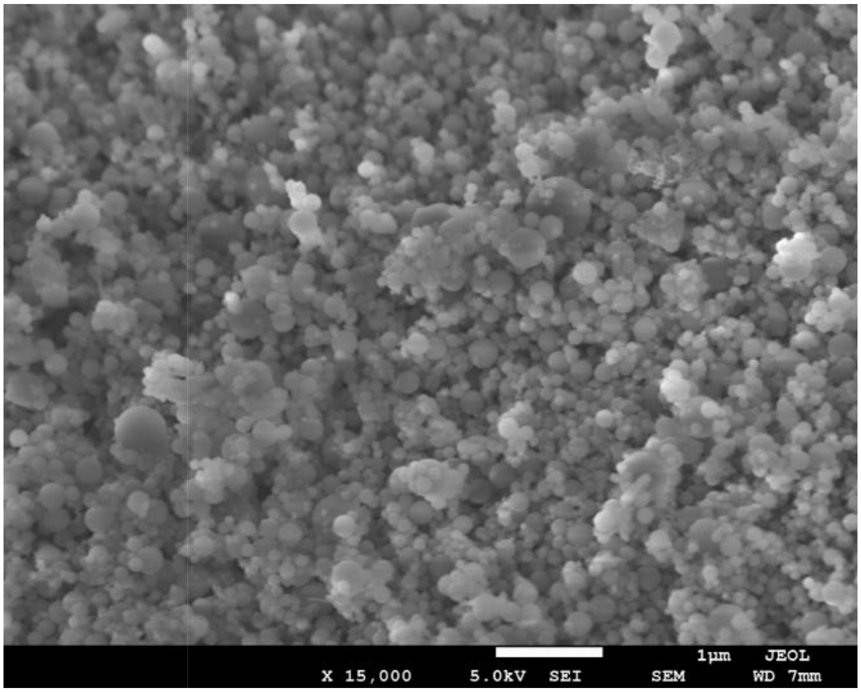


Figure 3.4 SEM picture showing particle size of nano silica fume.

Particle Size of Nano Silica Fume = 1.9 nm

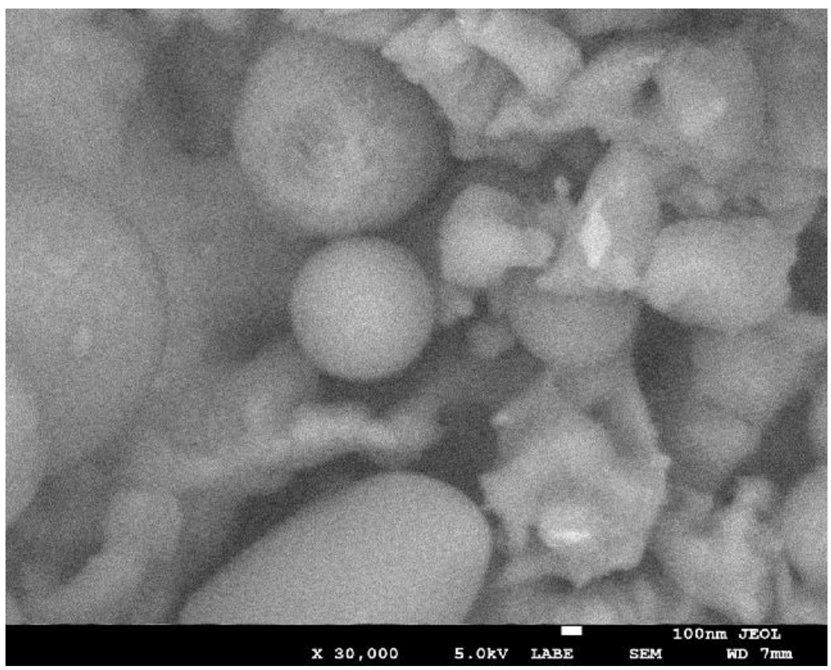


Figure 3.5 SEM picture showing particle size of flyash.

Particle Size of Flyash = 4.70 x 10^{-7}

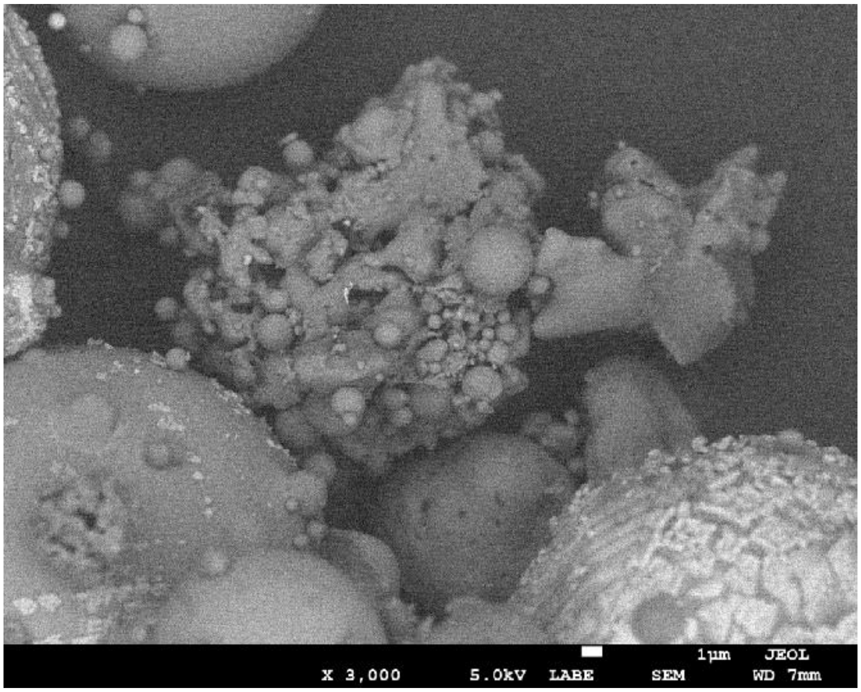


Figure 3.6 SEM picture showing particle size of nano flyash.

Particle Size of Nano Fly ash = 2.9 nm

Figure 3.7 Ball mill machine used for the conversion.

Figure 3.8 Inside view of ball mill machine used for the conversion.

Figure 3.9 Picture showing wet grinding of cement in ball mill machine chamber.

3.3 Stage II- Compressive Strength Test on Cement Matrix

In order to study the performance of the cement matrix, cubes of size 70.06×70.06 mm were cast. These cubes were demoulded after 24 hours and cured for 7, 14 and 28 days respectively in the curing tank. The cubes were tested under the compression testing machine up to failure to ascertain their crushing strength.

3.3.1 Constituent Materials

The constituent material used for cubes were cement, fine aggregate (tradition name badarpur) and water. Potable water was used for the preparation of matrix. The ratio of cement and fine aggregate was taken as 1:3 by weight. The water cement ratio was kept as 0.4 – 0.45.

Cement

Shree Ultra 43 grade ordinary portland cement was used in the mix. The physical property of cement were determined in the laboratory and presented in Table 3.1(a), 3.1(b) & 3.1 (c).

Fine Aggregate

Locally available Badarpur sand was used. The grading and fineness modulus of the sand are given in Table 3.2. Lumps of clay and other foreign matter were separated out from the sand and it was later washed with water and then air dried.

Fly ash

Fly ash was produced from Panipat Thermal Power Plant, Panipat (Haryana). The physical properties of fly ash are tabulated in the Table 3.3.

Silica Fume

Silica Fume was produced from Elkem Company (A Bluestar Company). The properties of silica fume are tabulated in the Table 3.4.

3.3.2 Casting of Test Specimens

The cement cubes were casted in the laboratory (Figure 3.10 (a), (b), 3.11 (a), (b)). Total 176 cement cubes samples were cast and specific designation assigned to them. A detail of the work plan is given in the Table A. After casting of the specimen the cubes were kept for curing (3.12 (a)) for specified duration of 7, 14 and 28 days.

(a)

(b)

Figure 3.10 (a) Preparation of cement mortar paste (b) Prepared cement mortar paste

(a)

(b)

Figure 3.11 (a) Cubes specimens before demolding (b) Cubes specimens after demolding

3.3.3 Testing of Specimens

Before testing, the specimens were taken out of curing tank and air dried for 24 hours. The cement cubes were tested for compressive strength under compression testing machine (3.12 (b)). The compressive strength of cement paste cubes is given in Tables 3.5-3.22. As can be seen the cement matrix cubes which incorporates the nano materials exhibit excellent strength both at 7, 14 and 28 days. Thus the material system can definitely be relied upon for the intended application.

(a)

(b)

Figure 3.12 (a) Curing of cube specimen (b) Testing of cube specimen

3.4 Stage III- Compressive Strength Test on Concrete

In order to study the performance of the concrete, cubes of size 150×150×150 mm were cast in the laboratory. These cubes were demoulded after 24 hours and cured for 7 days in the curing tank. The cubes were tested in the laboratory under the compression testing machine up to failure to ascertain their crushing strength.

3.4.1 Constituent Materials

The constituent material used for concrete cubes were cement, fine aggregate (tradition name badarpur), coarse aggregate and water. Potable water was used for the preparation of mix. Mix design of M20 was prepared. The water cement ratio was kept 0.5.

Cement

Shree Ultra 43 grade ordinary portland cement was used in the mix. The physical property of cement were determined in the laboratory as per IS code and presented in Table 3.1(a), 3.1(b) & 3.1 (c).

Fine Aggregate

Locally available Badarpur sand was used. The grading and fineness modulus of the sand are given in Table 3.2. Lumps of clay and other foreign matter were separated out from the sand and it was later washed with water and then air dried.

Coarse Aggregate

Coarse aggregate of 10 mm and 20 mm size were used in the mix design.

3.4.2 Casting of Test Specimens

The concrete cubes were casted in the laboratory. Total six concrete cubes samples were casted and were tabulated with the specific designation assigned to it. A detail of the work plan is given in the Table B. After casting of the specimen the cubes were kept for curing (Figures 3.13 (a) & (b), 3.14 (a)) for specified duration of 7 days.

3.4.3 Testing of Specimens

Before testing, the specimens were taken out of curing tank and air dried for 24 hours. The cement cubes were tested for compressive strength under compression testing machine. The compressive strength of concrete cubes is given in Tables 3.23. As can be seen the concrete cubes which incorporates the nano materials exhibit excellent strength at 7days (Figure 3.14 (b)).

Table A: Work Plan for Compressive Strength Test on Cement Matrix

TYPE	Composition	Ratio
I	Cement :Sand	1:3
II	Fine Cement: Sand	1:3
II	Fine Cement: Sand (Wet)	1:3
III	Cement: Fine Cement :Sand	0.5:0.5:3
IV	Cement: Silica Fume :Sand	0.9:0.1:3
V	Fine Cement :Silica Fume :Sand	0.9:0.1:3
VI	Cement: Fine Cement :Silica Fume :Sand	0.45:0.45:0.1:3
VII	Cement :Nano Silica Fume :Sand	0.9:0.1:3
VIII	Fine Cement :Nano Silica Fume :Sand	0.9:0.1:3
IX	Cement :Fine Cement :Nano Silica Fume :Sand	0.45:0.45:0.1:3
X	Cement :Flyash :Sand	0.9:0.1:3
XI	Fine Cement :Flyash :Sand	0.9:0.1:3
XII	Cement :Fine Cement :Flyash :Sand	0.45:0.45:0.1:3
XIII	Cement :Nano Flyash :Sand	0.9:0.1:3
XIV	Fine Cement :Nano Flyash :Sand	0.9:0.1:3
XV	Cement :Fine Cement :Nano Flyash :Sand	0.45:0.45:0.1:3
XVI	Fine Cement :Nano Silica Fume :Sand	0.95:0.05:3

Table B: Work Plan Compressive Strength Test on Concrete

TYPE	Mix Design	Composition	Ratio
XVII	M20	Cement :Sand: Coarse Aggregate	1:1.5:3.3
XVIII	M20	Cement :Fine Cement :Sand :Coarse Aggregate	0.75:0.25:1.5:3.3

(a)

(b)

Figure 3.13 (a) Concrete specimen in the mould on vibrating table (b) Concrete specimen placed in the mould

(a)

(b)

Figure 3.14 (a) Concrete mould specimen (b) Testing of concrete cube specimen

3.5 Stage IV- Microscopic Examination of Cement Matrix

The cement cubes which are casted and then tested under compressive machine is now studied under microscope. The pieces of cube after testing are converted into thin microscopic slides to study under microscope. For this, we first grind the thick pieces of cement cubes to a thin piece and stick it on the glass to make slide. (Figure 3.15 (a) & (b)). The slide of different types of cement cubes was prepared and kept under microscope for investigation.

(1) Normal Cement Cube (figure 3.16 (a), (b), (c) & (d))
(2) Dry Grinded Cement Cube (figure 3.17 (a), (b), (c) & (d))
(3) Wet Grinded Cement Cube (figure 3.18 (a), (b), (c) & (d))

3.6 Concluding Remarks

In this chapter results were obtained through testing of various different cement matrix and concrete cubes. A total of 51 nos. cement cube groups with three replications each totaling to 153 nos. cement cube specimen of size 70.7 mm were cast. Another two nos. concrete cube groups with three replications each totaling to six nos. concrete cube specimens of size 150 mm were cast. The results have been presented in the Chapter 4.

(a)

(b)

Figure 3.15 (a) Platform where the cement cube piece is converted to thin film using grinding process (b) Prepared slide

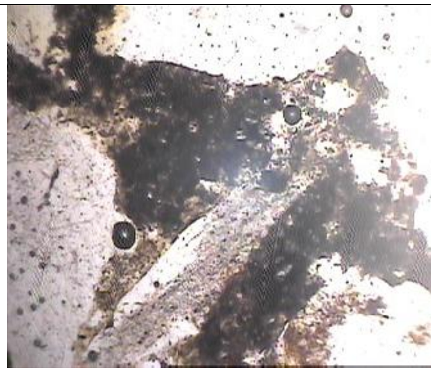


Figure 3.16 a: Photomicrograph of normal cement and fine aggregate mix, showing micropores within cement and loose contact between cement paste and aggregate grains (magnification 60X under non polarized light).

Figure 3.16 c: Photomicrograph of normal cement and fine aggregate mix, showing micropores within cement and loose contact between cement paste and aggregate grains (magnification 60X under polarized light).

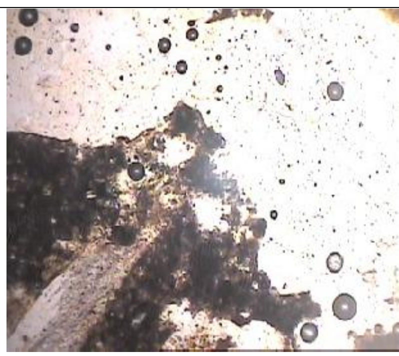


Figure 3.16 b: Another View of photomicrograph of normal cement and fine aggregate mix, showing micropores within cement and loose contact between cement paste and aggregate grains (magnification 60X under non polarized light).

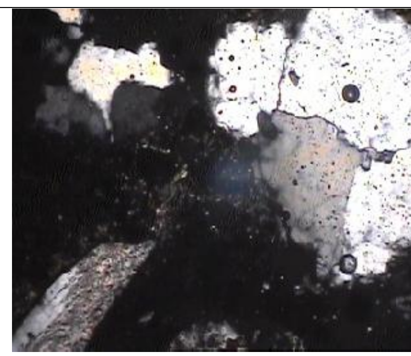


Figure 3.16 d: Another View of photomicrograph of normal cement and fine aggregate mix, showing micropores within cement and loose contact between cement paste and aggregate grains (magnification 60X under polarized light).

