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Application of Carbon Nanotube in Cement Mortar as a Sensor - A State of Art Review

Jay viradiya[1], Siddharth shah[2]
[1, 2] *Civil engineering department, Marwadi education foundation*

Abstract: This paper reviews the current state of the art of application of carbon nanotubes in cement-based composites. The carbon nanotubes have superior mechanical and electrical property than mild steel. In this paper, comprehensive study of research and development in the field of carbon nanotube cement composites is presented. The various researchers have experimented with different amounts of CNTs and different dispersion techniques leading to a conclusion that 0.2 to 5% additions of CNTs to cement has imparted self-sensing through piezo resistivity characteristics. This ability has great potential in future in smart concrete, for ambient vibrations and deformation measurement.
Keywords: Carbon nanotubes, piezoresistivity, deformation, structural health monitoring.

I. INTRODUCTION

Nanotechnology has generated a great deal of contentment worldwide and is being lead to as the key technology of the 21st century. Nanotechnology has its applications in various sectors such as materials and manufacturing coatings and composites for products like that building materials [1].Concrete is a composite material with a low tensile strength and strain ability. An addition of carbon nanotube into the cement mortar mix can significantly improve the engineering properties of the cement such as the compression strength [2]. Day by day the carbon nanotubes and nanomaterials are added to cement mix, causing beneficial changes in material properties [3].

1) *Carbon Nanotubes-History, Manufacturing and General Properties:* Carbon nanotubes is a very high mechanical property compared to all other types of nanomaterials.Carbon nanotubes having nanoscale dimension have been well-known over the past 15 years. The CNT was first discovered by Iijima in 1991 [4] when he was studying the synthesis of fullerenes by using electric arc discharge technique. Carbon nanotubes that Iijima observed were so-called multi-walled carbon nanotubes (MWNTs) as containing at least two graphitic layers and that have inner diameters of around 4 nm. Thus the Carbon nanotubes (CNTs) are cylinders made up of rolled graphene layers. Two types of CNTs are transforming and they depend on that graphene shape and they consist of a single wall carbon nanotubes (SWCNTs), and multiwall carbon nanotubes (MWCNTs).The typical diameters of SWCNTs and MWCNTs range from 0.4 to 10 nm and from 4 to 100 nm [26]. In the early 1990s, two research groups predicted electronic properties of individual SWNTs [7-9]. From their calculations, then they found that SWNTs can be either metallic or semiconducting depending on their diameter. Then these particular predictions were confirmed by experiments [10-11]. The CNTs can be produced of various purities usually containing 70 to 95% carbon. There can be infinitely many forms in which SWCNTs can exist, each one can be individually characterize by its chiral angle, which defines the rolling direction of a graphene layer, its diameter, and its length, along with the description of its terminations or caps, while the different possible combinations of walls an MWCNT can have given rise to infinitely more forms of CNTs [27-28]. In the following sections, the structure, synthesis, properties, and applications of CNTs are discussed in details.
2) *Carbon nanotube: applications in concrete composites:* Carbon nanotubes have been widely used with polymers in composites to enhance mechanical and electromagnetic properties.Carbon nanotubes are innovative material that can be used as a light reinforcement for cement composites. The mechanical properties of CNTs are better to many other nanoscale reinforcements, with Young's Modulus of 1GPa, yield stresses of about 20 to 60 GPa with yield strain 10% and density 1.33 gm/cm^3. Along with the mechanical properties CNTs also have a very high aspect ratio - 1000 and reaching up to 2.5x10^{7}specimen with aspect ratio 1.32x10^7:1 has also been produced, thus making them superior to traditional reinforcing materials in terms of providing strength to cement composites. The CNTs have a very high specific surface area as high as 790m^2/gm and generally up to 200m^2/gm for MWCNT. The size of the CNT and high aspect ratio results in higher dispersion on a finer scale and hence better reinforcement as they reduce porosity in cement mortar paste and resist crack propagation. The carbon nanotubes are one of the strongest and stiff materials.

