Influence of Multi-walled carbon nanotubes on mechanical properties of cement concrete

Mavjot Kaur¹, Krishna Murari² and Gurpuneet Singh³

¹UG Student, Guru Nanak Dev Engineering College, Ludhiana, Punjab, India
²PG Student, Guru Nanak Dev Engineering College, Ludhiana, Punjab, India
³Assistant Professor, Guru Nanak Dev Engineering College, Ludhiana, Punjab, India

E-mail: mavjotkaur@gmail.com

Abstract. The mechanical characteristic of cement concrete with incorporation of multi-walled carbon nanotubes (MWCNT) has been investigated in this paper. Disparate concrete mixes were prepared incorporating CNT-to-cement weight fractions of 0.075, 0.1, 0.125 wt.% in traditional concrete. The flexural and compressive strength were determined after 7 and 28 days of curing. The results of the experimental work showed the maximum increase in the strength was almost 1.5 times than the conventional concrete which is believed to occur due to effective dispersion and nano-scale particle size. This was obtained in mix containing 0.075 wt.% of CNTs, making it the optimum content for improving strength parameters. Moreover, the post cracking strength of concrete after CNTs addition was found to be more than the conventional concrete with the reduction in the abrasion of the concrete.

1. Introduction

Plain concrete is the prominent material for construction around the globe [1] and having typical characteristics like quasi-brittle failure, low tensile strength and high crack propagation. To overcome these drawbacks, many approaches have been introduced, such as fibre incorporation [2], mineral admixtures [3–7] and many more. The Nano-materials, including Nano silica, Nano titanium, Nano alumina and, more lately, carbon nanotubes (CNTs), have been the focus of attention recently for the purpose of reinforcing cementitious matrix. Carbon nanotubes, discovered in 1991 by Iijima [8], are carbon allotropes and characterized as cylinders of graphite sheets of varying length from 1 to 100µm. [9]. The modulus of elasticity of CNTs is approximately 1TPa, that is, almost five-fold of steel, making it the quintessential material for reinforcement at Nano-scale [10-11].

Luo et al. [12] discussed the influence of the addition of CNTs varying between 0.1% and 1.0% by cement weight with flumed silica on properties of cement paste, obtained results, after 28 days curing for flexural strength, showed highest improvements in 0.5 wt% batch. Nasibulina and coworkers [13] scrutinized the influence of using long functionalized CNTs of 0.02, 0.03, 0.05 and 0.09 wt%. The results show that the mix containing 0.03 wt% observed highest strength improvement while the lowest improvement was witnessed in 0.09 wt% mix. Xu et al [14] added 0.025, 0.05, 0.1 and 0.2% CNT-to-cement weight into cement paste and investigated their result on mechanical properties. The microstructurally supported results depicted slight improvement in both flexural and compression test with the gradational increase in content of CNTs.
So far, hardly any works regarding characterization of CNT-reinforced concrete have been published [15-16]. Therefore, the present work investigated the effect of incorporation of functionalized MWCNT of carboxyl group in pozzolana cement concrete on the compression, flexural strength as well as abrasion resistance.

2. Experimental methods and materials

2.1 Materials

The carbon nanotubes were purchased from United Nanotech Innovation Company (India). These were carboxyl group functionalized MWCNT in powder form. The properties are shown in Table 1 which has been taken from company's datasheet. Ethyl alcohol, as a surfactant, was used to aid CNT dispersion. For production of concrete, Portland Pozzolana cement (PPC) of grade 43 conforming to IS-1489, coarse sand (specific gravity 2.63, fineness modulus 2.94) was obtained by sieving normal river sand and crushed aggregate of 20mm size (specific gravity 2.68, fineness modulus 7.54) were selected.

| Table 1. Properties of MWCNT |
|-----------------------------|
| Parameters | Value              |
| Density     | 2.1 gm/cm³         |
| Length (µm) | 10-30              |
| Purity (%)  | >95%               |
| w (ash) %   | < 1.5              |
| Poison ratio| 0.1                |

2.2. MWCNT Dispersion

A physical and chemical process is involved in the Multi-walled CNT dispersion, which are in powder form: (a) magnetic stirring for deagglomeration of CNT, (b) to incorporate Ethanol for ensuring stability of the dispersion. The CNTs to dispersant mass ratio was 0.03:1. The suspension was subjected to magnetic stirring for 40mins. Subsequently, an aqueous suspension was prepared by mixing water and stirring magnetically for 40mins again.