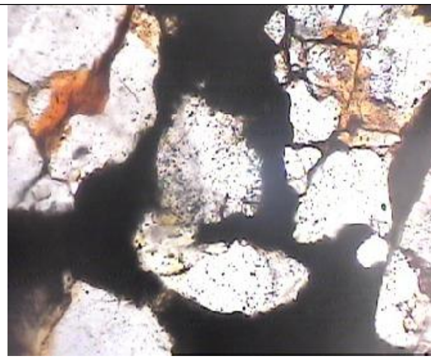


Figure 3.17 a: Photomicrograph of fine sized dry grinded cement and fine aggregate mix, showing dense cement phase and good contact between cement paste and aggregate grains (magnification 60X under non polarized light).

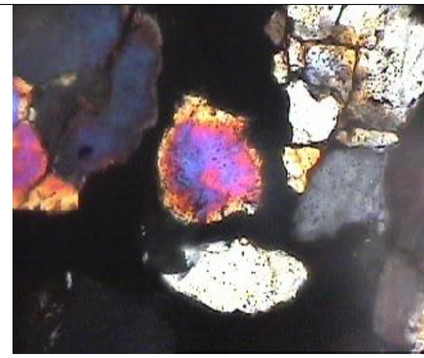


Figure 3.17 c: Photomicrograph of fine sized dry grinded cement and fine aggregate mix, showing dense cement phase and good contact between cement paste and aggregate grains (magnification 60X under polarized light).

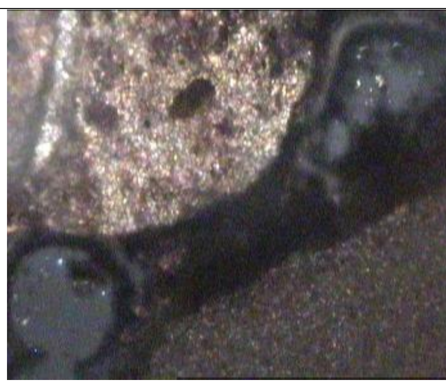


Figure 3.17 b: Another View of photomicrograph of fine sized dry grinded cement and fine aggregate mix, showing dense cement phase and micro-pores with good contact between cement paste and aggregate grains (magnification 60X under non polarized light).

Figure 3.17 d: Another View of photomicrograph of fine sized dry grinded cement and fine aggregate mix, showing dense cement phase and micro-pores with good contact between cement paste and aggregate grains (magnification 60X under polarized light).

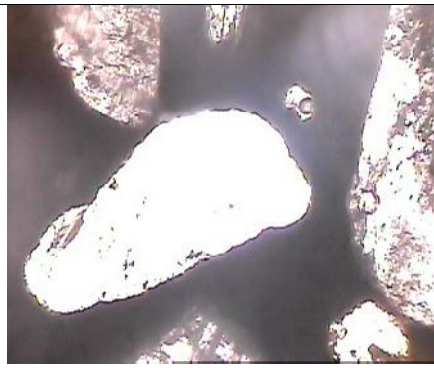


Figure 3.18 a: Photomicrograph of fine sized wet grinded cement and fine aggregate mix, showing dense cement phase and good contact between cement paste and aggregate grains (magnification 60X under non polarized light).

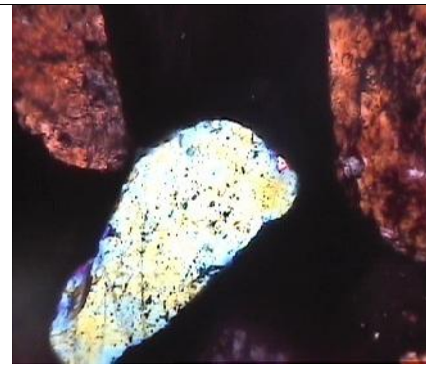


Figure 3.18 c: Photomicrograph of fine sized wet grinded cement and fine aggregate mix, showing dense cement phase and good contact between cement paste and aggregate grains (magnification 60X under polarized light).

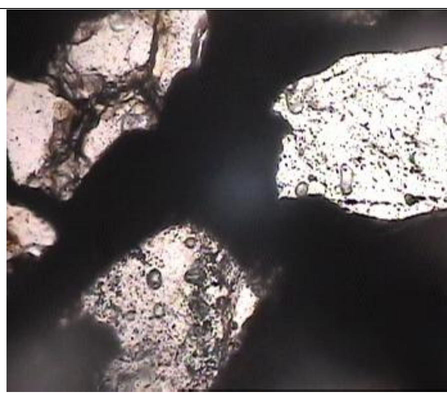


Figure 3.18 b: Another View of photomicrograph of fine sized wet grinded cement and fine aggregate mix, showing dense cement phase and good contact between cement paste and aggregate grains (magnification 60X under non polarized light).

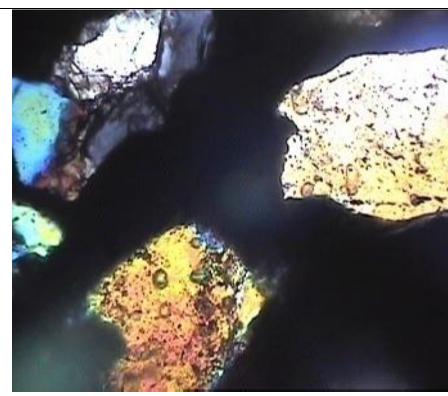


Figure 3.18 d: Another View of photomicrograph of fine sized wet grinded cement and fine aggregate mix, showing dense cement phase and good contact between cement paste and aggregate grains (magnification 60X under polarized light).

Table 3.1(a): Properties of cement

S. No	Properties	Values
1.	Consistency	28.50%
2.	Initial Setting Time (minutes)	61
3.	Final Setting Time (minutes)	294

Table 3.1 (b): Properties of fine cement (dry grinded)

S.No	Properties	Values
1.	Consistency	30.00%
2.	Initial Setting Time (minutes)	58
3.	Final Setting Time (minutes)	291

Table 3.1 (c): Properties of fine cement (wet grinded)

S.No	Properties	Values
1.	Consistency	32.00%
2.	Initial Setting Time (minutes)	54
3.	Final Setting Time (minutes)	290

Table 3.2: Sieve analysis of fine aggregate (sand)

S. No	IS: Sieve Designation	Weight Retained (g)	Cumulative Weight Retained (g)	% Cumulative Weight Retained
1.	4.75 mm	Nil	0	0
2.	2.36 mm	20	20	1
3.	1.18 mm	235	255	12.75
4.	600 micron	560	815	40.75
5	300 micron	1102	1917	95.85
6.	150 micron	83	2000	100.00

$$\textit{Fineness Modulus} = \frac{250.35}{100} = 2.5035$$

Table–3.3 Physical properties of fly ash

S. No.	Constituent/Property	Value
1.	Colour	Grey
2.	Percent passing 45 micron sieve	90%
3.	Size of the particle	4.70×10^{-7}
4.	Maximum dry density (MDD)	9.30 kN/m^3
5.	Optimum moisture content (OMC)	27.5%
6.	Specific gravity	2.02 at 27^{o}C
7.	Surface area	3060 cm^2/g

Table 3.4 Physical properties of silica fume

S. No	Description	Results
1.	Particle Size	6.09×10^{-8}
2.	Surface Area	14 m^2/gm
3.	Density	2.2 g/cm^3

Table 3.5: Test results of cube with cement & fine cement

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
I	C:S	1:3	0.4	---	**15.33**	**17.33**	**20.88**
II	FC: S	1:3	0.4	Dry	**24.33**	**26.73**	**34.33**
II	FC:S	1:3	0.5	Wet	**27.00**	**30.33**	**40.00**
III	C:FC:S	0.5:0.5:3	0.5	Wet	**24.45**	**27.30**	**37.20**

Table 3.6: Test results of cube with cement, fine cement & silica fume

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
IV	C:SF:S	0.9:0.1:3	0.45	---	**20.50**	**22.60**	**26.75**
V	FC:SF:S	0.9:0.1:3	0.45	Dry	**22.30**	**24.40**	**27.00**
VI	C:FC:SF:S	0.45:0.45:0.1:3	0.45	Dry	**21.70**	**23. 05**	**26.80**

C: Cement FC: Fine Cement	S: Sand SF: Silica Fume

Table 3.7: Test results of cube with cement, fine cement & nano silica fume

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
VII	C:NSF:S	0.9:0.1:3	0.45	---	**21.00**	**23.10**	**26.90**
VIII	FC:NSF:S	0.9:0.1:3	0.45	Dry	**23.46**	**25.50**	**29.20**
IX	C:FC:NSF:S	0.45:0.45:0.1:3	0.45	Dry	**22.24**	**24.63**	**28.86**

Table 3.8: Comparison of Test Results of Cube with Cement, Fine Cement, Silica Fume with Test Results of Cube with Cement, Fine Cement & Nano Silica Fume

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
IV	C:SF:S	0.9:0.1:3	0.45	---	**20.50**	**22.60**	**26.75**
V	FC:SF:S	0.9:0.1:3	0.45	Dry	**22.30**	**24.40**	**27.00**
VI	C:FC:SF:S	0.45:0.45:0.1:3	0.45	Dry	**21.70**	**23. 05**	**26.80**
VII	C:NSF:S	0.9:0.1:3	0.45	---	**21.00**	**23.10**	**26.90**
VIII	FC:NSF:S	0.9:0.1:3	0.45	Dry	**23.46**	**25.50**	**29.20**
IX	C:FC:NSF:S	0.45:0.45:0.1:3	0.45	Dry	**22.24**	**24.63**	**28.86**

C: Cement FC: Fine Cement NSF: Nano Silica Fume	S: Sand SF: Silica Fume

Table 3.9: Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Silica fume

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
I	C:S	1:3	0.4	---	**15.33**	**17.33**	**20.88**
II	FC: S	1:3	0.4	Dry	**24.33**	**26.73**	**34.33**
II	FC:S	1:3	0.5	Wet	**27.00**	**30.33**	**40.00**
III	C:FC:S	0.5:0.5:3	0.45	Wet	**24.45**	**27.30**	**37.20**
IV	C:SF:S	0.9:0.1:3	0.45	---	**20.50**	**22.60**	**26.75**
V	FC:SF:S	0.9:0.1:3	0.45	Dry	**22.30**	**24.40**	**27.00**
VI	C:FC:SF:S	0.45:0.45:0.1:3	0.45	Dry	**21.70**	**23. 05**	**26.80**

C: Cement FC: Fine Cement	S: Sand SF: Silica Fume

Table 3.10 Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Nano Silica fume

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
I	C:S	1:3	0.4	---	**15.33**	**17.33**	**20.88**
II	FC: S	1:3	0.4	Dry	**24.33**	**26.73**	**34.33**
II	FC:S	1:3	0.5	Wet	**27.00**	**30.33**	**40.00**
III	C:FC:S	0.5:0.5:3	0.45	Wet	**24.45**	**27.30**	**37.20**
VII	C:NSF:S	0.9:0.1:3	0.45	---	**21.00**	**23.10**	**26.90**
VIII	FC:NSF:S	0.9:0.1:3	0.45	Dry	**23.46**	**25.50**	**29.20**
IX	C:FC:NSF:S	0.45:0.45:0.1:3	0.45	Dry	**22.24**	**24.63**	**28.86**

C: Cement FC: Fine Cement	S: Sand NSF: Nano Silica Fume

Table 3.11: Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Silica fume and Test Results of Cube with Cement, Fine cement & Nano Silica fume

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
I	C:S	1:3	0.4	---	**15.33**	**17.33**	**20.88**
II	FC: S	1:3	0.4	Dry	**24.33**	**26.73**	**34.33**
II	FC:S	1:3	0.5	Wet	**27.00**	**30.33**	**40.00**
III	C:FC:S	0.5:0.5:3	0.45	Wet	**24.45**	**27.30**	**37.20**
IV	C:SF:S	0.9:0.1:3	0.45	---	**20.50**	**22.60**	**26.75**
V	FC:SF:S	0.9:0.1:3	0.45	Dry	**22.30**	**24.40**	**27.00**
VI	C:FC:SF:S	0.45:0.45:0.1:3	0.45	Dry	**21.70**	**23. 05**	**26.80**
VII	C:NSF:S	0.9:0.1:3	0.45	---	**21.00**	**23.10**	**26.90**
VIII	FC:NSF:S	0.9:0.1:3	0.45	Dry	**23.46**	**25.50**	**29.20**
IX	C:FC:NSF:S	0.45:0.45:0.1:3	0.45	Dry	**22.24**	**24.63**	**28.86**

C: Cement FC: Fine Cement S: Silica Fume	S: Sand NSF: Nano Silica Fume

Table 3.12: Test results of cube with cement, fine cement & flyash

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
X	C:FA:S	0.9:0.1:3	0.45	---	**22.70**	**24.35**	**27.03**
XI	FC:FA:S	0.9:0.1:3	0.45	Dry	**26.26**	**27.45**	**31.00**
XII	C:FC:FA:S	0.45:0.45:0.1:3	0.45	Dry	**23.30**	**24.50**	**29.00**

Table 3.13: Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Fly ash

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
I	C:S	1:3	0.4	---	**15.33**	**17.33**	**20.88**
II	FC: S	1:3	0.4	Dry	**24.33**	**26.73**	**34.33**
II	FC:S	1:3	0.5	Wet	**27.00**	**30.33**	**40.00**
III	C:FC:S	0.5:0.5:3	0.45	Wet	**24.45**	**27.30**	**37.20**
X	C:FA:S	0.9:0.1:3	0.45	---	**22.70**	**24.35**	**27.03**
XI	FC:FA:S	0.9:0.1:3	0.45	Dry	**26.26**	**27.45**	**31.00**
XII	C:FC:FA:S	0.45:0.45:0.1:3	0.45	Dry	**23.30**	**24.50**	**29.00**

C: Cement FC: Fine Cement	S: Sand FA: Flyash

Table 3.14: Test Results of Cube with Cement, Fine Cement & Nano Fly ash

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
XIII	C:NFA:S	0.9:0.1:3	0.45	---	**24.13**	**26.75**	**29.03**
XIV	FC:NFA:S	0.9:0.1:3	0.45	Dry	**29.20**	**31.60**	**35.20**
XV	C:FC:NFA:S	0.45:0.45:0.1:3	0.45	Dry	**26.33**	**28.33**	**31.33**

Table 3.15: Comparison of Test Results of Cube with Cement, Fine Cement & Fly ash with Test Results of Cube with Cement, Fine Cement & Nano FA

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
X	C:FA:S	0.9:0.1:3	0.45	---	**22.70**	**24.35**	**27.03**
XI	FC:FA:S	0.9:0.1:3	0.45	Dry	**26.26**	**27.45**	**31.00**
XII	C:FC:FA:S	0.45:0.45:0.1:3	0.45	Dry	**23.30**	**24.50**	**29.00**
XIII	C:NFA:S	0.9:0.1:3	0.45	---	**24.13**	**26.75**	**29.03**
XIV	FC:NFA:S	0.9:0.1:3	0.45	Dry	**29.20**	**31.60**	**35.20**
XV	C:FC:NFA:S	0.45:0.45:0.1:3	0.45	Dry	**26.33**	**28.33**	**31.33**