II. MIXING OF CNT IN CEMENT COMPOSITES:

CNT appears as black powder of very fine particles, it's mixing to the cement composite is a great challenge; it cannot be mixed directly in the dry form or with water. In the previous case it may be blown away due to nano sizes and very costly .inthe latter case, the bubbling effects are observed. Hence special dispersing agents are required to mix the CNT in concrete composites. Different researchers use a variety of the dispersing agents like Polycarboxylate ether-based plasticizer, Sky 521 plasticizer, Ammonium polyacrylate-based dispersant are used.

III.FABRICATION PROCESS OF CARBON NANOTUBE CEMENT PASTE SENSORS

This section describes the fabrication process of a CNT cement-paste sensor as used in the cementitious matrix of the sensors is a cement paste. Cement paste is more consistent and potentially more strain-sensitive than cement mortar or concrete because there is no sand or coarse aggregates. The cement paste consists of a mixture of Portland cement with a water-cement ratio between 0.40. The nanotubes etched in the composite are Multi-Wall Carbon Nanotubes (MWCNTs). They are used in the amount of 2% by mass of cement. Sky 521 plasticizer is added to the mix in the amount of 1% by mass of cement to increase workability. Physical dispersants are used to improve the dispersion of nanotubes. For**a** block of dimension 40x40x160 mm^3 (Figure 1.1), the Sky 521 is also used as a dispersant [30]. For parallel blocks of dimension 40x50x40 mm^3 (Figure 1.1(a)), the electrodes are made using nets, stainless steel or copper wires, embedded in the center of the samples and placed symmetrically along the central axis.

