International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Experimental Investigation on Carbon Nanotube (CNT) in Concrete

Priyanka Dutta[1], Dr. Biman Mukherjee[2]

[1] Narula Institute of Technology, Department of Civil Engineering, Kolkata, India
Email: mamontulip.dutta[at]gmail.com

[2] Narula Institute of Technology, Department of Civil Engineering, Kolkata, India
Email: *bimanmukherjee56[at]gmail.com*

Abstract: ***Carbon nanotubes (CNTs) are carbon structures which take the shape of cylinders in nanometric scale. They exhibit exceptional electrical, thermal and mechanical properties. This experimental investigation shows the effect of compressive strength of concrete embedded with single-walled carbon nanotube (SWCNT) in different percentages starting from 0.01% to 0.05%; increasing at 0.01%. CNT is mixed with water and kept aside for 30 minutes to avoid dispersion of particles and then thoroughly mixed with dry mix consisting of Portland Pozzolana cement, fine aggregate and coarse aggregate. Compressive strength of 7 days, 14 days and 28 days have been observed and recorded. It has been seen that CNTs with 0.03% gives the best result and increasing the percentages of CNTs decreases the compressive strength.***

Keywords: Carbon Nanotube, Compressive Strength, Concrete, Nanometric

1. Introduction

A carbon nanotube (CNT) is a tube made of carbon with diameters typically measured in nanometers. Carbon nanotube can also refer to tubes with an undetermined carbon-wall structure and diameters less than 100 nanometres. Such tubes were discovered in 1952 by Radushkevich and Lukyanovich. The length of a carbon nanotube produced by common production methods is often not reported, but is typically much larger than its diameter. Thus, for many purposes, end effects are neglected and length of carbon nanotube is assumed infinite.

Single-wall carbon nanotubes (SWCNTs) are one of the allotropes of carbon, intermediate between fullerene cages and flat graphene, with diameters in the range of a nanometre. Although not made this way, single-wall carbon nanotubes can be idealized as cutouts from the two dimensional hexagonal lattice of carbon atoms rolled up along one of the Bravais lattice vectors of the hexagonal lattice to form a hollow cylinder. In this construction, periodic boundary conditions are imposed over the length of this roll-up vector to yield a helical lattice of seamlessly bonded carbon atoms on cylinder surface.

Multi-wall carbon nanotubes (MWCNTs) consisting of nested single-wall carbon nanotubes weakly bound together by Van der Waals interaction in a tree ring-like structure. If not identical, these tubes are very similar to Oberlin, Endo and Koyama's long straight and parallel carbon layers cylindrically arranged around a hollow tube. Multi-wall carbon nanotubes are also sometimes used to refer to double and triple wall carbon nanotubes. MWCNTs consist of multiple carbon nanotubes nested within one another. The number of nanotubes that are within a MWCNT can vary – from as little as 3 to 20. At the same time the diameter of both the internal nanotube and the external nanotube can vary from 2nm for the innermost tube to over 50nm for the outer wall. Just like single-walled nanotubes, they exhibit exceptional electrical, thermal and mechanical properties. However, due to the increased number of walls, there is a higher likelihood of defects being present compared to single-walled nanotubes, resulting in reduced performances. The outer walls of MWCNTs can be modified with functional groups such as hydroxides, carboxylic acids, or amides to produce additional functionality. MWCNTs can be produced in high quantities and are easier to purify. This makes their produce costs significantly lower, and is a reason for their adoption in multiple areas of scientific research. Applications of MWCNTs have been mainly focused around their use in composites where they can be used as an additive either to improve mechanical properties of a material or to improve electrical properties of a material. Aside from being used as additives, functionalized MWCNTs are being utilized in a variety of medical and biotechnological applications. This is due to their high bio-compatibility of carbon nanotubes and the ability to attach specific proteins to functional groups. This can provide a wide variety of targeted therapies such as drug delivery, localized heating for triggering cell death, or even miniature biosensors for in-situ measurements.