C: Cement FC: Fine Cement NFA: Nano Flyash	S: Sand FA: Flyash

Table 3.16: Comparison of Test Results of Cube with Cement, Fine Cement with Test Results of Cube with Cement, Fine Cement & Nano Fly ash

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
I	C:S	1:3	0.4	---	**15.33**	**17.33**	**20.88**
II	FC: S	1:3	0.4	Dry	**24.33**	**26.73**	**34.33**
II	FC:S	1:3	0.5	Wet	**27.00**	**30.33**	**40.00**
III	C:FC:S	0.5:0.5:3	0.45	Wet	**24.45**	**27.30**	**37.20**
XIII	C:NFA:S	0.9:0.1:3	0.45	---	**24.13**	**26.75**	**29.03**
XIV	FC:NFA:S	0.9:0.1:3	0.45	Dry	**29.20**	**31.60**	**35.20**
XV	C:FC:NFA:S	0.45:0.45:0.1:3	0.45	Dry	**26.33**	**28.33**	**31.33**

C: Cement FC: Fine Cement	S: Sand NFA: Nano Flyash

Table 3.17: Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Fly ash and Test Results of Cube with Cement, Fine cement & Nano Fly ash

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
I	C:S	1:3	0.4	---	**15.33**	**17.33**	**20.88**
II	FC: S	1:3	0.4	Dry	**24.33**	**26.73**	**34.33**
II	FC:S	1:3	0.5	Wet	**27.00**	**30.33**	**40.00**
III	C:FC:S	0.5:0.5:3	0.45	Wet	**24.45**	**27.30**	**37.20**
X	C:FA:S	0.9:0.1:3	0.45	---	**22.70**	**24.35**	**27.03**
XI	FC:FA:S	0.9:0.1:3	0.45	Dry	**26.26**	**27.45**	**31.00**
XII	C:FC:FA:S	0.45:0.45:0.1:3	0.45	Dry	**23.30**	**24.50**	**29.00**
XIII	C:NFA:S	0.9:0.1:3	0.45	---	**24.13**	**26.75**	**29.03**
XIV	FC:NFA:S	0.9:0.1:3	0.45	Dry	**29.20**	**31.60**	**35.20**
XV	C:FC:NFA:S	0.45:0.45:0.1:3	0.45	Dry	**26.33**	**28.33**	**31.33**

C: Cement FC: Fine Cement FA: Flyash	S: Sand NFA: Nano Flyash

Table 3.18: Comparison of Test Results of Cube with Cement, Fine Cement & Silica Fume with Test results of Cube with Cement, Fine cement & Nano Fly ash, Test Results of Cube with Cement, Fine cement & Fly ash and Test Results of Cube with Cement, Fine cement & Nano Fly ash

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
IV	C:SF:S	0.9:0.1:3	0.45	---	**20.50**	**22.60**	**26.75**
V	FC:SF:S	0.9:0.1:3	0.45	Dry	**22.30**	**24.40**	**27.00**
VI	C:FC:SF:S	0.45:0.45:0.1:3	0.45	Dry	**21.70**	**23. 05**	**26.80**
VII	C:NSF:S	0.9:0.1:3	0.45	---	**21.00**	**23.10**	**26.90**
VIII	FC:NSF:S	0.9:0.1:3	0.45	Dry	**23.46**	**25.50**	**29.20**
IX	C:FC:NSF:S	0.45:0.45:0.1:3	0.45	Dry	**22.24**	**24.63**	**28.86**
X	C:FA:S	0.9:0.1:3	0.45	---	**22.70**	**24.35**	**27.03**
XI	FC:FA:S	0.9:0.1:3	0.45	Dry	**26.26**	**27.45**	**31.00**
XII	C:FC:FA:S	0.45:0.45:0.1:3	0.45	Dry	**23.30**	**24.50**	**29.00**
XIII	C:NFA:S	0.9:0.1:3	0.45	---	**24.13**	**26.75**	**29.03**
XIV	FC:NFA:S	0.9:0.1:3	0.45	Dry	**29.20**	**31.60**	**35.20**
XV	C:FC:NFA:S	0.45:0.45:0.1:3	0.45	Dry	**26.33**	**28.33**	**31.33**

C: Cement FC: Fine Cement FA: Flyash NSF: Nano Silica Fume	S: Sand NFA: Nano Flyash SF: Silica Fume

Table 3.19: Test results of cube with cement, fine cement& 5% nano silica fume

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
XVI	FC:NSF(Wet Grinded):S	0.95:0.05:3	0.5	Dry	**24.80**	**28.10**	**37.20**

Table 3.20: Comparison of Test Results of Cube with Cement, Fine Cement & Silica Fume with Test Results of Cube with Cement, Fine Cement & Fly ash

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
IV	C:SF:S	0.9:0.1:3	0.45	---	**20.50**	**22.60**	**26.75**
V	FC:SF:S	0.9:0.1:3	0.45	Dry	**22.30**	**24.40**	**27.00**
VI	C:FC:SF:S	0.45:0.45:0.1:3	0.45	Dry	**21.70**	**23. 05**	**26.80**
X	C:FA:S	0.9:0.1:3	0.45	---	**22.70**	**24.35**	**27.03**
XI	FC:FA:S	0.9:0.1:3	0.45	Dry	**26.26**	**27.45**	**31.00**
XII	C:FC:FA:S	0.45:0.45:0.1:3	0.45	Dry	**23.30**	**24.50**	**29.00**

C: Cement FC: Fine Cement FA: Flyash NSF: Nano Silica Fume	S: Sand SF: Silica Fume

Table 3.21: Comparison of Test Results of Cube with Cement, Fine Cement & Nano Silica Fume with Test Results of Cube with Cement, Fine Cement & Nano Fly ash

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
VII	C:NSF:S	0.9:0.1:3	0.45	---	**21.00**	**23.10**	**26.90**
VIII	FC:NSF:S	0.9:0.1:3	0.45	Dry	**23.46**	**25.50**	**29.20**
IX	C:FC:NSF:S	0.45:0.45:0.1:3	0.45	Dry	**22.24**	**24.63**	**28.86**
XIII	C:NFA:S	0.9:0.1:3	0.45	---	**24.13**	**26.75**	**29.03**
XIV	FC:NFA:S	0.9:0.1:3	0.45	Dry	**29.20**	**31.60**	**35.20**
XV	C:FC:NFA:S	0.45:0.45:0.1:3	0.45	Dry	**26.33**	**28.33**	**31.33**

C: Cement FC: Fine Cement NSF: Nano Silica Fume	S: Sand NFA: Nano Flyash

Table 3.22: Comparison of Test Results of Cube with Cement & Fine Cement with Test Results of Cube with Cement, Fine Cement & Silica Fume, Test Results of Cube with Cement, Fine Cement & Nano Silica Fume, Test Results of Cube with Cement, Fine Cement & Fly ash, Test Results of Cube with Cement, Fine Cement & Nano Fly ash and Test Results of Cube with Cement, Fine Cement & 5% Nano Silica Fume

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)	Compressive Strength 14 Days (MPa)	Compressive Strength 28 Days (MPa)
I	C:S	1:3	0.4	---	**15.33**	**17.33**	**20.88**
II	FC: S	1:3	0.4	Dry	**24.33**	**26.73**	**34.33**
II	FC:S	1:3	0.5	Wet	**27.00**	**30.33**	**40.00**
III	C:FC:S	0.5:0.5:3	0.45	Wet	**24.45**	**27.30**	**37.20**
IV	C:SF:S	0.9:0.1:3	0.45	---	**20.50**	**22.60**	**26.75**
V	FC:SF:S	0.9:0.1:3	0.45	Dry	**22.30**	**24.40**	**27.00**
VI	C:FC:SF:S	0.45:0.45:0.1:3	0.45	Dry	**21.70**	**23. 05**	**26.80**
VII	C:NSF:S	0.9:0.1:3	0.45	---	**21.00**	**23.10**	**26.90**
VIII	FC:NSF:S	0.9:0.1:3	0.45	Dry	**23.46**	**25.50**	**29.20**
IX	C:FC:NSF:S	0.45:0.45:0.1:3	0.45	Dry	**22.24**	**24.63**	**28.86**
X	C:FA:S	0.9:0.1:3	0.45	---	**22.70**	**24.35**	**27.03**
XI	FC:FA:S	0.9:0.1:3	0.45	Dry	**26.26**	**27.45**	**31.00**
XII	C:FC:FA:S	0.45:0.45:0.1:3	0.45	Dry	**23.30**	**24.50**	**29.00**
XIII	C:NFA:S	0.9:0.1:3	0.45	---	**24.13**	**26.75**	**29.03**
XIV	FC:NFA:S	0.9:0.1:3	0.45	Dry	**29.20**	**31.60**	**35.20**
XV	C:FC:NFA:S	0.45:0.45:0.1:3	0.45	Dry	**26.33**	**28.33**	**31.33**
XVI	FC:NSF(Wet Grinded):S	0.95:0.05:3	0.5	Dry	**24.80**	**28.10**	**37.20**

C: Cement FC: Fine Cement NSF: Nano Silica Fume SF: Silica Fume	S: Sand NFA: Nano Flyash FA: Flyash

***Table 3.23* Test results of concrete cube with cement & 25% fine cement**

TYPE	Composition	Ratio	W/C Ratio	Grinding Type(Cement)	Compressive Strength 7 Days (MPa)
XVII	C:S:CA	1:1.5:3.3	0.5	**---**	**23.33**
XVIII	C:FC: S:CA	1:1.5:3.3	0.5	Wet	**26.57**

C: Cement FC: Fine Cement	S: Sand CA: Coarse Aggregate

CHAPTER 4

DISCUSSION ON TEST RESULTS

4.1 General

Results obtained from various tests on cement matrix were presented in Chapter 3. A discussion on these test results is presented here with a view to draw qualitative as well as the quantitative conclusions. The results obtained from compressive tests on cement samples are given in Tables 3.5 to 3.22. These results have also been graphically presented in figures 4.1 to 4.18.

4.2 Compressive Strength

Results of 153 nos cement cube specimen of size 70.7 mm are given in the Tables 3.5 to 3.22. The Graphs shows the variation mainly where the fine cement and fine construction materials with aggregate are used. Figures 4.1 to 4.18 describe these variations in detail.

4.2.1 Test Results of Cube with Cement & Fine Cement

As can be seen in Figure 4.1, the compressive strength of fine cement (converted cement) for 7, 14 and 28 days is more than the compressive strength of normal cement. Fine cement (wet grinded) shows more strength than the fine cement (dry grinded) and the normal cement. The percentage increase in the strength of wet grinded cement with the normal cement at 7, 14 and 28 days is 76, 75 and 90% respectively.

Also the percentage increase in the strength of dry grinded cement with the normal cement at 7, 14 and 28 days is 59, 55 and 65% respectively. The strength of cubes made up of cement and fine aggregate lies in between the strength of cubes made up of fine cement matrix and normal cement matrix. The reason for gain in the strength at different stages is due to the fineness of cement which causes larger surface area of cement to come in contact with the water. Moreover the voids will be less and hence the strength increases as the cracks need space or void to propagate through.

4.2.2 Test Results of Cube with Cement, Fine Cement & Silica Fume

The compressive strength of fine cement matrix by adding 10% silica fumes is more than the compressive strength of normal cement having 10% silica fumes. This is because of the fineness of cement which increases the surface area and fills all the voids and hence the cracks don't propagate further.

4.2.3 Test Results of Cube with Cement, Fine Cement & Nano Silica Fume

Figure 4.3 shows the addition of 10% nano silica fumes to the cement matrix. From the figure it is clearly visible that the compressive strength of fine cement having 10% nano silica fumes is more than the compressive strength of normal cement having 10% nano silica fumes. The fine cement having nano silica fumes shows more strength as compared to other. There is a 9% increase in the strength of a fine cement having nano silica fume in comparison to the normal cement having nano silica fume.

4.2.4 Comparison of Test Results of Cube with Cement, Fine Cement, Silica Fume with Test Results of Cube with Cement, Fine Cement & Nano Silica Fume

Figure 4.4 shows the compressive strength comparison by adding 10% nano silica fumes and 10% normal silica fumes. Graph shows that the fine cement having 10 % nano silica fumes gives more compressive strength than the fine cement having 10% silica fume. Also fine cement having 10% nano silica fume gives more compressive strength than the normal cement having 10% silica fumes.

4.2.5 Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Silica fume

Figure 4.5 show that the wet grinded cement is having the maximum compressive strength. The second maximum strength is shown by the dry grinded cement. Figure also shows that the addition of 10% silica fumes to the cement matrix reduces the strength of the cement mortar matrix. The wet grinded cement exhibits maximum strength of 40 MPa. The fine cement having 10% silica fume shows lesser strength than dry grinded cement although the strength is more than the normal cement matrix (about 30 % higher).

4.2.6 Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Nano Silica fume

Figure 4.6 shows the maximum compressive strength of the wet grinded cement. In spite of addition of 10% nano silica fume to the dry grinded cement matrix, the strength remains low as compared to wet grinded cement.

4.2.7 Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Silica fume and Test Results of Cube with Cement, Fine cement & Nano Silica fume

In Figure 4.7 the maximum strength is shown by the fine cement matrix and the matrix which is having fine cement and nano materials in the cement matrix.

4.2.8 Test Results of Cube with Cement, Fine Cement & Fly ash

Figure 4.8 shows the compressive strength of the cement matrix with addition of 10% flyash in the matrix. The result shows that the fine cement having 10% flyash shows more strength than the other matrix. Also the combination of fine cement with the normal cement (50% each) and 10% flyash gives more strength than the normal cement having 10% flyash in the matrix.

4.2.9 Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Fly ash

The highest peak is obtained by wet grinded cement matrix and then the second and third maximum peak is obtained from the fine cement and combination of fine and normal cement respectively as shown in Figure 4.9. It can also be seen that 10% flyash in the matrix gives more strength then the normal cement having 10% flyash and combination of fine and normal cement with 10% flyash.

4.2.10 Test Results of Cube with Cement, Fine Cement & Nano Fly ash

Figure 4.10 shows that the maximum strength is governed by the fine cement having nano silica fumes at 7, 14 and 28 days. There is almost 21% increase in the strength of the fine cement having nano silica fume with the normal cement having nano silica fume.

4.2.11 Comparison of Test Results of Cube with Cement, Fine Cement & Fly ash with Test Results of Cube with Cement, Fine Cement & Nano Fly ash

Figure 4.11 shows the comparison of compressive strength comparison by adding 10% nano fly ash and 10% normal fly ash. It can be seen that the fine cement having 10 % nano fly ash gives more compressive strength than the fine cement having 10% fly ash. Also fine cement having 10% nano fly ash gives more compressive strength than the normal cement having 10% fly ash.

4.2.12 Comparison of Test Results of Cube with Cement, Fine Cement with Test Results of Cube with Cement, Fine Cement & Nano Fly ash

In the Figure 4.12 the maximum compressive strength is obtained for the wet grinded cement. In spite of addition of 10% nano fly ash to the dry grinded cement matrix, the strength remain low as compared to wet grinded cement.

