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Parametric Study of Fly Ash based Concrete with the Inclusion of Carbon Nanotubes (CNT) A Review

Mukesh Mokha[1], Anushri Satpute[2], Prachi Janbandhu[3], Kashish Charbhe[4], Khushi Chandragade[5] and Vivek Jayale[6]
[1]Eden Innovations India Private Limited, Noida, India
Email: mmokha@edeninnovations.in
[2-6]Yeshwantrao Chavan College of Engineering, Department of Civil Engineering, Nagpur, India
Email: anushrisatpute03@gmail.com, janbandhuprachi62@gmail.com

***Abstract*— Use of carbon nanotubes (CNTs) and fly ash in concrete has been of significant interest because of the ability of the products to improve the strength and capacity of construction products besides foster the sustainable construction activities. The examination examines experimental research studies that seek to integrate CNTs and fly ash cement-based composite both jointly. They are compressive strength, tensile performance, and microstructural modification and durability characteristics among others. The content of CNT (0.05 -0.2%) cement and levels of fly ash replacement (10 percent -30 percent) and different methods of dispersion are most important to be criticized. Previous studies indicate that even minor proportions of CNTs are also capable of boosting the mechanical and survival properties at a vast magnitude, should they be dispersed frequently among the cement material. Based on the data presented by scholars, optimal dispersion of CNTs is a value in improving load transfer and crack-bridging characteristics of cementitious composite. However, the issue of achieving homogeneous dispersion and high cost of CNTs still remains an issue and can be regarded as a considerable barrier to extensive usage. The impact of the important parameters is clearly presented and outlined in comparative table format as well as graphically. The review also identifies gaps to the research that is currently being utilized, and directions of future research and practice are also discussed.**

***Index Terms*— Fly Ash Concrete, Carbon Nanotubes (CNT), Nano-Modified Concrete, Supplementary Cementitious Material, Mechanical Properties, Durability, CNT Dispersion.**

I. INTRODUCTION

The cement content in building work using concrete is very high; this has a sharp impact on the environment and thus, researchers have sought to use other materials [1,2]. One of the researched alternatives is a by-product of coals burning and it is fly ash. The primary objective of moving cement substitutes is to reduce the high level of carbon dioxide released in the production of cement. In addition to environmental advantages, such substitutes can positively affect wearability, have some performance benefits, such as better chemical resistance or different setting behavior, cost reduction of materials, and enable useful utilization of industrial waste [3,4,5]. The fly ash has also been reported to increase the long-term strengths of concrete but with the sacrifice of strength development at young age. More recently carbon nanotubes (CNTs) have also been a nano-scale reinforced material of concrete due to its nature of spanning the microcracks and optimizing pore structure [6,7,8].

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CNTs possess very high tensile strength that is purported to be up to 100 GPa in terms of tensile and mechanical performance of cementitious composites. The previous studies claimed that the addition of carbon nanotubes raises the crack resistance enabling the effective transportation of stress across microcracks [9,10]. Table I has contained the parametric research used in the present paper with the aim of summarizing the findings of the parametric researches conducted on mechanical, microstructural as well as durability characteristics of fly ash based concrete incorporating CNTs. The review has been supported by the utilization of microstructural photographs such as SEM photos, curve of strength development and tabular data of mix proportions. The latter are useful in all of their turn in order to define the most efficient combinations of materials, achieve the synergistic effect of fly ash and CNTs, and define the gaps that can be observed and, consequently, can be researched in the future.

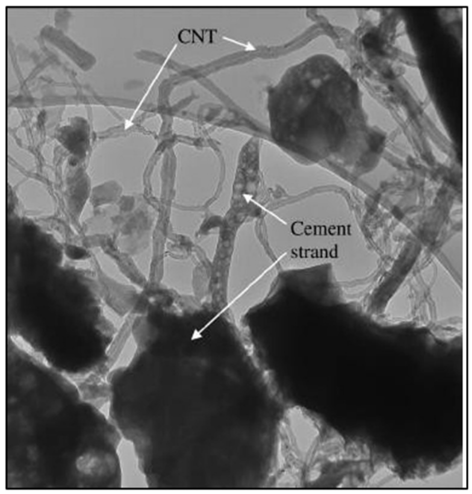

Figure 1 SEM Image of CNT in Cement Matrix [1]

Figure 1. SEM picture of carbon nanotubes (CNTs) across a microcrack in a cement micro matrix of fly ash 20 per cent. The figure 1 highlights the contribution in the use of CNTs as a nanoscale reinforcing material, in the sense of the nanotubes running through the crack, assist in the provision of a crack control and transfer of stress. The scale bar represents a mark of 500 nm, which represents the nano-contact of CNTs and cementitious matrix.

