Effect of multiwalled carbon nanotube incorporation in modulus elasticity of concrete with partial replacement of cement with flyash

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Abstract. The aim of this research article is to analyze the effects of Multiwalled Carbon Nanotube incorporation in the concrete and to discuss the significance of the changes in the mechanical property. In addition the cement replacement was also done. Hence in this research the combined effect will be analysed. The three different proportions such as 0.025%, 0.05% and 0.075% of incorporations were made along with 20% replacement of cement with Class-F flyash. The most important part in incorporation of MWCNTs in concrete is dispersion or surface decoration. It was done with Poly-Carboxylic Ether solution and magnetic stirring. After specimens casting and 28 days of immersed curing the specimens were tested for the elastic modulus of concrete.

1. Introduction
In the research of increasing the properties of the concrete with addition of chemical and mineral additives showed greater results. The addition of many nano particles such as carbon nanotubes, nano silica is also preferred due to the excellent increase in the concrete and mortar properties [11]. Hence this research on MWCNT incorporation in concrete was conducted due to the excellent increase in the properties of cementitious composites. In order to reduce the usage the partial replacement of cement with Class-F flyash was also done as a part of sustainable method to reduce the production of cement as cement manufacturing process has enormous amount of carbon emission [14].

2. Carbon Nanotube
Carbon is the strongest element discovered by mankind. Hence due to the strength and other physical properties the addition of carbon in various materials such as steel and other metal alloys are done. In many composite structures which require the very high strength and very less weight carbon composite material are in application [1] [5]. Carbon nanotubes are allotropes of carbon elements. They are produced from the carbon elements under three main processes which are Chemical Vapour deposition method, Electric Arc method, Laser Ablation method under certain conditions [15] The properties of the carbon nanotube such as high strength, high stiffness, less weight, high dimensional stability, electrical properties and so on it is desired to incorporate in materials for property enhancement [12]. There are two major types of Carbon Nanotubes they are Single Walled Carbon Nanotube and Multiwalled Carbon Nanotubes. Multi walled Carbon Nanotubes have more strength then the single walled Carbon Nanotubes. Hence it was decided to use Multiwalled Carbon Nanotubes in this research [11] [9]. The incorporation of CNT in cementitious composites has major process of surface preparation of CNT to create the bond between the CNTs and the CHS gel. [6] [7].
3. Literature Review
Rhee et. al. studied the properties of normal strength concrete with addition of MWCNT from 0.25% to 1.5% weight of cement with sodium naphthalene sulfonate formaldehyde solution with sonication process. It was found that the highest modulus of 25Gpa in 1.0% incorporation of weight of the cement. It was found that the addition of more amount of CNT in the concrete leads to the agglomeration of CNT in the concrete. It was mentioned that the method and material used in the dispersion was also much influence the mechanical property of the concrete.

Rashid et. al. incorporated the quantity of 0.1% and 0.2% functionalised CNT of the weight of the cement and found the improvement of mechanical properties of the concrete. In this research he used the CNT functionalised with nitric and sulphuric acid. It was observed the difference between the surfaces treated and surface untreated CNTs. It was found the increase of 25% increase in the modulus of elasticity than the conventional concrete for surface treated CNT at 28 days and 12% increase for surface untreated CNT. It was also found the strength of CNT incorporated concrete increase with curing period.

Tyson et. al. investigated the property enhancement of concrete with carbon nanotube and carbon nanofilaments. The quantity of 0.1% and 0.2% was used for the incorporation after proper dispersion of CNT and CNF with in water under sonication process. It was observed that the increase of 65% in the 0.2% of incorporation of CNT in concrete after 28 days of curing. It also concludes the dispersion and the amount of CNT incorporation affects the mechanical properties of the concrete.

Liu et al. conducted the research on the various surfactants used for the dispersion of CNT in the concrete for effective dispersion and to reduce the agglomeration in the CNT. After conducted many experiments with dispersants such as toluene, tetrahydrofuran, chloroform and dimethylformamide and poly carboxylic ether it was concluded that the Poly carboxylic ether solution have more dispersion than the other dispersants. The types of methods such as sonication and magnetic stirring was also analysed in that research.