4.2.13 Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Fly ash and Test Results of Cube with Cement, Fine cement & Nano Fly ash

The maximum strength is shown by the fine cement matrix and the matrix which is having fine cement and nano materials in the cement matrix as can be seen in Figure 4.13. The maximum value is attained by the wet grinded cement and minimum is attained by the normal cement matrix.

4.2.14 Comparison of Test Results of Cube with Cement, Fine Cement & Silica Fume with Test results of Cube with Cement, Fine cement & Nano Fly ash, Test Results of Cube with Cement, Fine cement & Fly ash and Test Results of Cube with Cement, Fine cement & Nano Fly ash

Figure 4.14 shows the strength of cement matrix with silica fume, nano silica fume, fly ash and nano fly ash. The maximum strength is attained by the fine cement matrix with nano silica fume and fine cement having nano fly ash. Almost 20% increase in the strength of fine cement having nano fly ash is observed as compared to the fine cement having nano silica fume.

4.2.15 Test Results of Cube with Cement, Fine Cement & 5% Nano Silica Fume

Figure 4.15 shows that even with an addition of 5% nano silica fume to the fine cement, the strength of the matrix show more strength as compared to fine cement having 10% nano silica fume and fine cement having 10% nano fly ash after 28 days.

4.2.16 Comparison of Test Results of Cube with Cement, Fine Cement & Silica Fume with Test Results of Cube with Cement, Fine Cement & Fly ash

Figure 4.16 shows that the maximum strength is given by the matrix of fine cement having 10 % fly ash in it. The reason for gain in the strength at different stages is due to the fineness of cement which causes larger surface area of cement to come in contact with the water and moreover the voids will be less and better compaction will be achieved.

4.2.17 Comparison of Test Results of Cube with Cement, Fine Cement & Nano Silica Fume with Test Results of Cube with Cement, Fine Cement & Nano Fly ash

Figure 4.17 shows the variation in the cement matrix with the fine cement, nano silica fume and nano fly ash. The strength of cubes after 28 days using nano fly ash with fine cement is more than that of nano silica fume with fine cement.

4.2.18 Comparison of Test Results of Cube with Cement & Fine Cement with Test Results of Cube with Cement, Fine Cement & Silica Fume, Test Results of Cube with Cement, Fine Cement & Nano Silica Fume, Test Results of Cube with Cement, Fine Cement & Fly ash, Test Results of Cube with Cement, Fine Cement & Nano Fly ash and Test Results of Cube with Cement, Fine Cement & 5% Nano Silica Fume

Figure 4.18 shows the summary of all the tables. In this we can easily conclude that the maximum strength is gained by the matrix which is having fine cement, nano silica fume and nano flyash.

4.3 Compressive Strength of Concrete Matrix

From the figure 4.19 it is clearly visible that the concrete cube which contains only 25% wet grinded cement is having more compressive strength than the concrete cube having normal cement for M20 mix design.

4.4 Microscopic Examination on Cement Matrix

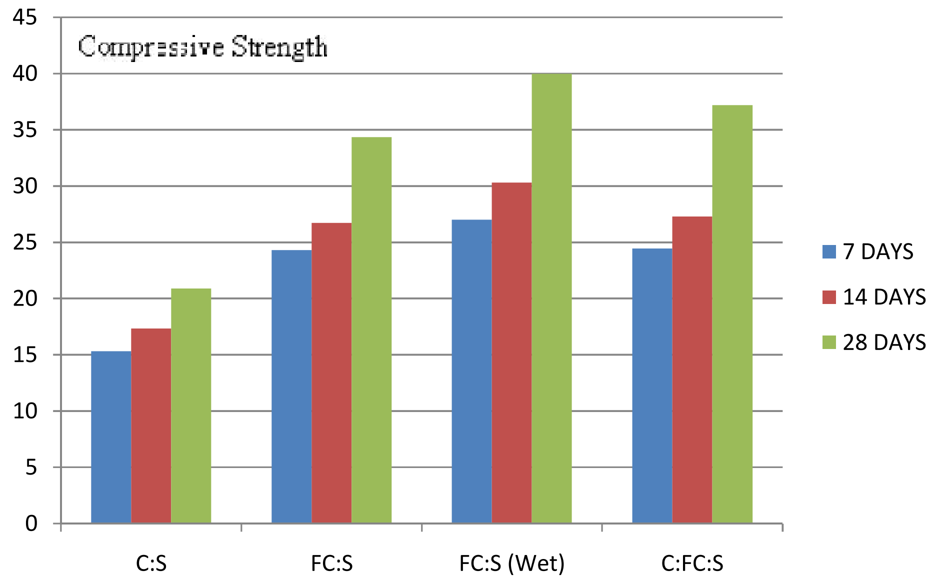
From the general photo micrographic studies it seems that in case of normal cement, micrpores are evident within the cement paste. The contacts with the aggregate grains too are not very dense (figure 3.16 a, 3.16b, 3.16c and 3.16d).

In the case of dry grinded nano sized cement the mix shows dense cement phase and good cement- grain contact (figure 3.17a and 3.17b). The dry grinded nano sized cement at places, show rounded pores formed due to air trapment in the mix (figure3.17 c and 3.17d).

The mix made up of wet grinded nano sized cement and aggregate shows characteristics similar to dry grinded nano sized cement and as such no differentiation could be made out at the magnification levels of petrographic microscopy (figure 3.18a, 3.18b, 3.18c and 3.18d). The scanning electron microscopy may be helpful in unraveling the difference in the two.

4.5 Concluding Remarks

It was observed that the cement matrix strength is improved by the addition of nano particles to the cement matrix or by using fine cement instead of normal cement. An increase up to 92% has been observed for cube specimen using fine cement as compared to the cube specimen using normal cement.



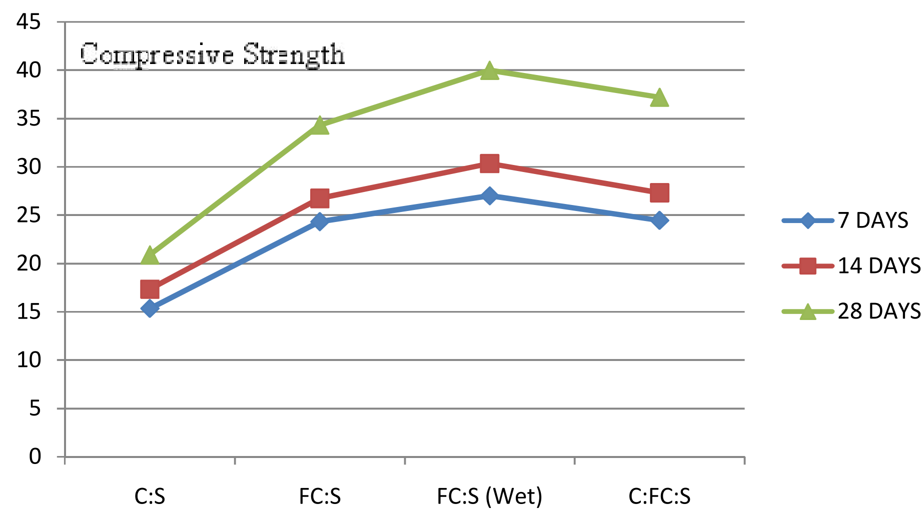
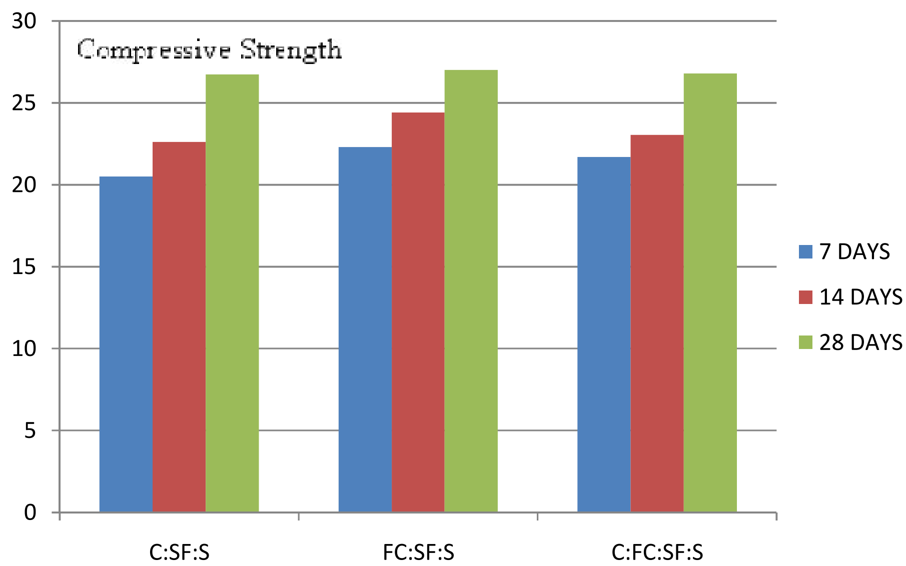


Figure 4.1 Graphs Showing Test Results of Cube with Cement & Fine Cement

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



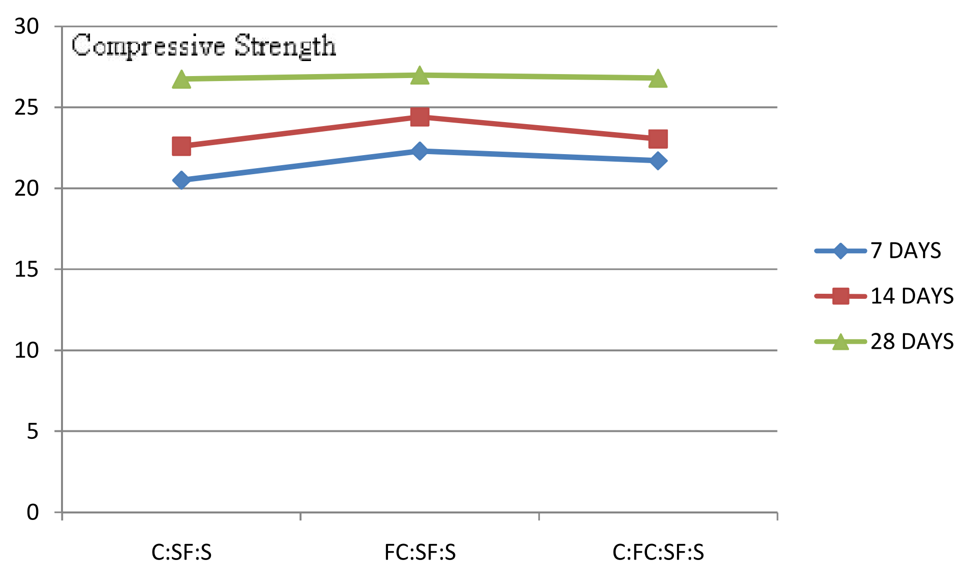
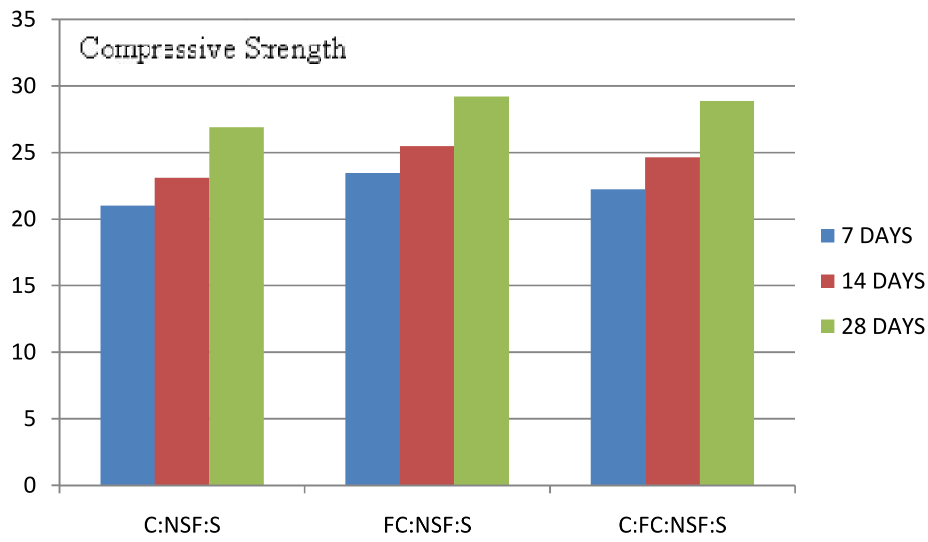


Figure 4.2 Graphs Showing Test Results of Cube with Cement, Fine Cement & Silica Fume

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



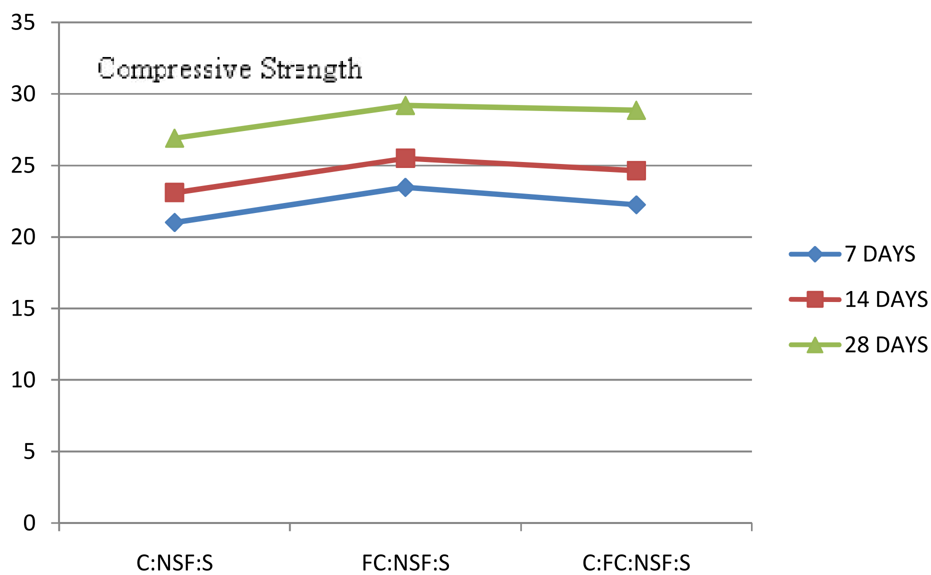
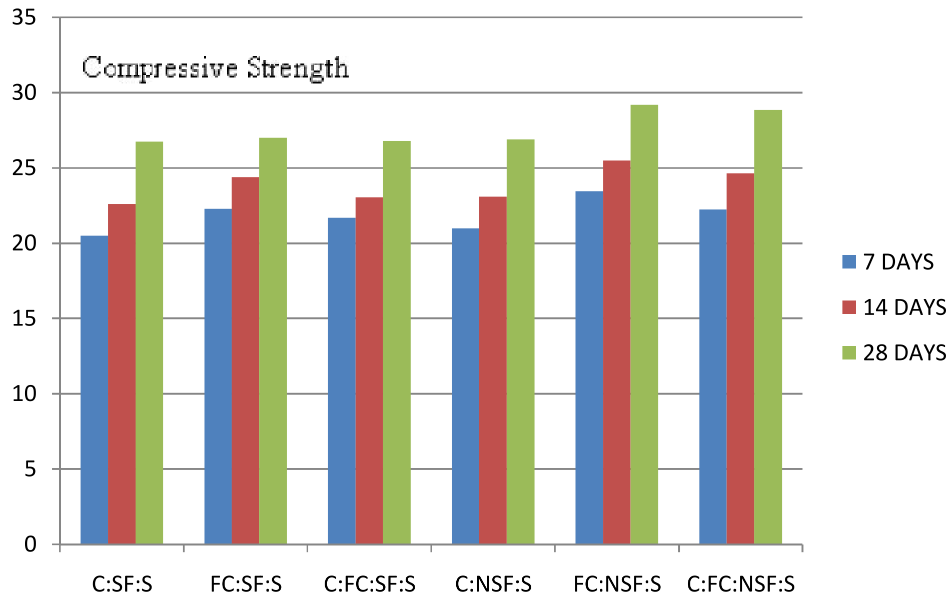