A. Problem Statement

Despite emerging need of high performance and material construction based on green building, construction using conventional cement concrete is major contributor to carbon dioxide emission in the globe. A fly ash is one such replacement of cement, it is an industrial by-product that is of high supply and the by-product can be partially utilized to replace cement and thus improve sustainability and enhance long term stability. However, concreteness that is prepared using fly ash may develop slower rate of strength at young age and it may perform poorly when it receives aggressive environmental conditions. Instead, it has been discovered that the carbon nanotubes (CNTs)- are superior in regard to their mechanical and physical characteristics and have been noted to address some of the drawbacks associated with fly ash concrete. They have been famous as regards their ability to add crack resistance as well as densification of the matrices. As it is practiced in literature, such CNTs incorporation has the potential to significantly increase the mechanical response of the cementitious composites as long as adequate dispersion of CNTs is achieved. However, the difficulties of establishing the optimal CNT dosage, distributing them perfectly, compatibility with cement-based systems, and the possibility of maintaining the low cost exclude their massive use. However, there is no homogeneous knowledge on the effect of the presence of individual parameters to CNTs performance of concrete composed of fly ash as of now. Therefore, the systematic review will be necessary that will critically discuss the research available, identify the current trends of performance, and propose the path of further research and practice.

II. Literature Review

The response of high temperature reinforced concrete beam strengthened with carbon nanotube (CNTs) has been discussed by Hala Elkady [1]. The flexural strength of the CNT-strengthened beams was compared with that of the conventional reinforced concrete beams at normal environmental conditions and subject to high temperatures to some on that of the ASTM E119-95a fire tests standards. The samples were heated to 400oC / 600oC and the duration was 1 and 2 hours. It was found that the flexural performance at room temperature and retention of most of the performance of the majority of the performance following exposure to 400oC by two hours was increased with the addition of CNT. However, CNT reinforced beams in other words when the beams are subjected to 600oC after two hours give in to bending ability by 14 per cent in comparison with the control samples. This reduction was attributed to thermal degradation of CNTs which later created the voids of concrete matrix. The experiment has discovered that under normal condition, CNTs enhance the ductility and strength, although their performance is highly disturbed in the event of severe thermal conditions. Seyed Esmaeil Mohammadyan-Yasouj et al. [2] examined the variance effect of waste glass powder (WGP), basalt fiber (BF) and CNTs on the mechanical characteristics of the concrete. Blends of concrete were prepared using various percentages of cement replacement with WGP, addition of BF and CNT. Tensile and flexural and compressive strengths were experimented. These results indicated that WGP enhanced workability and reduced a compressive strength to a small extent when replacement was enhanced. The tensile and flexural strength was enhanced by basalt fibers and all the mechanical properties were highly enhanced by CNTs particularly at low doses. A blend of 10% WGP, 0.5% BF and 0.1% CNTs provided the perfect profile of the balance of strength and workability. The paper has proved that waste materials and nanomaterials can be used in combination to establish high performance and environmentally friendly concrete. Nzar et al. [3] studied the behavior of compressive frequency of the CNT-modified concrete by the means of the multiscale testing and a multiple score numerical modelling. CNT doses were experimented at 0.05 -0.1% cement weight at 7, 28 and 90 days to curing. The findings indicated tremendous improvement in the strength at the lower contents of CNT (0.1 -0.2%), and the maximum strength was recorded at the 