4. Experimental Investigation
The experiment was conducted for finding the modulus of elasticity of concrete. The test setup was conventional concrete, concrete with partial replacement of cement with flyash at 20% without Carbon Nanotubes and three concrete with partial replacement of cement with flyash at 20% and MWCNT incorporation at 0.025%, 0.050%, 0.075%. In total 30 specimens were casted for the experiment. The standard cylinder size of 150mm diameter and 300mm height cylinder was used. The concrete specimens’ descriptions are given below in Table 1.

| S.No | Mix Description | Fly ash | CNT   |
|------|-----------------|---------|-------|
| 1    | Conventional Concrete (M30) | -       | -     |
| 2    | CF              | 20%     | -     |
| 3    | CNT 1           | 20%     | 0.025%|
| 4    | CNT 2           | 20%     | 0.050%|
| 5    | CNT 3           | 20%     | 0.075%|

5. Casting of Specimens
After the detailed literature survey the dispersion method was finalised as magnetic stirring and the dispersant was Poly Carboxylic Ether solution [2] [3] [4]. The grade of concrete was selected was M30 and the flyash was class-F was finalised. As mentioned above five different mixes were done. After all tests the concrete casting was arranged. The dispersion of the MWCNT was done by magnetic stirring and Polycarboxylic ether solution at various conditions. After dispersion of
MWCNT with Poly Carboxylic Ether solution in magnetic stirrer at 600 rpm for 60 minutes the specimens were casted and kept under immersed curing for 28 days [8] [13]. The properties of the MWCNTs are given in Table 2 and mix proportioning of the concrete are given Table 3.

Table 2. Properties of CNT

| Property               | Range         |
|------------------------|---------------|
| Diameter               | ~10 nm        |
| Length                 | 6-9 micron    |
| Purity                 | >98%          |
| Metal Particles        | <1%           |
| Amorphous Carbon       | <1%           |
| Specific Surface Area  | 250-300 sq.m/g|
| Bulk Density           | 0.10-0.06 g/sq. cm |

Table 3 Mix Proportion

| Description | Cement | FA | CA | W/C | SP |
|-------------|--------|----|----|-----|----|
| Mix Ratio   | 1      | 2.26 | 3.6 | 0.4 | 0-3% |

6. Testing of specimens
The modulus of elasticity of concrete cylinders was done in the compression testing machine with the proper compressometer and dial gauge setup. The compressometer was fixed in the concrete cylinder at the point 5 cm from the both top and bottom. The load was given at the rate of 0.3 Ton and the corresponding dial gauges were taken. From the dial gauge readings the modulus of elasticity of the concrete was calculated. The typical testing is shown in the Figure 1.

Figure 1 Typical Testing for Modulus of Elasticity of Concrete

7. Results and Discussions
After the computation of the results it was observed that there was increase in the modulus of elasticity of the concrete incorporated with MWCNTs. The average increase in the modulus of elasticity was found as 3.5% compared to the conventional Concrete without flyash and 15% increase with the concrete with flyash for the incorporation of 0.025% of MWCNT with the concrete. For the 0.05% of MWCNT incorporation of concrete 8.5% and 20% increase with the CC and CF concrete respectively on average. In the 0.075% of MWCNT incorporation it was found the 14.3% increase and 25% increase with the CC and CF concrete proportions respectively. The graphical representations of the
Modulus of Elasticity Values are given in the Figure 2 and the Typical stress strain curve for the specimens is given in Figure 3.