Figure 4.3 Graphs Showing Test Results of Cube with Cement, Fine Cement & Nano Silica Fume

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



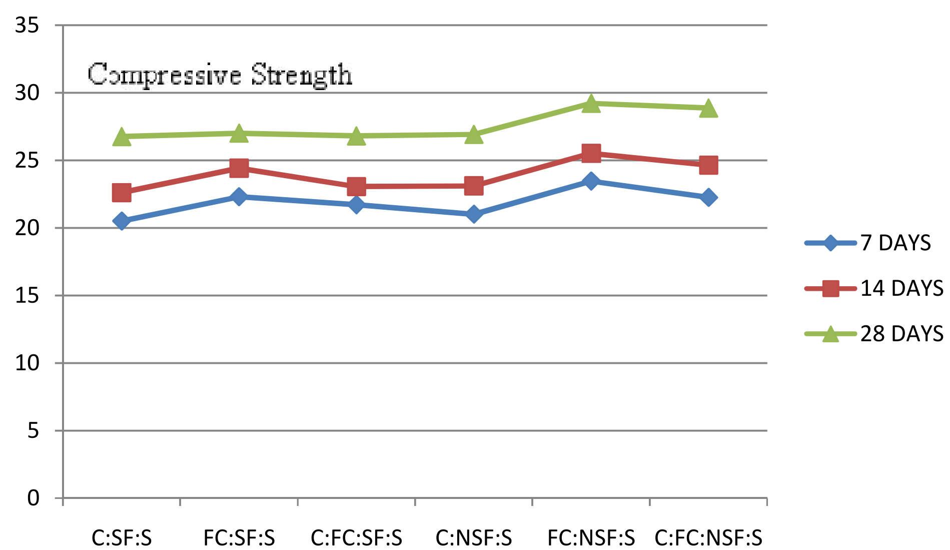
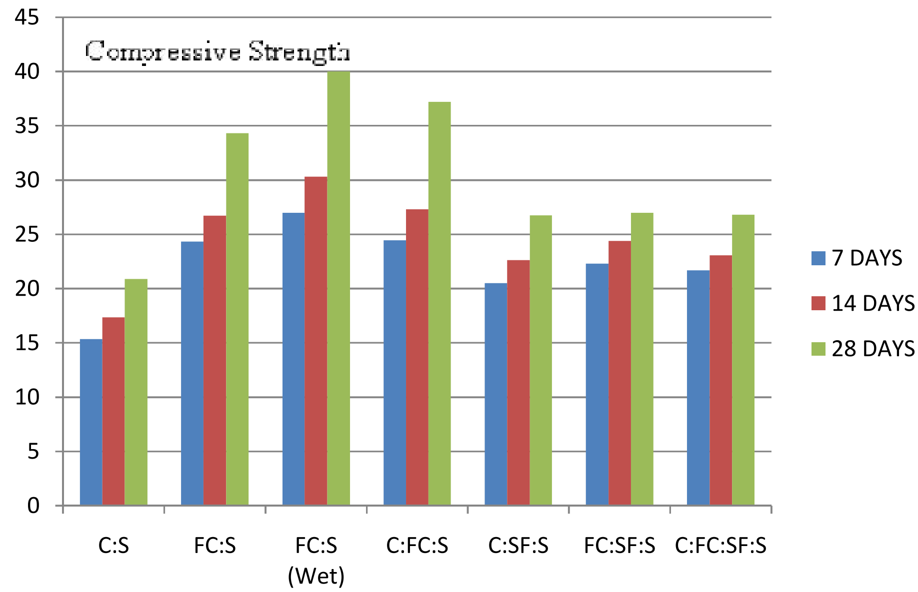


Figure 4.4 Graphs Showing Comparisons of Test Results of Cube with Cement, Fine Cement, Silica Fume with Test Results of Cube with Cement, Fine Cement & Nano Silica Fume

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



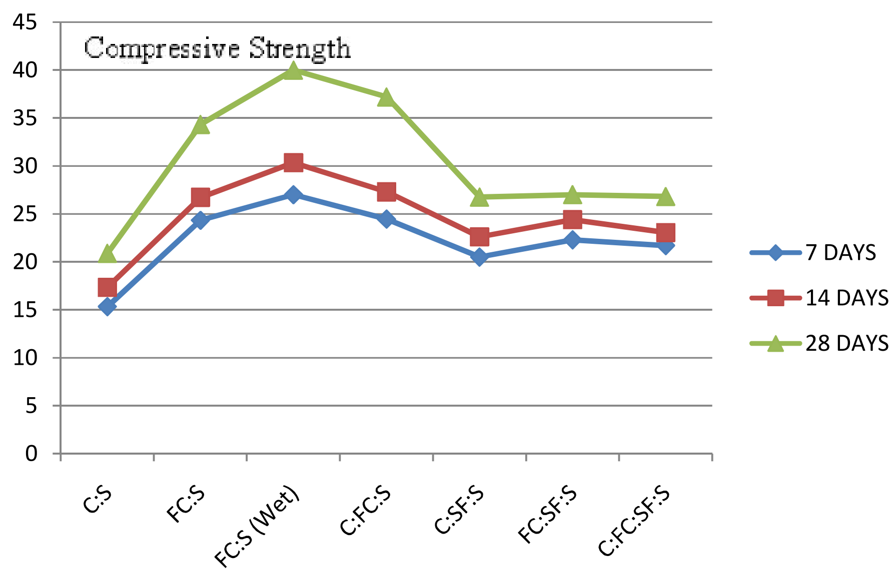
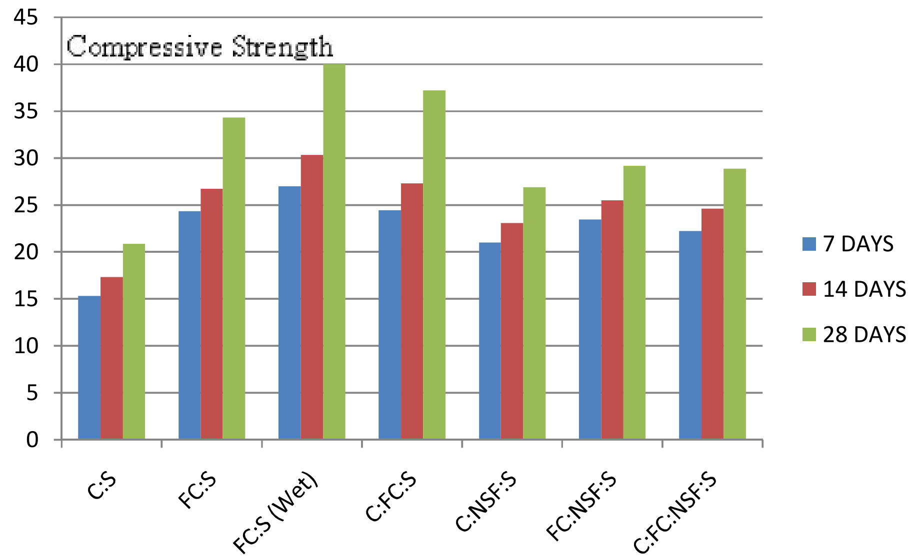


Figure 4.5 Graphs Showing Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Silica fume

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



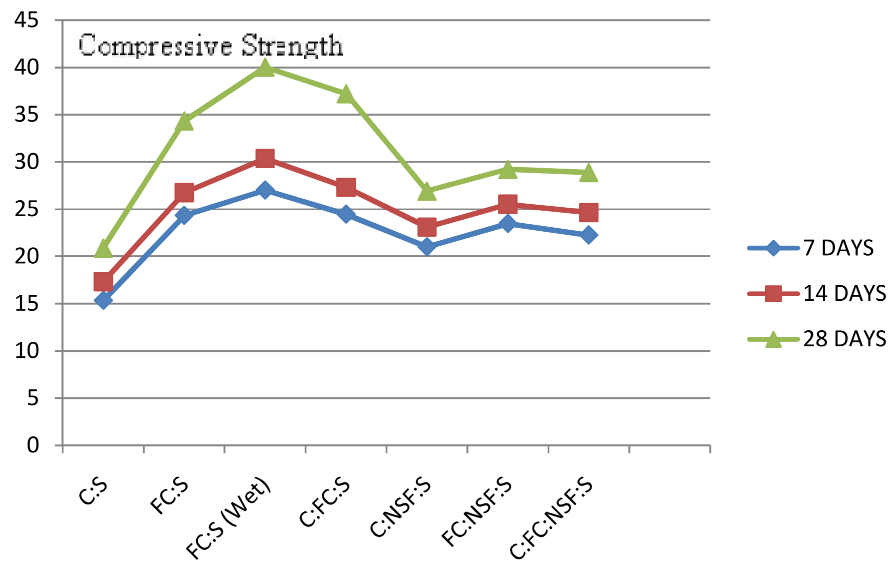
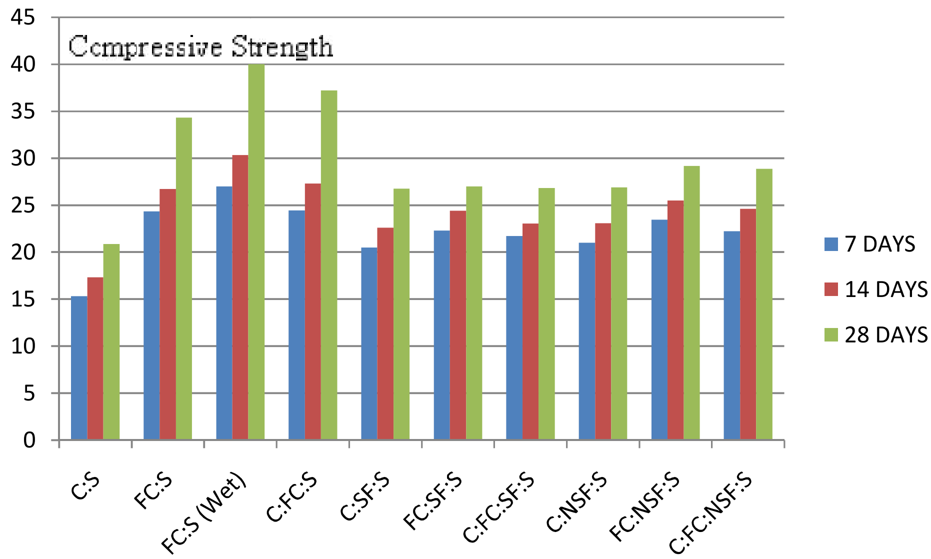


Figure 4.6 Graphs Showing Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Nano Silica fume

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



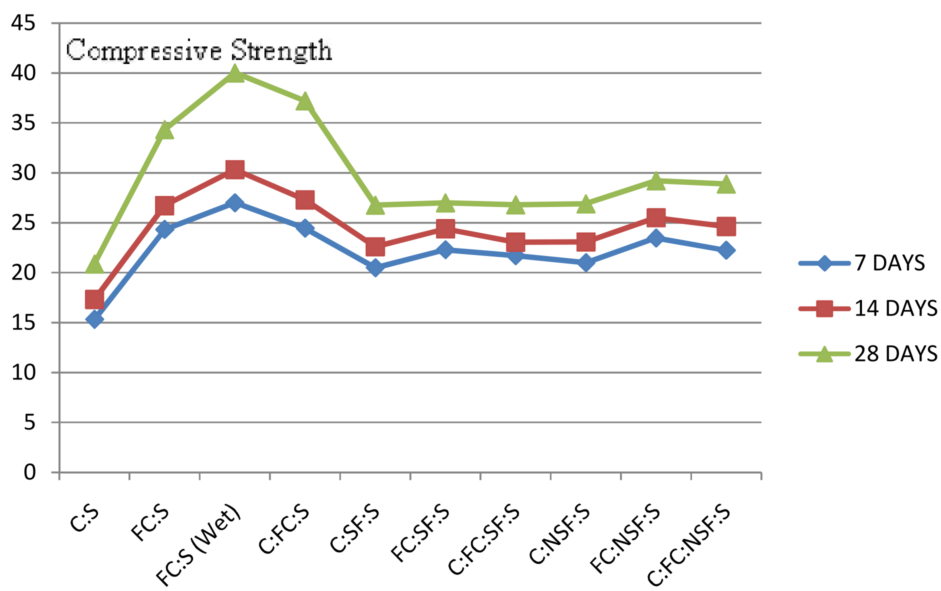
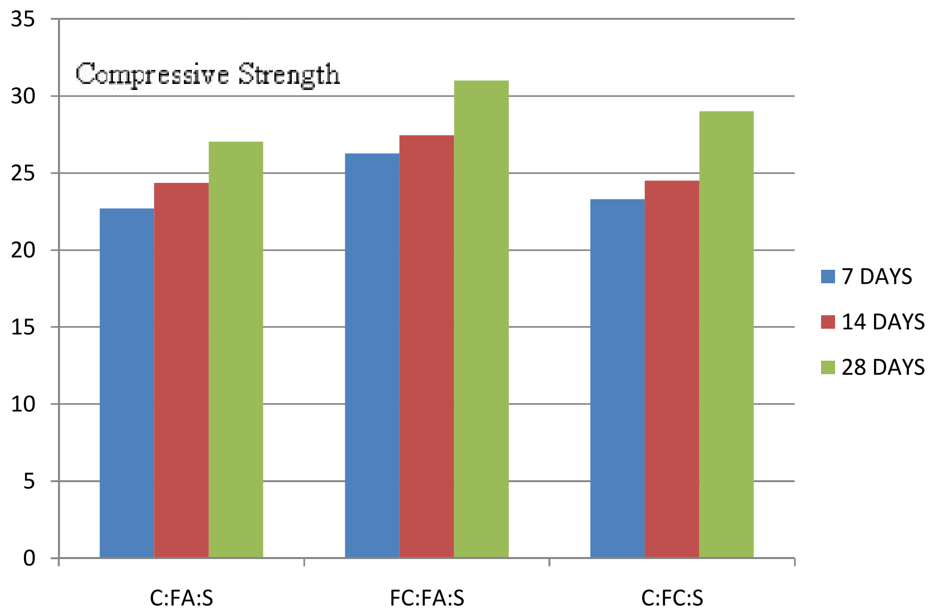


Figure 4.7 Graphs Showing Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Silica fume and Test Results of Cube with Cement, Fine cement & Nano Silica fume