Because of their exceptional mechanical, electrical and thermal properties, carbon nanotubes are one of the most investigated materials. CNTs are expected to be the ultimate high-strength fibers. SWNTs are stiffer than steel, and are very resistant to damage from physical forces. Pressing on the tip of a nanotube will cause it to bend, but without damage to the tip. When the force is removed, the tip returns to its original state. This property makes CNTs very useful as probe tips for very high-resolution scanning probe microscopy. Although the strength of individual CNT shells is extremely high, weak shear interactions between adjacent shells and tubes lead to significant reduction in the effective strength of multiwalled carbon nanotubes and carbon nanotube bundles down to only a few GPa. This limitation has been recently addressed by applying high-energy electron irradiation, which crosslinks inner shells and tubes, and effectively increases the strength of these materials to ≈60 GPa for multiwalled carbon nanotubes and ≈17 GPa for double-walled carbon nanotube bundles. CNTs are not nearly as strong under compression. Because of their hollow structure and high aspect ratio, they tend to undergo buckling when placed under compressive, torsional, or bending stress. Carbon nanotubes are thus being explored as interconnects and conductivity-enhancing components in composite materials, and many groups are attempting to commercialize highly conducting electrical wire assembled from individual carbon nanotubes. There are significant challenges to be overcome however, such as undesired current saturation under voltage, and the much more resistive nanotube-to-nanotube junctions and impurities, all of which lower the electrical conductivity of the macroscopic nanotube wires by orders of magnitude, as compared to the conductivity of the individual nanotubes.

Carbon naotubes are utilized in energy storage, device modelling, automative parts, boat hulls, sport goods, water filters, thin-film electronics, coatings, actuators, and electromagnetic shields. Because of their large surface area, CNTs have been successfully used in pharmacy and medicine to adsorb or conjugate a wide range of medicinal and diagonistic substances. CNTs have a number of unique chemical, size, optical, electrical and structural properties that make them appealing as drug delivery and biosensing platforms for the treatment of a variety of diseases and noninvasive monitoring of blood levels and other chemical properties of the human body, respectively. CNTs have unique qualities, such as high surface-to-volume ratios, increased conductivity and strength, bio-compatibility, ease of functionalization, optical properties, and so on.

2. Literature Review

B. B. Das (2014) [1] has explained about all the types of nanomaterials used for construction purposes such as carbon nanotubes, nanoclays, nanoflex, nanowires, nanoceramic coating, nanosilica, nanocrystalline materials, etc. The properties and applications have been highlighted so that the readers can get the brief overview of the nanomaterials, considering the design of sustainable and durable structures.

N. Yazdani [2] has been created a focus on the carbon nanofibers (CNF). The history of CNF and method of synthesizing is being tracked. The basic physical properties of CNF is tabulated. The utilization of CNF and its first usage in cement mortar was 0.2% by weight of cement.

Dr. B. Vidivelli (2018) [3]discuss about the physical, mechanical, thermal, electrical and electronics properties of single-wall carbon nanotibes (SWCNT) and multi-wall carbon nanotubes (MWCNT). It has been concluded that addition of small amounts of CNT can improve the mechanical properties of samples consisting of the main Portland cement phase and water. Oxidized multi-walled carbon nanotubes show the best improvements both in compressive strength and flexural strength compared to the sample without reinforcement.

Hardik Bhatia (2014) [4] discussed about the methods of synthesis of nanomaterials by grafting in C-S-H composites and sol gel process. Different nanomaterials with their applications and newly introduced properties such as electrical conductivity, temperature, moisture, stress-sensing abilities, etc. are explained briefly. Even the future developments such as mechano chemistry and nano-catalyst can change the face of modern cement industry. Nanomaterials coating on the concrete proves to be self-cleansing and self-healing. It has been concluded with the next level development of cementitious based materials through nano-engineering.

Mani. M (2017) [5] carried out a review about nanomaterials such as nanosilica, nanotitanium dioxide and carbon nanotubes. Analysis of different papers and conclusion drawn shows the factual features of nanoconcrete.

Heba A. Gamal (2021) [6] analyse the efficiency of CNTs. They used 15% of nano clay and 0.01%, 0.02% and 0.04% of CNTs by weight with the mix. Different tests are carried out such as air content, workability, compressive strength test, tensile strength test, flexural strength test, sorptivity, water penetration test, chloride penetration test, corrosion resistance and scanning electron microscope (SEM). The test result are concluded that increase in bond strength, slight increment in sorptivity, increment trend in chloride penetration, hybrid nanoparticles improve the corrosion resistance and enhancing the durability properties.