28 days curing. When the dosage of CNT was increased, agglomeration and low strength gains were obtained. The application of multiscale modelling technique proved to explain the influence of CNT dispersion, interfacial bond, and the qualities of the base material as a consequence of the considerable effect of the optimum dosage of CNT and the period of the curing time. The research conducted by Alexandre Boga et al. [4] was conducted to measure the durability performance in a state of a cracked structure of CNT-reinforced concrete in terms of water absorption, chloride penetration, and carbonation resistance. Regulation of crack widths was carried out in concrete specimens of CNT content of 0.05 percent up to 0.2 percent. It was also found that higher dosage of CNT (0.1 percent) produces a better-water and chloride ingress resistance based on a refined pore structure and the crack-bridging phenomenon. This loss in the durability of CNTs however subsided with the crack's widths beyond 0.3 mm at which the CNTs were no longer effective to bridge bigger cracks. The increase in the carbonation resistance was small, as it occurred due to the ingress of CO 2, which predominantly depended on the width of the crack. The University of Lisbon conducted further experiments within the effect of different shapes of CNTs including single-walled CNTs (SWCNTs) and multi-walled CNTs (MWCNTs) with different aspect ratios and functionalized surfaces. The doses that were taken into consideration were 0.05 percent up to 0.2 percent of cement structure. It was noted that mechanical analyses showed the inclusion of CNT to improve compressive strength, tensile strength and elastic modulus and MWCNTs was seen to work better than the SWOTCNTs due to the affinity of CNT interfaces and their high dispersion. The best CNT content was that giving maximum 20 percent of strength in compression and 15 percent tension. Greater dosages led to CNT agglomeration and reduced efficacy. Mohsen and Al-Ansari [7] conducted an experiment on flexural strength, ductility and permeability of the concrete which utilizes CNTs. CNT content of 0.05 to 0.2 was checked. This was established to have significant positive effect on flexural strength (peak 18 at 0.1 per cent CNT) and ductility due to an enhanced crack-bridging and load transfer mechanism. Optimal dosage of CNT also reduced cell permeability which was characterized by increased density of the microstructure. However, these advantages were reduced in CNT agglomeration with increased dosage. Liu et al. [8] provided comprehensive literature review of application of carbon-based nanomaterials in cementitious composites like CNTs, graphene and carbon nanofibers. The review discovered 20 structure improvement with 30 percent at optimal dosage of nanomaterials (0.1%-0.2%), and enhanced durability of low permeability and high resistance to chloride and sulphate aggression. It is reported that despite all these strengths, the dispersion, agglomeration, cost, and sustainability problems had been reported to hinder massive implementation. Hyojeon Yun and other researchers [9] were interested in the combined impact of the existence of coarse aggregate material and multi-wall CNTs on the hydration heat development of concrete. The hydration kinetics were measured through the isothermal calorimetry and compressive strength tests on 7- and 28-days' time established the effect of CNT addition to hydration process and it found that CNT addition enhanced the strength at medium CNT doses. The results identified the correlation between CNT content and aggregate volume to control the hydration behavior and strengthening at early age.

TABLE I. SUMMARY OF REVIEWED STUDIES ON FLY ASH AND CNT CONCRETE

Sr No	Reference No.	Grade	Fine Aggregate	Coarse Aggregate	GGBS	Fly Ash (%)	CNT (%)	Additional Material Used
1.	[2]	-	2.5mm	-	-	49.82	-	Multi walled carbon nanotubes
2.	[3]	42	1-2mm	-	-	-	-	Ordinary Portland cement
3.	[4]	-	300kg	400kg	-	-	0.25	Ordinary Portland cement
4.	[5]	-	-	-	-	-	-	Ordinary Portland cement, reactive powder concrete
5.	[6]	-	-	-	-	-	0.25	-
6.	[7]	42.5	-	-	-	-	-	-
7.	[8]	32.4	0.25-0.5mm	5-20mm	-	-	-	-
8.	[9]	42.5	-	-	-	-	0.1	-
9.	[1]	-	175.5kg/m3	498kg/m3	-	-	0-10	-
10.	[10]	-	-	-	-	-	0.1	-