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



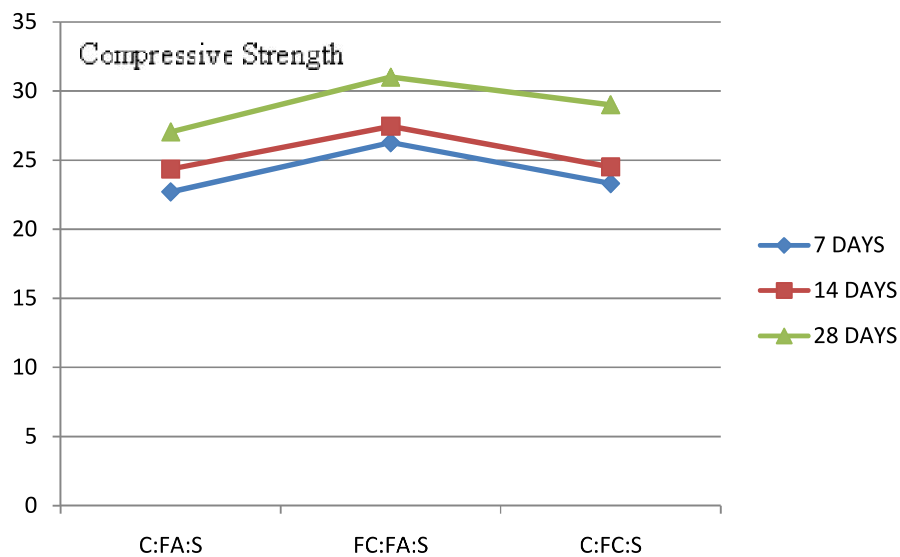
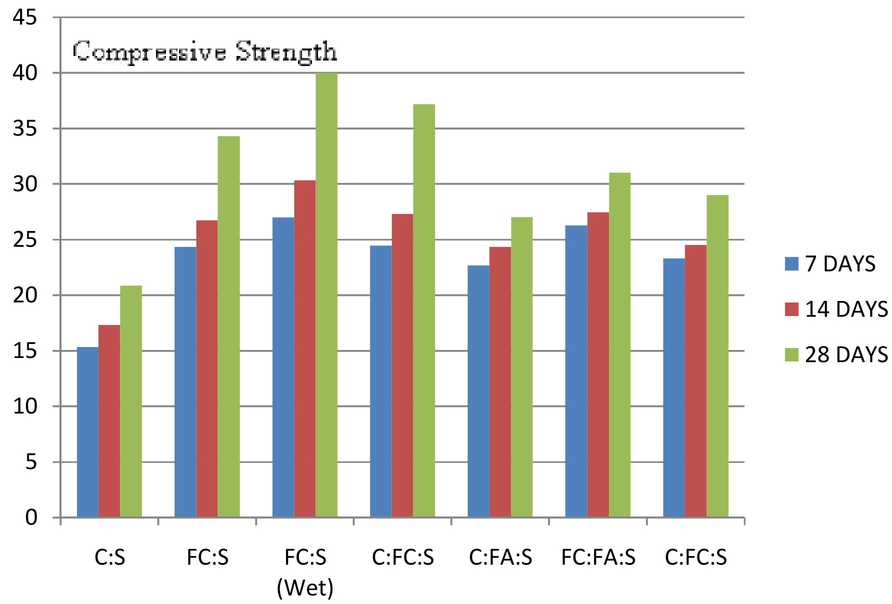


Figure 4.8 Graphs Showing Test Results of Cube with Cement, Fine Cement & Fly ash

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



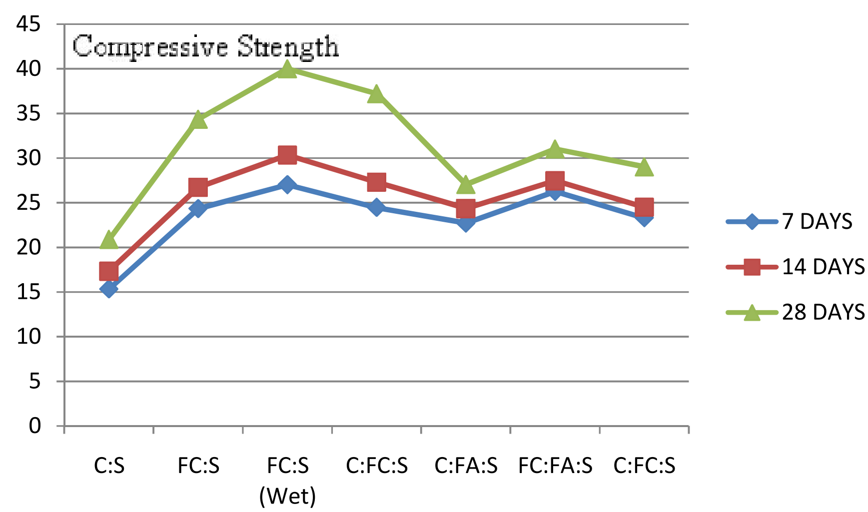
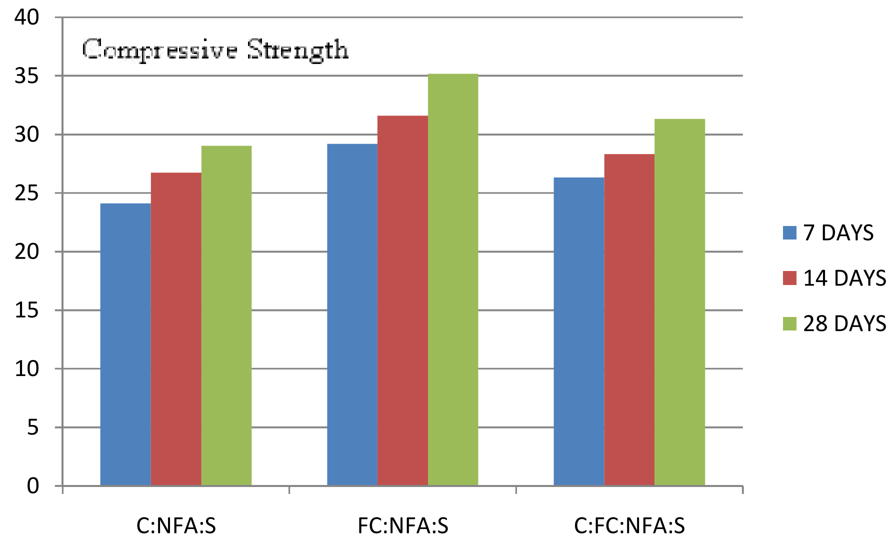


Figure 4.9 Graphs Showing Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Fly ash

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



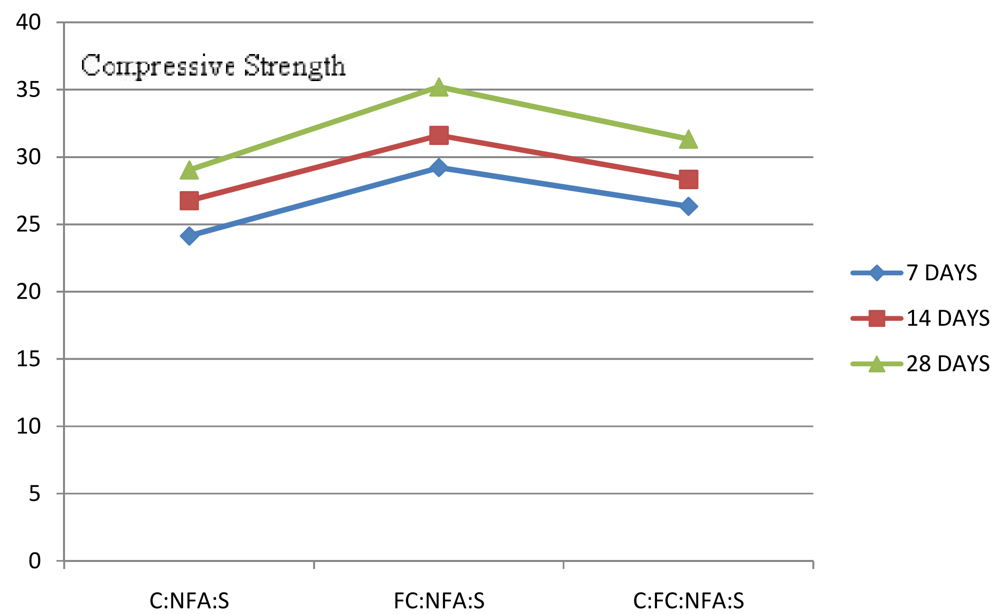
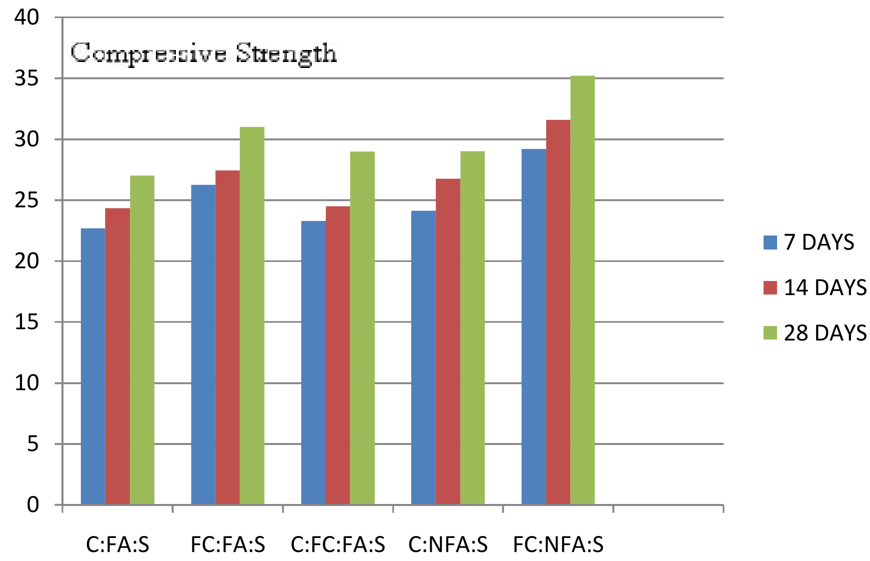


Figure 4.10 Graphs Showing Test Results of Cube with Cement, Fine Cement & Nano Fly ash

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



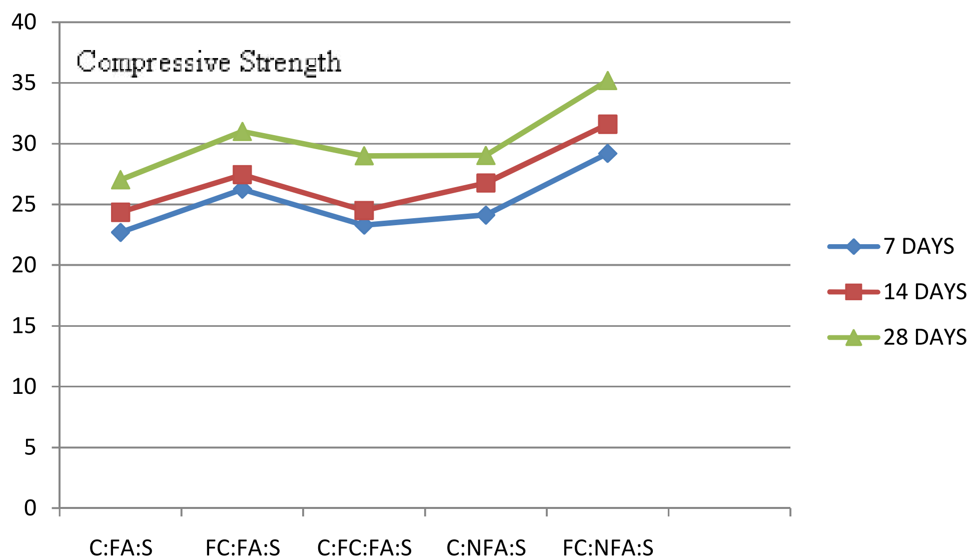
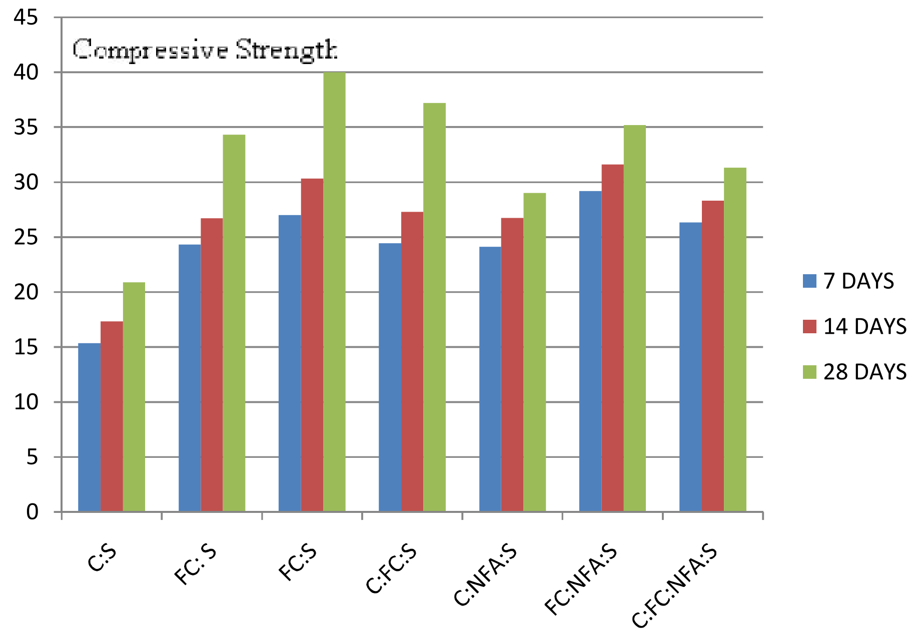


Figure 4.11 Graphs Showing Test Comparison of Test Results of Cube with Cement, Fine Cement & Fly ash with Test Results of Cube with Cement, Fine Cement & Nano Fly ash