2.3. Mix Compositions

As per IS 10262, M25 grade of was prepared. The proportions are shown in the Table 2. To investigate the effect of MWCNTs in cementitious concrete, four concretes were prepared with same composition but having varying amount of CNTs. The proportions of CNTs utilised in this study are 0%wt (control), 0.075%wt, 0.01%wt and 0.125%wt.

| Table 2. Final Mix Proportions |
|-------------------------------|
| Concrete Grade | Cement | FA | CA | w/c |
|-----------------|--------|----|----|-----|
| M25             | 1      | 1.61 | 2.67 | 0.45 |
2.4. Mixing and Casting
The aggregates and cement are first dry mixed in rotating drum mixer for approximately 3 minutes which is followed by addition of aqueous suspension, having dispersed CNTs, in three equal parts. After achieving the required rheology of the concrete, the concrete was poured into the moulds, which were cleaned and lubricated with mineral oil, within 15 minutes. The concrete was poured into the moulds in three equal layers. Then, compaction was carried out using vibrating table. The fresh concrete was casted into cube specimens (150×150×150mm$^3$) for compression test, prismatic beam specimen (100×100×500mm$^3$) for flexural test, as per IS 516: 1959 and cube specimen (70×70×70mm$^3$) for abrasion test. For each composition and curing period, three specimens were fabricated. The specimens were demoulded after 24 hours and water cured in laboratory at temperature of 24±2°C.

2.5. Testing
The uniaxial compression test and flexural test on standard cubes was carried as per the provisions of IS-516:1959 after 7 and 28 days of curing. For the compression test, Universal testing machine with 2000KN capacity was utilised (Figure 1). Meanwhile, methodology for three-point flexural test was used for ultimate load and load-deflection analysis of the beam specimen. Abrasion test was only carried out on the optimal CNT (with respect to cement weight) content after 28 day curing. The specimen was loaded with 300N and the disk was given 22 revolutions at a speed of 30rpm and the loss in thickness is measured.

3. Experimental Results and Discussion
The results of the experiments conducted for Compressive strength after 7 days and 28 days of curing age and Flexure strength also abrasion resistance are shown in Figures (2 and 3) and Tables (3 and 4).

3.1. Compressive Strength
As expected, the incorporation of MWCNTs shows increase in the compressive strength. For this study cube were casted with concrete mixes having four distinct proportion of MWCNTs (0%, 0.075%, 0.1% and 0.125%) by weight of cement and compressive test was conducted on three samples of each mixes. Figure 1 represents the compressive strength after 7 days and 28 days of curing age, from which it is observed that the increase in strength is maximum for concrete mix with 0.075% of MWCNT by weight of cement.
Mainly the reason for increase in strength is bridging effect and packing effect [14]. The small MWCNTs fills the spaces between the atoms in the crystal matrix of hydration product also combines the different components of hydration products in cement. Similar finding of filler effect were observed by other authors [14, 17]. As a consequence of agglomeration of CNTs, richer proportion of CNTs could not work effectively [11].

3.2. Flexural Strength
It can be seen in Table 1, there is increase in flexural strength due to addition of MWCNTs. Some of other authors [9,11,14] also found similar results. In the present study the flexural strength test was conducted for three beams casted with concrete mixes having distinct proportion (0%, 0.075% and 0.1%) of MWCNTs by weight of cement and the results are tabulated below.