III. METHODOLOGY

The present paper provides parametric reviews of the studies held on experimental basis that investigate incorporation of carbon nanotubes (CNTs) and fly ash in concrete. The existing bodies of knowledge were collected using the academic databases such as ScienceDirect, Elsevier, and SpringerLink; however, highlighting the articles which were published not before 2015. The experimental investigations that incorporated fly ash and CNTs in the concrete were the only form of experiment that was considered. Primary parameters of every study in this work were determined (CNT content, most typically 0.05% to 0.2%, by weight of cement), fly ash substitution rates most of the time fall within 10% to 40% and CNT dispersion schemes (ultrasonication, mechanical and the employment of superplasticizers), Curing regimes, and testing schemes. The type of data collection done was in the lines of determining the impact of such parameters on the mechanical and durability performance of concrete. The compressive strength, flexural strength, tensile strength, porosity, chloride penetration, carbonation depth, and other durability characteristics results in the research were reviewed and correspondingly compared in a congruent manner. The obtained data enabled to establish a comparative summarizing table II to be in a position to show the difference in performances based on the mix composition differences and the experimental methodology. Besides, a graphical analysis was developed to demonstrate the relationship between the CNT dosage and the compressive strength. The results were also uniform as the compressive strength increased with the addition of CNT up to a concentration of around 0.1 to 0.2 concentration which was then succeeded by reduction in strength gains due to North graphene agglomeration. The previously conducted research states that clustering of the particles due to the overload of CNT content adversely affects the stress transmission and the establishment of the strengths (Liu et al., 2020) [8]. Compressive strength and flexural strength with split tensile strength and modulus of elasticity were the most common mechanical properties that were reported and the last two were looked into in less literature. Durability tests involved directed permeability tests and chloride penetration tests as well as porosity tests. In a number of studies, microstructural and thermal analyses, that is scanning electron microscopy (SEM), heat of hydration, which involved carbonation depth, were also involved. This review was done thoroughly, and it was possible to make a general comparison of the research offered and to decide about the most effective CNT fly ash mixes to enhance the concrete performance. On the whole, the review is aimed to support future research reports and assist the practitioners to develop high-performance, as well as sustainable concrete mixtures.

TABLE II. TEST PERFORMED ON SAMPLE

Sr No.	Reference no.	Compressive Strength (%)	Flexural Strength (%)	Tensile Strength (%)	Durability	Additional Tests Performed
1.	[2]	-	-	-	-	Fractured test
2.	[3]	41.48	-	-	-	Flowability, water diffraction
3.	[4]	-	-	-	-	Heat generation
4.	[5]	4	-	-	-	Porosity, split tensile
5.	[6]	-	Increased by 100% for 0.15 and 0.25wt %	-	Increased by 100% for 0.15 and 0.25wt %	Permeability test
6.	[7]	36.8	5.6	2.8	-	Modulus of elasticity
7.	[8]	33	-	-	-	Chloride ion colour test
8.	[9]	45.6	-	-	-	Carbonation depth
9.	[1]	66.7	-	-	-	-
10.	[10]	43.71	7.03	3.08	-	-

A. Fly Ash in Concrete

According to the ASTM C618, the fly ash is divided into Class F and Class C, the Class F fly ash is burnt using anthracite or bituminous coal and contains less than 10 percent of calcium oxide (CaO). Comparatively, Class C fly ash is obtained as a byproduct of burning sub-bituminous or lignite coal, and is likely to contain more CaO with a range of 15 to 30 percent. The primary chemical compositions of fly ash are Silicon dioxide (SiO 2), Aluminium oxide (Al 2 O 3), threats to human health and environment Iron oxide (Fe 2 O 3) and calcium oxide (CaO). These proportions of these oxides also vary according to the type of coal and situations of combustion during the production of power.

B. Pozzolanic Reaction and Microstructural Development

The polyvalent elements of fly ash that mainly enhance pozzolanic activity of the mineral are the contents of alumina and silicon, which reacts with the calcium hydroxide (CH) produced during the hydration of cement. The consequence of such a reaction is the formation of additional calcium silicate hydrate (C -S -H) and calcium aluminate hydrate (C -A -H) which enhances the strength and longevity of concrete in the long run. The slow rate of the pozzolanic reaction causes low early-age strength and more excellence later in life. The pozzolana reaction could be expressed as: Pozzolan + CH + H_2O → C–S–H + C–A–H.