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



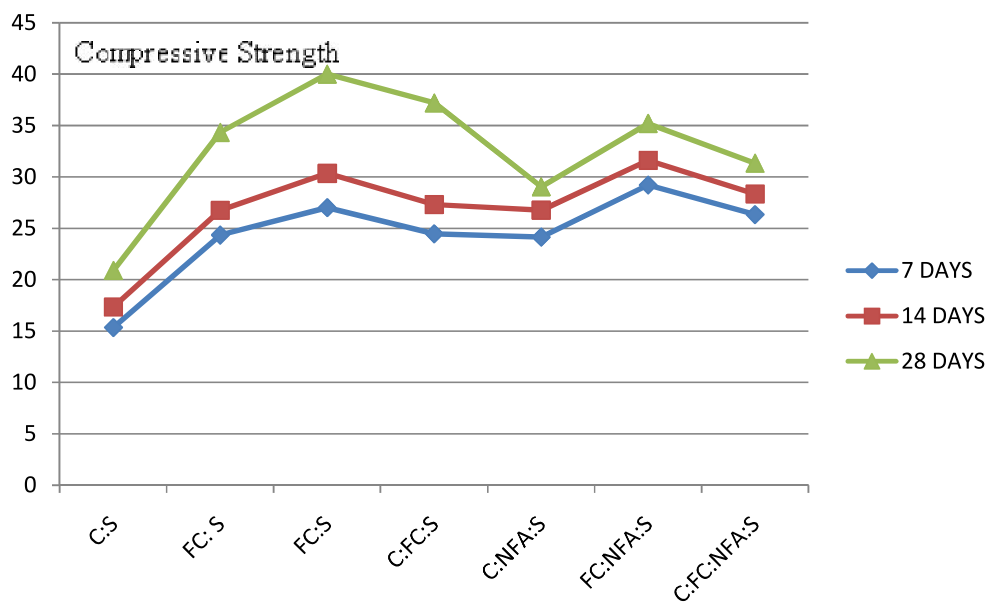
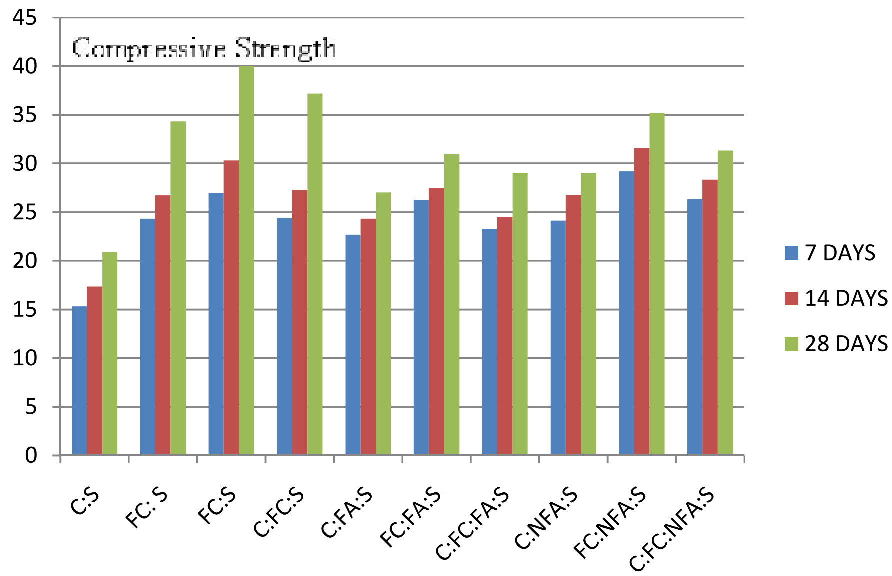


Figure 4.12 Graphs Showing Comparison of Test Results of Cube with Cement, Fine Cement with Test Results of Cube with Cement, Fine Cement & Nano Fly ash

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



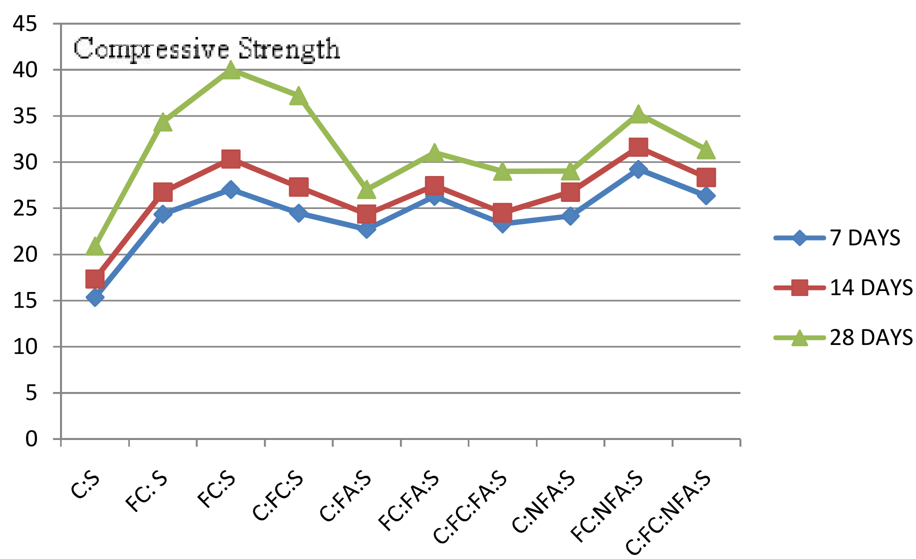
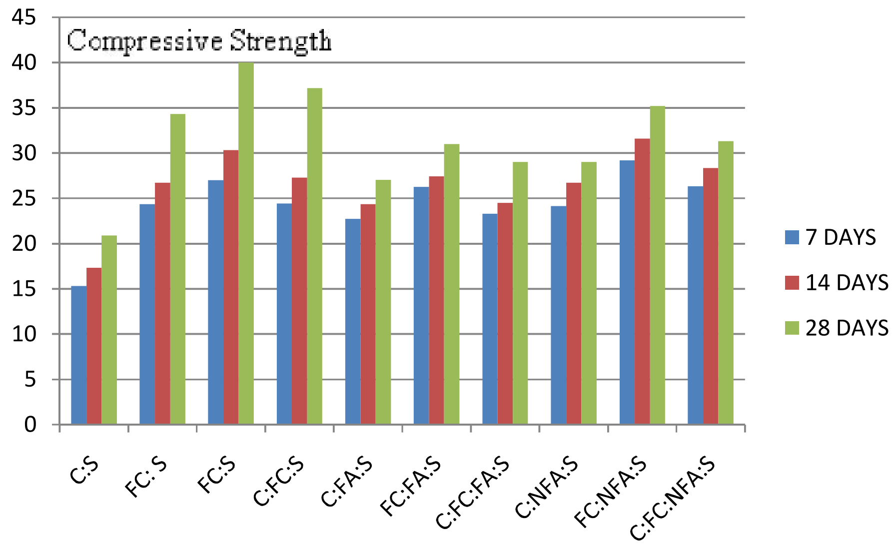


Figure 4.13 Graphs Showing Comparison of Test Results of Cube with Cement & Fine Cement with Test results of Cube with Cement, Fine cement & Fly ash and Test Results of Cube with Cement, Fine cement & Nano Fly ash

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



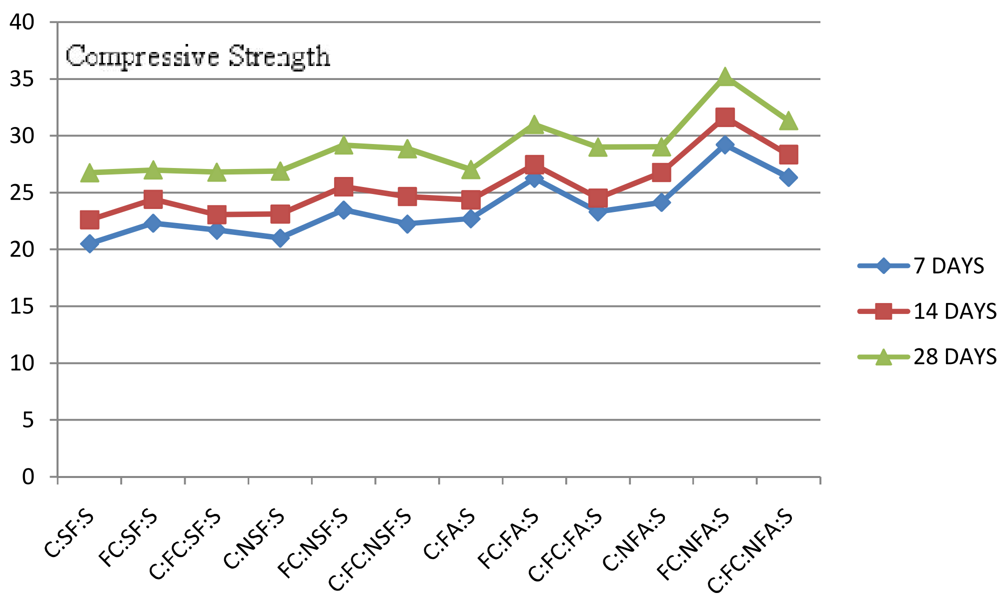
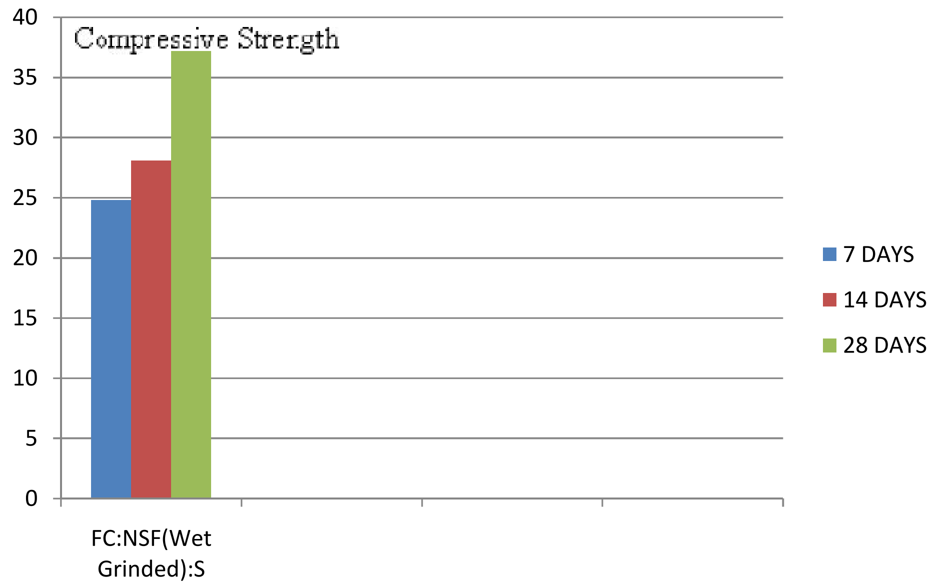


Figure 4.14 Graphs Showing Comparison of Test Results of Cube with Cement, Fine Cement & Silica Fume with Test results of Cube with Cement, Fine cement & Nano Fly ash, Test Results of Cube with Cement, Fine cement & Fly ash and Test Results of Cube with Cement, Fine cement & Nano Fly ash

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



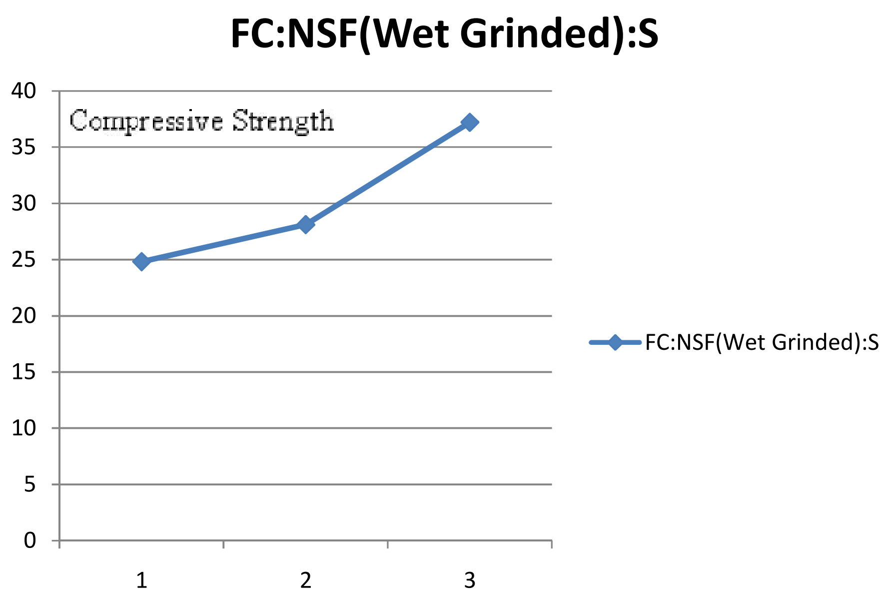
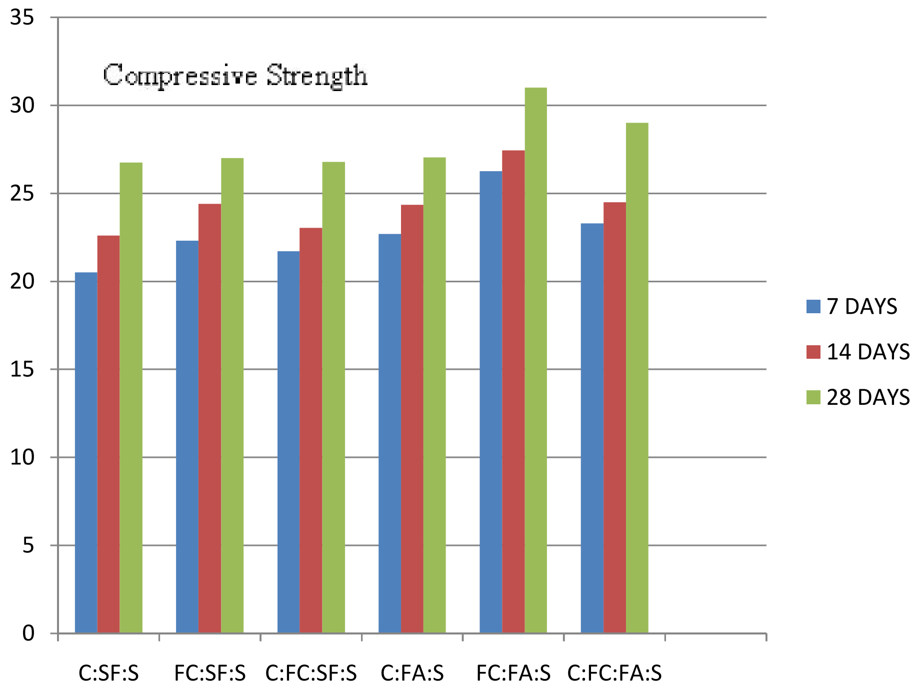


Figure 4.15 Graphs Showing Test Results of Cube with Cement, Fine Cement & 5% Nano Silica Fume