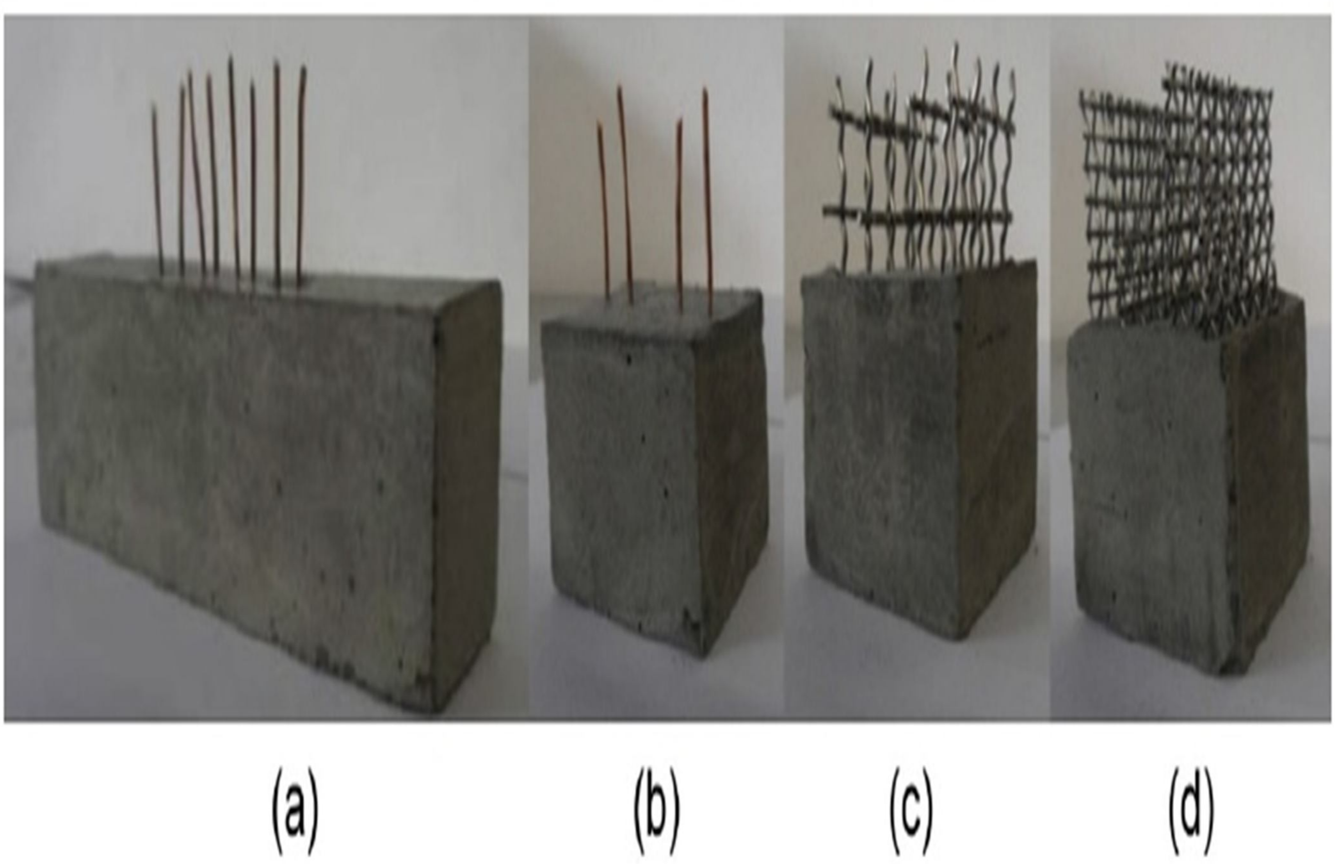

Figure 1.1 Different models of CNTCS: parallelepipeds (a), prisms with wire (b), and net electrodes (c-d).

A. Physical Properties Of Mwcnts And Mix Design

The applicable properties of the carbon nanotubes used in the fabrication process. MWCNT were selected with a carbon content greater than 90%. These MWCNTs have an outer mean diameter between 10 and 20 nm and a length between 0.1 and 5 mm. They are created by multiple concentric cylindrical graphene sheets and characterized by an improved sensitivity to stress changes compared to SWCNTs due to the higher probability of forming contact atoms. The use of MWCNTs results in a significant decrease of electrical resistivity with mechanical strain.

Table-1 Constituents And Properties Of Cement Composites With Multi-Walled Cnts

Researchers	Binder Type/Ratio	The ratio of the weight of cement		Compressive Strength (MPa)	Flexural Strength(MPa)
		W/C Ratio	CNT Ratio %		
G.Y. Li et al(2005)	OPC/1:1.5	0.45	0.5	62.13	8.37
G.Y. Li et al(2007)	OPC/Paste	0.4	0.5	72.13	9.97
A.Cwirzen et al(2008)	Sulfate Resisting cement/Paste	0.4	0.14	70	2.5-3.0
S Musso et al (2009)	OPC/1:3.8	0.4	0.5	-	10.1
J. Lou et al (2009)	OPC/Paste	0.4	-	44	4.5
M.S. Morsy et AL (2011)	OPC/1:2	-	0.02	60	-
F. Collins et al (2012)	OPC/Paste	0.6	2	69.4	-
R.K. Abu AL-Rub(2012)	OPC/Paste	0.4	0.2	-	10-12
V. Smilauer(2012)	OPC/Paste	0.4	0.2	80	-
T.Ch. Madhavi(2012)	OPC/1:2.5	0.4	0.045	49.18	-
J Bharj (2014)	OPC/Paste	0.425	0.1	20-21	-
J Bharj (2014)	OPC/Paste	0.4285	0.2	20.08	-
T. Manzur (2014)	OPC/1:2.75	0.6	0.5	40	-
M. Lelusz (2014)	OPC/1:3	0.45	0.12	31	-
N. Yazdani and V. Mohanam (2014)	OPC/1:2.75	0.45	0.5	50	12
J. Esmaeili and A.R. Mohammadja(2014)	OPC/Paste	0.485	0.7	27.63	5.4
H. Cui (2015)	PPC/Paste	0.35	1.0	27.6	5.39
N. Sakthieswaran and M. Surekh (2015)	OPC/1:3	0.7	0.1	35	-
M.A. Ahmed (2015)	OPC/1:2.5	0.4	0.3	43	6
M. Ghosal and A.K. Chakaborty (2015)	OPC/1:3	0.4	0.02	43.75	-
S. Alrekabi (2016)	OPC	0.45	0.05	50-58	-

IV. EFFECTS OBSERVED IN CONCRETE COMPOSITES DUE TO THE ADDITION OF CNT

Property of cement based material directly depends upon the properties of qualities of Calcium-Silicate-Hydrate gel (C-S-H gel) which is the main hydration product. The property of C-S-H gel at nanoscale level affects the properties at macro scale level; therefore, nanoparticles like CNTs have enhanced the property of cement composites.