Abhinayaa (2014) [7] investigated and understood that the increasing the proportions of functionalized MWCNT into concrete increases the compressive strength. In fact the compressive strength of the concrete with a proportion of 0.045% of functionalized MWCNT increases by 26.69%. the split tensile strength increased by 66.3% for 0.045% of MWCNT. With increase in MWCNT, the rate of increase of the tensile strength is greater than that of the rate of increase of the compressive strength.

Rafat Siddique (2014) stated that the compressive strength of plain concrete and MWCNTs reinforced mortar increased as 150%, 170% and 120% respectively at 7, 14 and 28 days.

R. Vetrivel aims to highlight the most important and novel studies of the mechanical behavior and applications of carbon nanotubes reinforced composites. The carbon nanotubes play a vital role due to their better structural and functional properties and it has a broad range of applications when it is reinforced with metal and polymer matrix composites. It is used as a potential candidate to be incorporated into marine current turbines and it is also aims to act as a starting point to connect the research areas.

Coppola (2011) [8] investigated about cement pastes reinforced with MWNTs are smart materials with piezoresistivity properties. MWNTs were dispersed in a surfactant (Sodium Linear Alkyl Benzene Sulphonate – LAS), and then mixed with cement and a defoamer (tributyl phosphate) to decrease the air bubble in MWNT filled cement-based composites. These findings seem to indicate that self-sensing CNTs/cement composites can be produced. These smart materials (Concrete with CNT) have great potential and they could be used in the next future in concrete field for practical applications to monitor stress level of reinforced concrete elements subjected to static, dynamic and impact loads.

Su-Tae Kang investigated the effects of acid-treated MWCNTs on the workability, compressive and tensile strength, porosity and microstructure of CNT/cement composites. While workability decreased with acid treatment of CNTs, compressive and tensile strength improved significantly. Strength was also enhanced by using acid-treated CNTs alone, compared to using a surfactant with acid-treated CNTs. MIP analysis revealed that the porosity decreases from using acid-treated CNTs and that using acid-treated CNTs without a surfactant was more effective in reducing the size of micropores. A SEM analysis revealed improved CNT dispersion and dense hydration products in cement composites containing acid-treated CNTs.

TanzirManzur [2] has done a parametric experimental investigation to determine optimum mix dosage of CNT for cement mortar. Different dosage rates of surface treated MWCNTs, water-cement ratios and plasticizers amounts were investigated through compressive and flexural strength determination. A mixing technique was proposed to address the issues related to dispersion of nanotubes within cement matrix. Both enhances the strength compared to control samples with no MWCNTs.

3. Experimental Work

3.1 Introduction

Concrete is most usable material in construction industry. It's been required to improve its behavior and quality. By using Nano-Materials, the improvement can affirm. Nano-Materials are added in mixes of concrete. A method to reduce the cement content in concrete mixes is the use of nano materials. Nanotechnology is an enabling technology that opens new possibilities in construction sustainability. If Portland cement can be formulated with nano size cement particles, it will open up a large number of opportunities. The cement will not only be more economical than organic polymers but also will be fire resistant. Also, nanotechnology enables us to develop materials with improved or totally new properties. Nano concrete have the ability to control or manipulate materials at the atomic scale.

3.2 Mix Design

The mix proportioning of the concrete is performed using the packing density method. This approach is carried out in two step. The determination of the fine and coarse aggregate fraction is accomplished in the first step by evaluating the maximum bulk density of the aggregate and the minimum void content. The percentage content of the fine and coarse aggregate at which the maximum packing density achieved is confirmed from the graphical representation. In the second step, the mix proportionating of the binder material, fine and coarse aggregate and water are calculated using packing density approach.

Table 1: Bulk Density and Specific Gravity of Materials

Materials	Bulk Density (Compacted condition) Kg/m^3	Specific Gravity
Fine Aggregate	1337.74	2.63
Coarse Aggregate (10mm)	1535.85	2.7

The proportion obtained for the maximum bulk density is fixed as the ratio of graded coarse aggregate and fine aggregate at 70: 56. Therefore the total proportion of the aggregates namely 10 mm single sized coarse aggregate and fine aggregate is imposed as 70: 56. The graphical representation (Figure 1) also indicates that the bulk density and packing density is maximum and the voids content and voids ratio is minimum for the above volume fraction of the coarse and fine aggregates. The bulk density, packing density and the voids ratio of the compound aggregate are mentioned in table and are exhibited by the graphical representation. The maximum bulk density of the compound aggregate is mentioned as 1.735 gm/cc, the maximum packing density 0.501 gm /cc and the minimum voids content is 34.03.