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



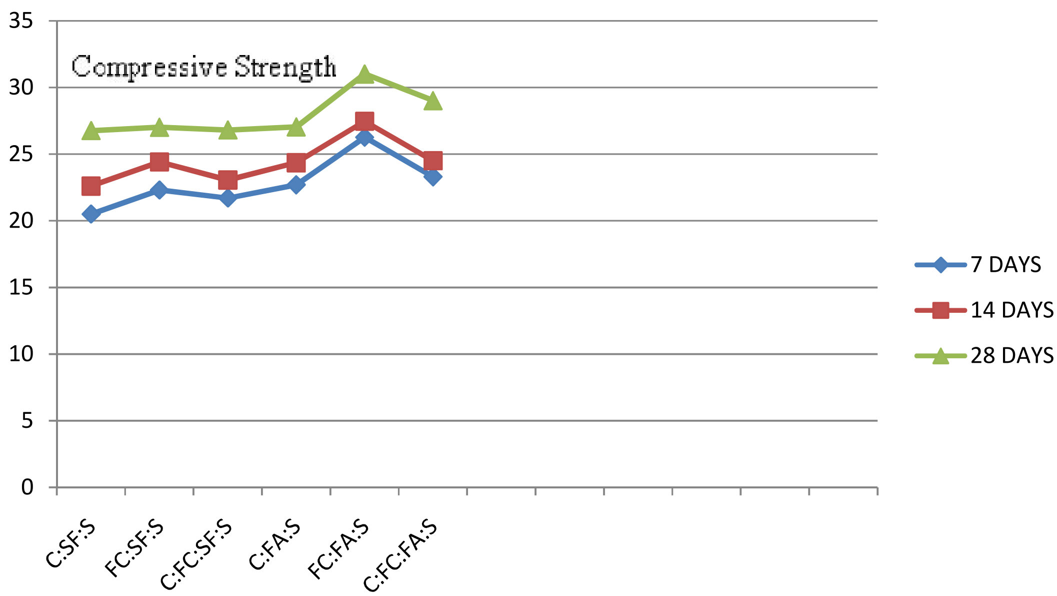
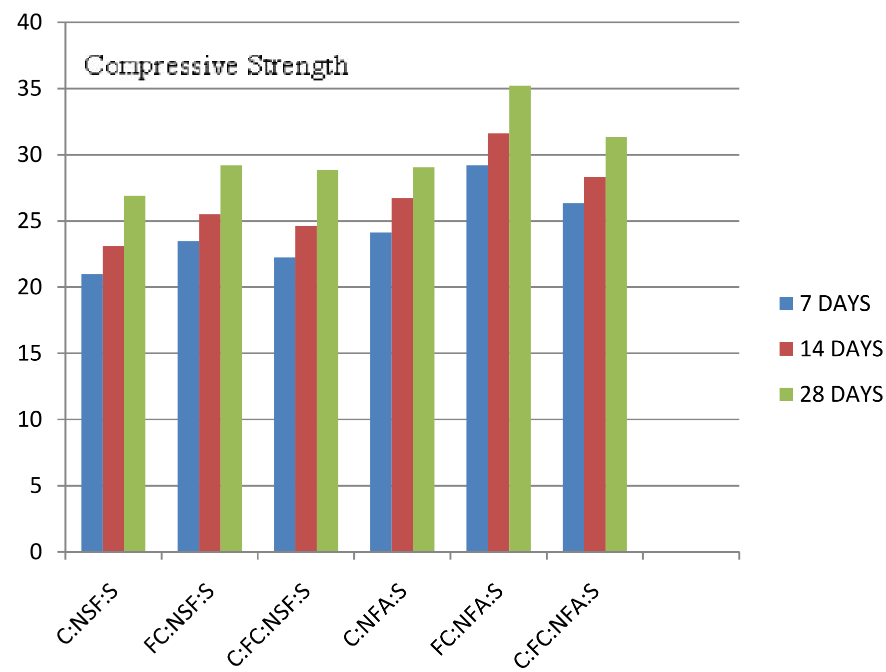


Figure 4.16 Graphs Showing Comparison of Test Results of Cube with Cement, Fine Cement & Silica Fume with Test Results of Cube with Cement, Fine Cement & Fly ash

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



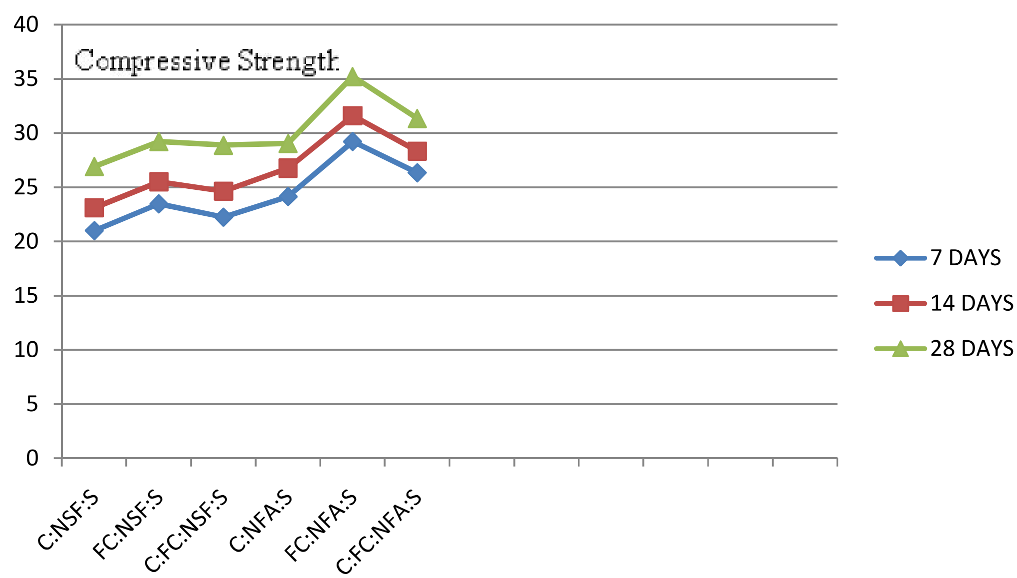
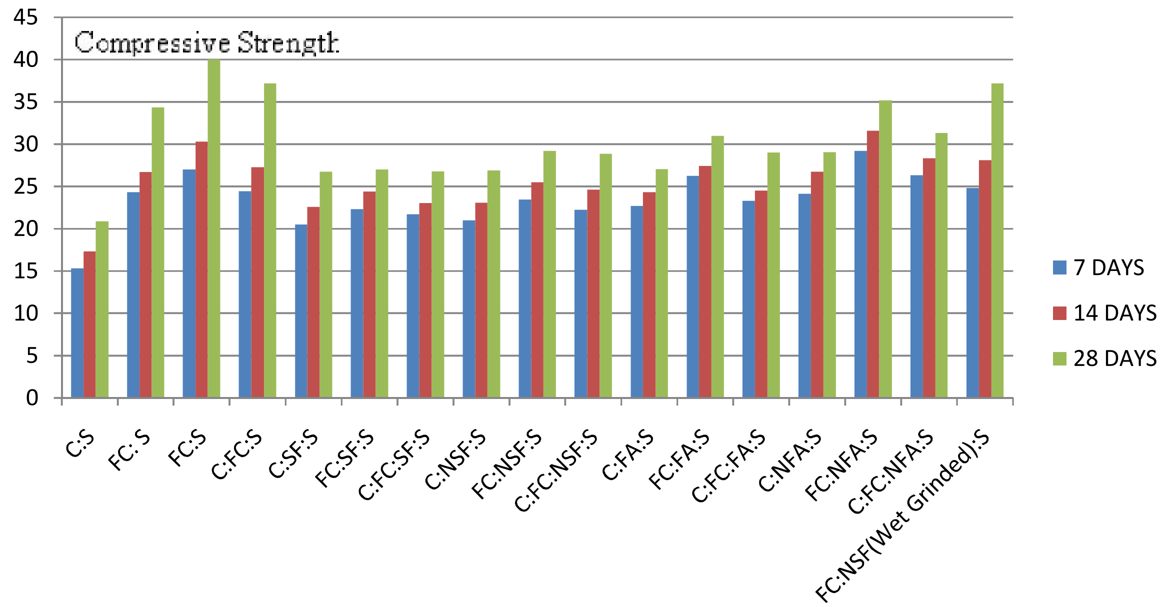


Figure 4.17 Graphs Showing Comparison of Test Results of Cube with Cement, Fine Cement & Nano Silica Fume with Test Results of Cube with Cement, Fine Cement & Nano Fly ash

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



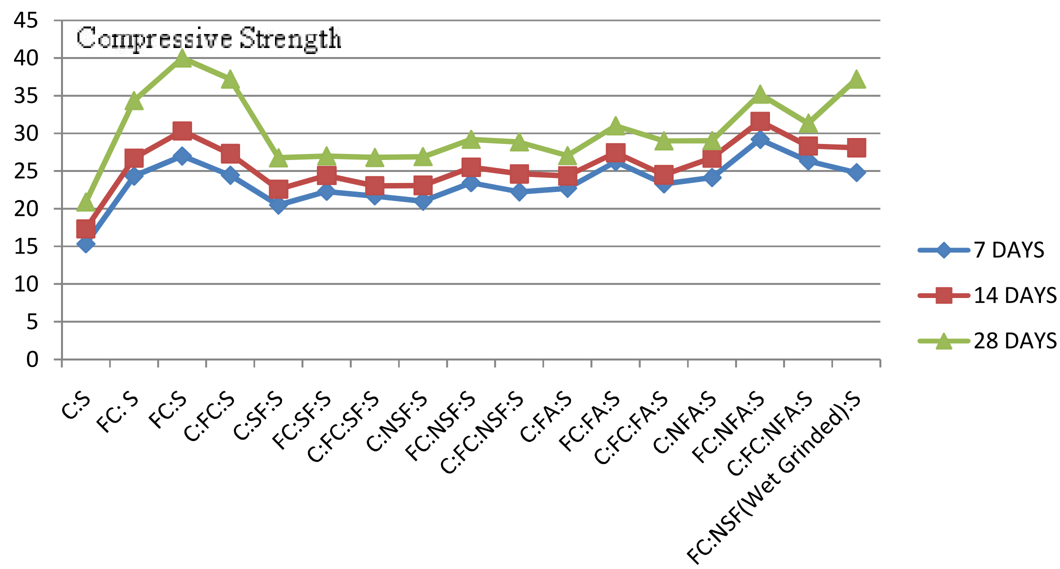
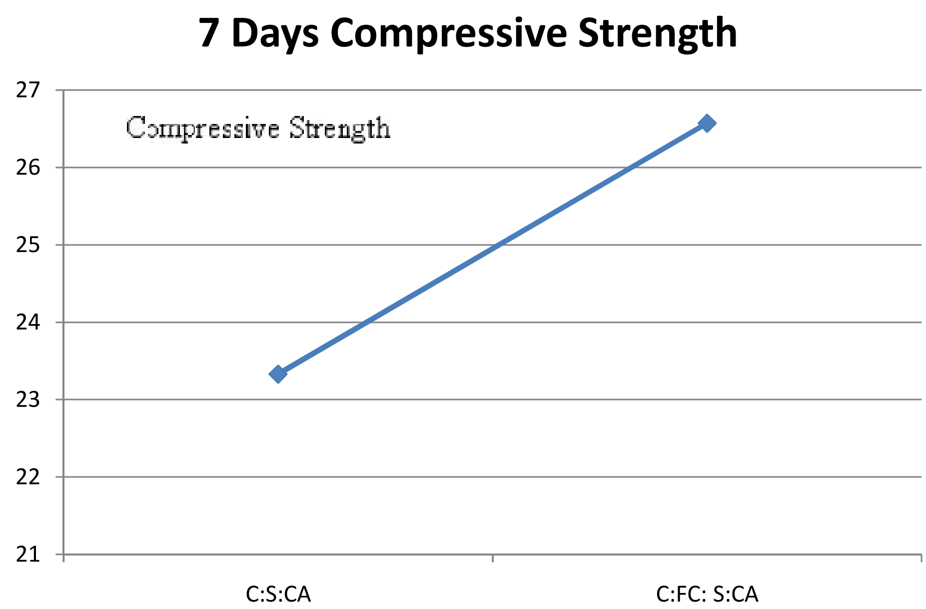


Figure 4.18 Graphs Showing Comparison of Test Results of Cube with Cement & Fine Cement with Test Results of Cube with Cement, Fine Cement & Silica Fume, Test Results of Cube with Cement, Fine Cement & Nano Silica Fume, Test Results of Cube with Cement, Fine Cement & Fly ash, Test Results of Cube with Cement, Fine Cement & Nano Fly ash and Test Results of Cube with Cement, Fine Cement & 5% Nano Silica Fume

C: CEMENT FC: FINE CEMENT S: SAND (BADARPUR)	SF: SILICA FUME NSF: NANO SILICA FUME	NFA: NANO FLY ASH FA: FLY ASH



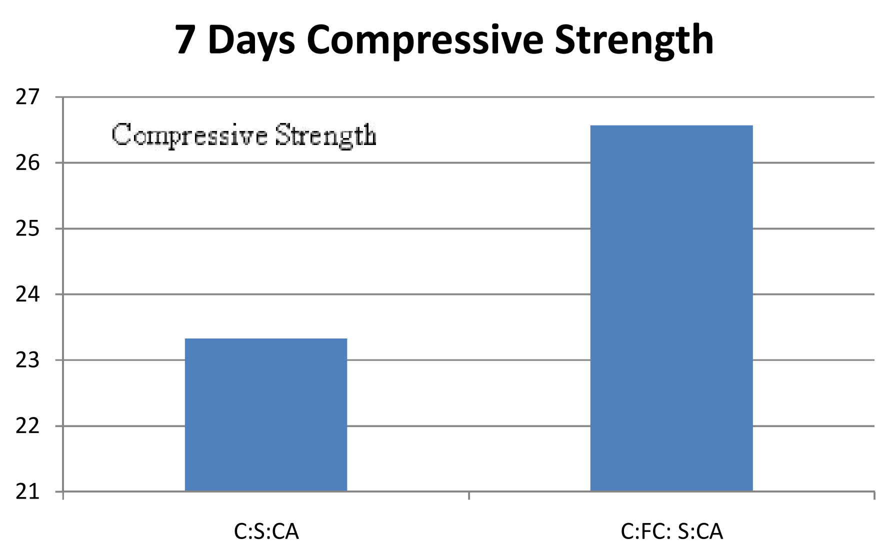


Figure 4.19 Graphs Showing Test Results of Concrete Cube with Cement & 25% Fine Cement

C: Cement FC: Fine Cement	S: Sand CA: Coarse Aggregate

CHAPTER 5

CONCLUSIONS & SCOPE FOR FURTHER STUDIES

5.1 Conclusions

Based on limited experimental investigations the following conclusions are drawn.

1. The nanofibers improve the fracture properties of cement matrix, by controlling of the matrix cracks at the nanoscale level.
2. Nanofibers also improve the compressive strength of the cementitious matrix by producing a high performance nanocomposite.
3. Photo micrographic study suggests that in case of normal cement, micrpores are evident within the cement paste. The contacts with the aggregate grains too are not very dense.
4. In the case of dry grinded nano sized cement the mix shows dense cement phase and good cement- grain contact.
5. The mix made up of wet grinded nano sized cement and aggregate shows characteristics similar to dry grinded nano sized cement and as such no differentiation could be made out at the magnification levels of petrographic microscopy. The scanning electron microscopy may be helpful in unraveling the difference in the two.
6. The properties of cement matrix and concrete are improved by the use of nano powders, since nano particles fill the voids between cement grains and also consume a part of calcium hydroxide which results in additional formation of calcium silicate hydrate (C.S.H.) and more improvement of interface structure.
7. The reason for gain in the strength at different stages is due to the fineness of cement which causes larger surface area of cement to come in contact with the water and moreover the voids will be less and hence the strength increases due to better compaction.
8. The efficiency of nano particles such as nano-Si02 and nano fly ash depends on their morphology.
9. Nano-Silica and Nano Fly ash addition results in significant increase in concrete compressive strength after 28-days up to one year and the optimum

amount of nano silica and nano fly ash by weight is required for cementitious material.

10. The maximum strength is gained by the matrix which is having fine cement, nano silica fume and nano flyash.
11. An increase up to 92% has been observed for cube specimen using fine cement as compared to the cube specimen using normal cement.

5.2 Scope for Further Studies

1. Studies must be aimed to investigate the behavior of cubes at sustained age.
2. Effect of aggressive environment conditions should also be explored.
3. Specimens with varying quantities of additives e.g. flyash, silica fumes should also be tested.
4. Other additives like GGBFS (Ground Granulated Blast Furnace Slag), RHA (Rice Husk Ash) etc should also be used.
5. Additives like nano $Ti0_2$, nano Al_20_3 and nano Fe_20_3 can be used in the cement matrix.
6. The detail investigation of nano cementitious composites can further studied under SEM & TEM.

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