The attractive properties of MWCNTs mainly depend upon the length of particles and dispersion method used. The interfacial bonding can be achieved by either chemical iteration between CNT functional groups i.e. carboxylic acid (COOH) or C-S-H hydration product resulting information of their internal bonds or by using a surfactant and admixes resulting physical interactions. Konsta-Gdoutas et al. [31] found in his studies that CNTs might also act as nucleating sites as high stiffness C-S-H phase.

Concrete is a brittle material and is therefore susceptible to cracking, which pose the problem of durability. Fiber reinforcements have established useful in resisting crack propagation in concrete and increasing flexural strength. But they work at macro and micro level while CNTs are nanoscale particles and can be effectively used as fillers for gaps and voids resulting in more efficient reinforcement and also crack bridging has been observed in CNT-cement composites which increase its resistance to cracking and enhances durability.

V. SENSING MEASUREMENTS

The electrical behavior of the sensors under a step change in the input voltage is measured to validate the equivalent circuit model A National Instruments NI PXIe-1073 chassis which has used to measure a defects of the material, Keithly meter is used for data acquisition in system hosts a module which provides the stabilized potential difference applied to the electrodes of the specimens through coaxial cables. A high-speed digital multimeter is used to acquire current intensity outputted by the sensor. Output data are optimally fitted to identify relevant parameters (identification of R_0, R, and C).

Sensor specimens were subjected to compressive loading using a 150kN set up maximized testing capabilities (MTS) loading machine. One on either side of the specimen was used to measure displacement. For comparison purposes, 10 mm foil strain gauges were also attached to either side of the specimen. The corresponding electrical resistance was simultaneous, measured using LCR meter at 100 kHz frequency direct current (DC) measurement of electrical resistance is technically difficult and problematic due to the polarization effects [32-35], and resistance measurements were made using alternating current. The four-probe technique was employed whereby current flows between the two outer electrodes and the voltage between the inner electrodes is measured. Acquired load, displacement, strain and resistance data were transferred to a PC equipped with NI LabVIEW platform. To take into account the nature and geometry of the sensors, the resistance measurements were converted to electrical resistivity (q) calculated as resistance per unit length:

$$\rho = \frac{RA}{l}$$

Where ρ is the electrical resistivity (Ω cm), R the electrical resistance (Ω), A the cross-sectional area (cm^2), and l is the length between the inner electrodes (cm). A set of preface experiments were conducted on the sensors to obtain the maximum load capacity of the specimens. The response of the sensors to cyclic loading with various load amplitudes was also assessed. Next, the response of CF and hybrid sensors to cyclic loading with ca hosen amplitude of 30kN was compared.

VI. CONCLUSION

The excellent and quite great properties of carbon nanotube have resulted in wide research into its application in polymer composites as a reinforcing material. The superior mechanical properties of carbon nanotubes have direct to their application in cementitious material composites. The addition of carbon nanotubes mostly shown improvement of mechanical properties of cement mixers, however, the consistency is yet to be achieved.

Although the authors could not determine any optimum dosage of carbon nanotube, but addition in small amounts ranging from 0.2% to 5% by weight have shown the best results; improving strength of compressive the authors after doing the comprehensive review than conclude that the amount of carbon nanotube used, dispersion methods and chemicals used for dispersion have varied effects on cement mixes.

Carbon nanotubes significantly increase the electrical conductivity of cementitious materials. These conductive cement-based materials are also piezo-resistive and can thus produce excellent sensors. The sensor material responds well to an applied compressive strain by depicting a decrease in its resistivity, and this applies to both monotonically and cyclically applies strain fields formation of microcracks is signified by a steady increase in the resistivity which then changes to a sudden increase when microcracks combine and failure occurs. Thus, in addition to strain sensing, these materials can sense microcracking and failure and that field is more research is initialized on that topics.