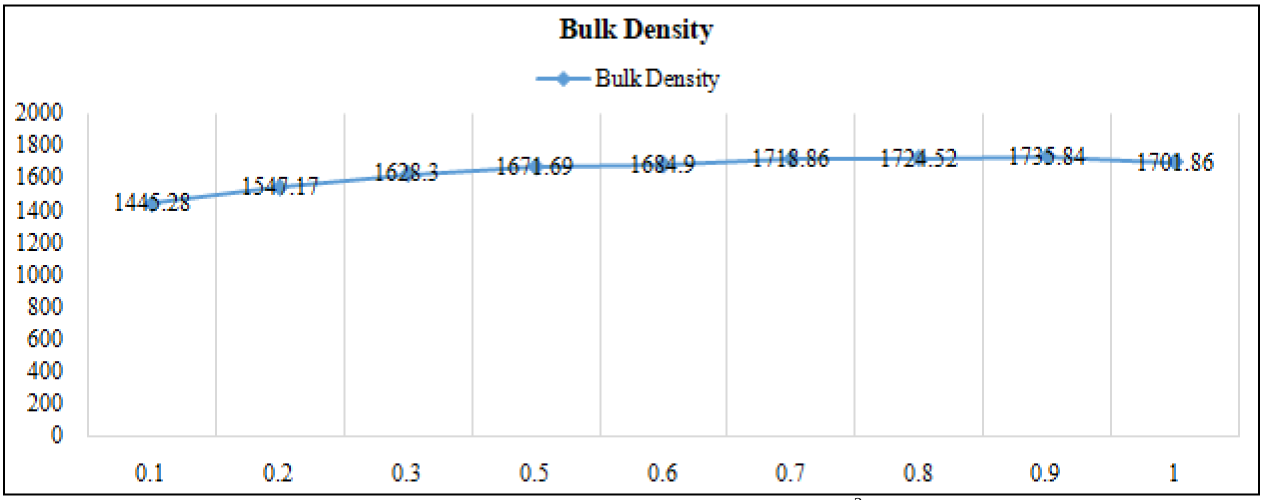

Figure 1: Testing data-Bulk Density (kg/m^3)

3.3 Preparation of Specimen

The materials such as cement, fine aggregate and coarse aggregate were batched and taken. W/C ratio of 0.35% of water is measured and taken. The cube moulds were prepared by applying oil on the inner surface of it. The CNT is mixed thoroughly with water and left aside for 30 minutes. The dry mix is done. Then water with CNT mixed with the dry mix and the mixture is mixed for 3-4 minutes thoroughly. The mixture is filled in the mould in three layers with each layer compacted 25 times using the tamping rod. Similarly, different percentages of moulds are prepared and kept for 24 hours. The concrete specimen are demoulded after 24 hours. Each batch of concrete specimen is marked with cement paste and proceed for the curing process.

4. Results and Discussion

Below tables shows the moulds embedded with different percentages of CNTs. After 28days of curing, cubes are taken out and dried in SSD condition. The cubes are placed in the compressive strength testing machine (CTM) and are tested. Compressive strength of 7 days, 14 days and 28 days are observed and tabulated.

Table 2: Observation Table

SL. No.	Mould	Dimension (mm X mm)	Compressive Strength (N/mm^2)		
			7 days	14 days	28 days
1.	0.01% CNT	70.6 X 70.6	9.4	23.6	24.6
2.	0.02% CNT	70.6 X 70.6	19.8	33	41.2
3.	0.03% CNT	70.6 X 70.6	30.4	33.8	41.2
4.	0.04% CNT	70.6 X 70.6	31.8	32.7	38.2
5.	0.05% CNT	70.6 X 70.6	21.6	23.8	28.8