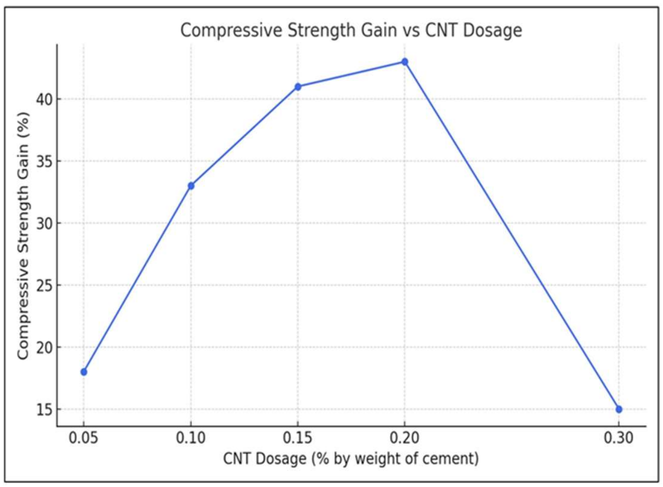

Figure 2. Variation of CNT doses

Microscopically, the fly ash particles act as nucleation points of hydration products and refine the pores by taking part in both pozzolanic reaction as well as filler activity. This causes it to give a denser microstructure and lower porosity according to report [11,12,13]. Moreover, the fly ash particle shape is round, therefore, enhancing the workability of fresh concrete in terms of reducing the amount of water and maximization of particle packing. To obtain a more detailed concept on the role of carbon nanotubes (CNTs), the dependence between the CNTs dosage and compressive strength enhancement of CNTs was plotted based on the available data in the chosen works as shown in Figure 2. As it is observed in the trend, compressive strength increases with addition of CNTs to a certain optimum range that lies between 0.1 and 0.2% normally [14,15,16,17,18]. Beyond this regime, strength begins to decrease due to CNT agglomeration that has a negative effect on dispersion and stress transfer. Such a graphical analysis affirms that small doses of CNT at equal distribution are superior in enhancing the strength of concrete. It also shows the sensitivity of concrete performance to nanoparticle contents, and the nature of the content of nano-particles employed should depend on the dosage in a mix specially.

IV. Applications and Future Research

- Fly ash-CNT-concrete shows a high potential of being employed in high strength, structural objects, and in repair and rehabilitation materials of the structures, and fire-proof materials.
- The main focus of the future research must be based on the creation of viable methods to achieve homogeneous and non-homogenized separation of CNTs in cementitious components.

- The research relating to the durability and stability of fly ash-CNT concrete under the condition of aggressive environment (high temperatures, chemical exposure, cyclic loading, etc.) should be performed in the framework of a long-term follow-up.
- It is needed that some degree of design mix directions should be put in place so that performance and viable implementation can be attained uniformly.
- Future research should aim at hybrid systems of reinforcement (e.g. co-existence and use of CNTs with common fibers e.g., steel fibers and CNTs) so as to enhance mechanical workability and durability through synergetic behavior.

V. Conclusion

Talking about the analysis of various references of the experiments, one should mention that the idea of the usage of fly ash and carbon nanotubes (CNTs) in the combination provides a great chance of the concrete performance improvement. The compression and flexural strength, porosity, strength and durability can be enhanced by the addition of the CNTs that are high tensile strength, and the ability of the crack-bridging. The synergistic effect, when coupled with fly ash results in the density of the microstructure and increases their mechanical behavior because of the fact that the play of long-term pozzoleric response also proves to be environmentally effective. The highest performances were referred to the CNT content of 0.05-0.1% by weight of the cement with the fly ash replacement rates kept at 20-30%. The impact of increased doses of CNT was more likely to cluster and develop irregular distribution thereby reducing the effects of reinforcement. As a result, ultrasonic dispersion techniques, such as ultrasonic dispersion or addition of suitable surfactants were suggested to be significant in the distribution homogeneity of CNT in the cement skeleton. Although positive outcomes are observed, on the general level, the problems related to the cost of the material, the massive dispersion processes, and the lack of standardization in the guidelines referring to the mix design remain present. The dynamic among CNTs, fly ash, and other admixtures under various curing conditions, and environmental conditions, should be further examined in details in order to understand the nature of CNTs-related interactions in a better way. The additional research may be also related to the hybridization of reinforcement structures with CNTs and traditional fibers, in particular, in the case of their application in the hostile environment and structural repair.

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