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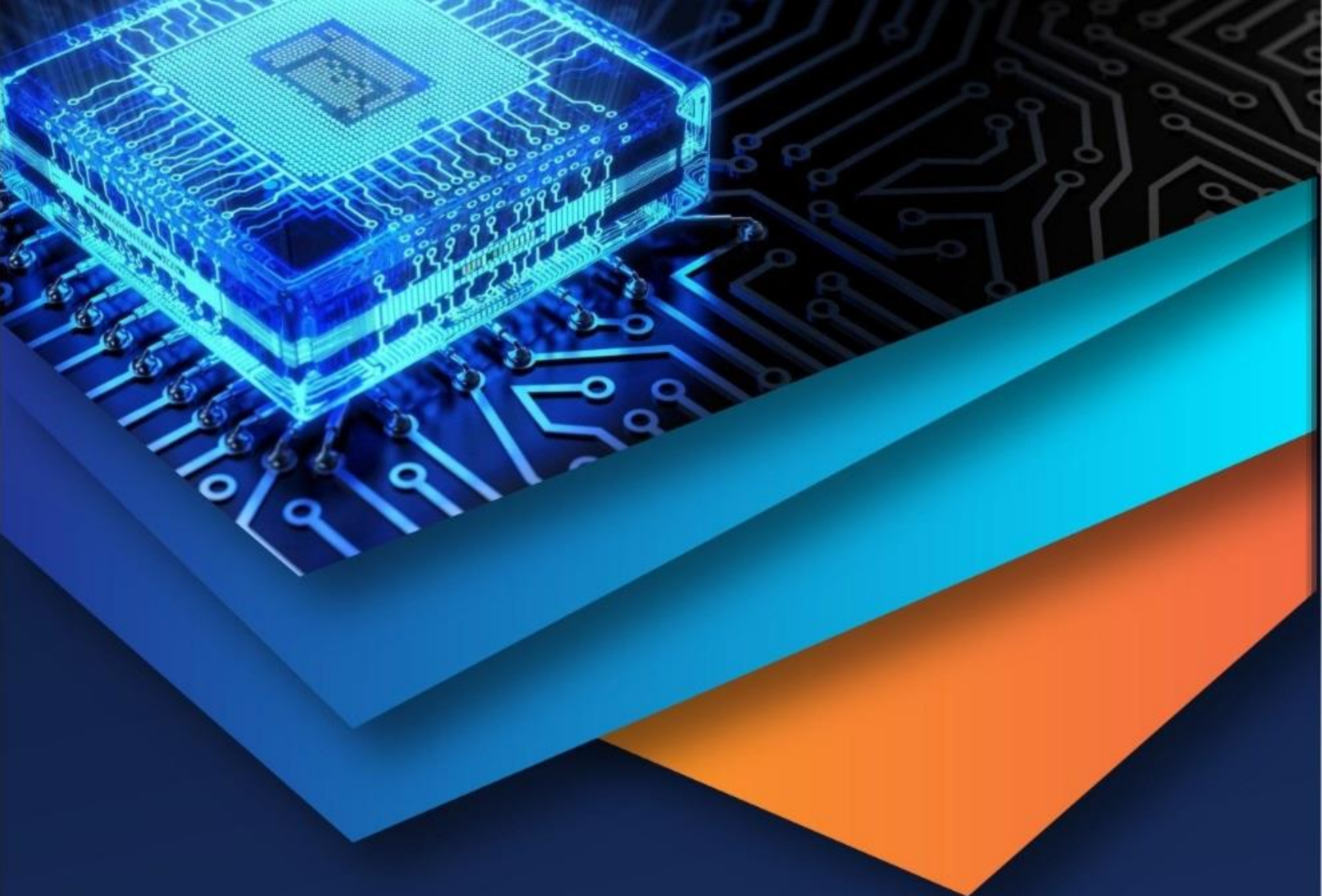

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