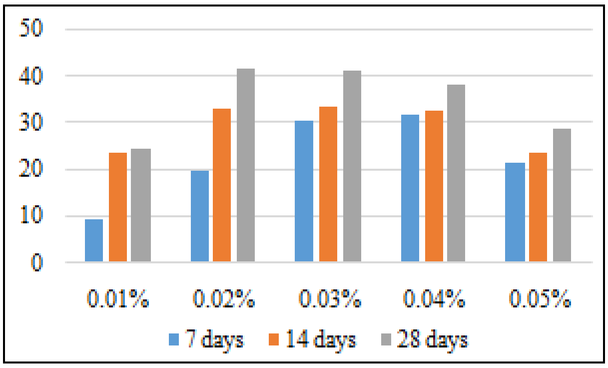

Figure 2: Comparison of Compressive Strengths

From the tabulated observation (Table 2) and graph (Figure 2), we can see that 0.02% CNT and 0.03% CNT gives same compressive strength on 28 days, i. e, 41.2 N/mm^2. But the initial strength of 7 days are different.0.03% CNT gives 30.4 N/mm^2 compressive strength in 7 days, whereas 0.02% CNT gives 19.8 N/mm^2 compressive strength in 7 days. The compressive strength of 28 days is seen reduced for 0.04% CNT and 0.05% CNT.

5. Conclusion

1) 0.03% CNT is considered to be appropriate amount, increasing and decreasing of percentages of CNT leads to differ in compressive strength.
2) Early initial strength of concrete can lowers the time of construction.
3) One of the main challenges would be to disperse the carbon nanotube uniformly in the concrete mix due to its high reactive surface. Improper dispersion would lead to bigger chunks of unreacted nano particles, decreasing the bond of CSH and thus decreasing the strength of concrete.
4) This finding has significant practical implications since more crack resistant concrete can be produced with the introduction of carbon nanotube without compromising structural capacity of the concrete elements.
5) Introduction of carbon nanotube increases the flexural property of the concrete.

References

[1] BibhutiBhusan Das and Arkadeep Mitra, International Journal of Materials, Mechanics and Manufacturing, Vol.2, No.1, Feb., 2014.
[2] TanvirManzur and NurYazdani, “Optimum Mix Ratio for Carbon Nanotubes in Cement Mortar”, KSCE Journal of Civil Engineering, 19 (5): 1405-1412.
[3] Dr. B. Vidivelli, B. Ashwini, “A study on Carbon nanotube (CNT) ”, IRJET, Volume 05, Issue 07, July, 2018.
[4] Hardik Bhatia and Kavach Mishra, “Nanomaterials in Concrete: A Review of their synthesis, Properties, Applications and future developments”, International Conference on Multidisciplinary Research & Practice, Volume I, Issue VIII. Nov., 2014.
[5] Mani. M and Dr. G. Nandini Devi, “Study on Behaviour of Nanoconcrete”, IJETTCS, Volume 6, Issue 5, Sept.-Oct.2017.
[6] Heba A. Gamal, M. S. El-Feky, Yousef R. Alharbi, Aref A. Abadel and Mohamed Kohail, “Enhancement of the concrete Durability with Hybrid Nanomaterials”, Sustainability, Jan., 2021.
[7] Abinayaa, Chetha, Chathuska, Praneeth, Vimantha and Wijesundrara, “Improving the properties of concrete using Carbon Nanotubes”, SAITM Research Symposium on Engineering, 2014.
[8] Luigi Coppola, Alessandra Buoso and Fabio Corazza, “Electrical properties of Carbon Nanotubes Cement composites for monitoring stress conditions in concrete structures”, Applied Mehanics and Materials, Vol 82, 2011.
[9] SudiptaNaskar and Arun Kumar Chalraborty, “Carbon Nanotubes and its Applications”, IJMPERD, Vol.8, Special Issue 7, Oct.2018.

Author Profile

Priyanka Dutta pursuing M. Tech degree in Structural Engineering from Narula Institute of Technology and graduated in Civil Engineering from Narula Institute of Technology in 2020.

Biman Mukherjee is the professor and Head of Department of Civil Engineering at Narula Institute of Technology, JIS Group of Engineering, Kolkata. He was the Former Vice President at Simplex Infrastructures Limited and Former Engineering Manager at Kuljian Corporation.

Paper ID: SR23523115929 DOI: 10.21275/SR23523115929