**Table 3. Ultimate Load Carrying Capacity of Beams of distinct samples**

| Beams specimen of distinct % of MWCNTs | Ultimate load carrying capacity (N) |
|----------------------------------------|-----------------------------------|
| 0                                      | 7500                              |
| 0.075                                  | 10500                             |
| 0.1                                    | 8750                              |

Results presented in Figure 2 shows Load v/s Deflection curve for 0%, 0.075 & 0.1% MWCNTs sample. Figure 3 shows a typical flexural crack observed in the CNT reinforced concrete samples.
3.3. Abrasion Resistance

The results of flexure test showed that 0.075 % by weight of cement is optimum proportion of MWCNTs in cement concrete. Hence specimen for abrasion test was casted using the cement concrete with this proportion only. The results of abrasion resistance values are shown in Table 4.

| % of MWCNTs | Thickness loss in abrasion (mm) |
|-------------|---------------------------------|
| 0           | 1.77                            |
| 0.075       | 1.05                            |
4. Conclusion
In this paper, cement concretes, with CNTs as reinforcement in different proportions, were evaluated for their mechanical properties and the following conclusions have been drawn:

- Generally, MWCNTs with were effective in increasing the mechanical properties of the concrete, after 28 days curing, with an improvement of 23.35% and 40% in compressive strength and flexural strength respectively. These results were obtained for 0.075% CNTs, making it the optimum content.
- At early ages, MWCNTs were more effective in enhancing the compressive strength, i.e. 45.4%.
- Presence of MWCNTs also reduces the wear of concrete as it improves the abrasion resistance by 40.22%. Although, the improvement in mechanical strength is significant but it is not economically feasible to utilise it in general construction.

References
[1] Komloš, K., B. Babál, and T. Nürbergerová. 1995 Nuclear Engineering and Design 156 (1–2) 195–200.
[2] Hameed Rashid, Anaclert Turatsinze, Frédéric Duprat, and Alain Sellier. 2009 J. Engineering and Applied Sciences 4 (5) 67–72.
[3] Bogas, J. Alexandre, and Augusto Gomes. 2014 International Journal of Civil Engineering 12 (2 A) 268–78.
[4] Bogas, J. Alexandre, Rita Nogueira, and Nuno G. Almeida. 2014 Materials and Design 56 1039–48.
[5] Mikhailova, Olesia, Grigory Yakovlev, Irina Maeva, and Sergey Senkov 2013 Procedia Engineering 57 775–80.
[6] Ramezanianpour, A. A., and H. Bahrani Jovein. 2012. Construction and Building Materials 30 470–79.
[7] Li, Zongjin, and Zhu Ding 2003 Cement and Concrete Research 33 (4) 579–84.
[8] Tang, Z.R., Han, B., Han, C. and Xu, Y.J. 1991 Nature 354 56–58.
[9] Jarolím, Tomas, Martin Labaj, Rudolf Hela, and Kamila Michnova. 2016 Advances in Materials Science and Engineering 1–7..
[10] Lefèvre, R., M. F. Goffman, V. Derycke, C. Miko, L. Forró, J. P. Bourgoin, and P. Hesto. 2005 Physical Review Letters 95 (18) 1–4.
[11] Ahmed, Hawreen, José Alexandre Bogas, and Mafalda Guedes. 2018 J. Materials in Civil Engineering 30 (10) 1–14 https://doi.org/10.1061/(ASCE)MT.1943-5533.0002470.
[12] Luo, Jianlin, Zhongdong Duan, Tiejun Zhao, and Qiuyi Li. 2011 Advanced Materials Research 146–147: 581–84.
[13] Nasibulina, Larisa I., Ilya V. Anoshkin, Albert G. Nasibulin, Andrzej Cwirzen, Vesa Penttala, and Eso K. Kauppinen. 2012 Journal of Nanomaterial.
[14] Xu, Shilang, Jintao Liu, and Qinghua Li. 2015 Construction and Building Materials 76 16–23.
[15] Wille, Kay, and Kenneth J. Loh. 2010 Transportation Research Record, no. 2142: 119–26.
[16] Keriene, Jadvyga, Modestas Kligys, Antanas Laukaitis, Grigory Yakovlev, Algimantas Špokauskas, and Marius Aleknevičius 2013 Construction and Building Materials 49 527–35.
[17] Carriço, A., J. A. Bogas, A. Hawreen, and M. Guedes. 2018 Construction and Building Materials 164 121–33.