![Figure 2](image1.png)

**Figure 2. Average Modulus of Elasticity of Specimens (MPa)**

![Figure 3](image2.png)

**Figure 3. Typical Stress Vs Strain Curve**

8. Conclusion

- It is found that the 0.075% of MWCNT incorporation increased the modulus of elasticity value of the concrete than other two proportions hence the rate of increase is corresponding to the MWCNT ratio in the concrete.
- The replacement of the cement with flyash affects the concrete strength by 12% to 15% which reflected in the concrete with MWCNTs also. Hence the increase in modulus of elasticity is less comparatively.
- When the specimens have proper dispersion and optimum MWCNTs in concrete the replacement of the cement does not affect the strength in large scale.
References

[1] Abu Al-Rub, R.K., Tyson, B.M., Yazdanbaksh, A. and Grasley, Z., 2012. Mechanical properties of nanocomposite cement incorporating surface-treated and untreated carbon nanotubes and carbon nanofibers. Journal of nanomechanics and micromechanics, 2(1), pp.1-6.

[2] Collins, F., Lambert, J., & Duan, W. H. (2012). The influences of admixtures on the dispersion, workability, and strength of carbon nanotube--OPC paste mixtures. Cement and Concrete Composites, 34(2), 201-207.

[3] Cwirzen, A., Habermehl-Cwirzen, K., & Penttala, V. (2008). Surface decoration of carbon nanotubes and mechanical properties of cement/carbon nanotube composites. Advances in cement research, 20(2), 65-73.

[4] Foldyna, J., Foldyna, V., & Zelenák, M. (2016). Dispersion of carbon nanotubes for application in cement composites. Procedia engineering, 149, 94-99.

[5] Haddad, A. N., de Morais, J. F., & Evangelista, A. C. J. (2013). Variation of Concrete Strength with the Insertion of Carbon Nanotubes. In Advanced Materials Research (Vol. 818, pp. 124-131). Trans Tech Publications.

[6] Hamzaoui, R., Bennabi, A., Guessasma, S., Khelifa, R., & Leklou, N. (2012). Optimal carbon nanotubes concentration incorporated in mortar and concrete. In Advanced Materials Research (Vol. 587, pp. 107-110). Trans Tech Publications.

[7] Kowald, T., & Trettin, R. (2004, September). Influence of surface-modified carbon nanotubes on ultrahigh performance concrete. In Proceedings of International Symposium on Ultra High Performance Concrete (pp. 195-203).

[8] Liu, C.X. and Choi, J.W., 2012. Improved dispersion of carbon nanotubes in polymers at high concentrations. Nanomaterials, 2(4), pp.329-347.

[9] Norhasri, M. M., Hamidah, M. S., & Fadzil, A. M. (2017). Applications of using nano material in concrete: A review. Construction and Building Materials, 133, 91-97.

[10] Purohit, R., Purohit, K., Rana, S., Rana, R. S., & Patel, V. (2014). Carbon nanotubes and their growth methods. Procedia materials science, 6, 716-728.

[11] Rhee, I., & Roh, Y. S. (2013). Properties of normal-strength concrete and mortar with multi-walled carbon nanotubes. Magazine of Concrete Research, 65(16), 951-961.

[12] Sahranavard, S., Haji-Kazemi, H., & Abbasi, S. (2014). Effect of multi-walled carbon nanotubes on mechanical properties of high-performance mortar. Magazine of Concrete Research, 66(18), 948-954.

[13] Samchenko, S. V., Zemskova, O. V., & Kozlova, I. V. (2014). Stabilization of carbon nanotubes with superplasticizers based on polycarboxylate resin ethers. Russian Journal of Applied Chemistry, 87(12), 1872-1876.

[14] Shah, S. P., Konsta-Gdoutos, M. S., Metaxa, Z. S., & Mondal, P. (2009). Nanoscale modification of cementitious materials. In Nanotechnology in Construction 3 (pp. 125-130).Springer,Berlin,Heidelberg

[15] Tyson, B.M., Abu Al-Rub, R.K., Yazdanbaksh, A. and Grasley, Z., 2011. Carbon nanotubes and carbon nanofibers for enhancing the mechanical properties of nanocomposite cementitious materials. Journal of Materials in Civil Engineering, 23(7), pp.1028-1035.