ISSN 1027-5495. Functional Materials, 26, No.4 (2019), p. 779-783.
doi:https://doi.org/10.15407/fm26.04.779 

# Study on mechanical properties of modified nano-concrete based on carbon nanotubes

***Y.Zhang, L.Xia, S.Wang***

Chizhou Vocational and Technical College, Chizhou, 247000 Anhui, China

*Received April 28, 2019*

The influence of modified carbon nanotubes (P-CNT) and unmodified carbon nanotubes (CNT) on the compressive strength and crack strength of concrete materials under condition of the fixed water-cement ratio was studied. The results show that, when the water-cement ratio is 0.4, the optimal content of plasma carbon nanotubes (P-CNT) is about 0.3 %, the appropriate quantity of the plasma carbon nanotubes can be evenly dispersed in the concrete material, and the mechanical properties of concrete can be effectively improved.
**Keywords:** multiwalled carbon nanotubes, concrete, water cement ratio, mechanical properties.

Исследованы механические свойства нанобетона, модифицированного углеродными нанотрубками. Изучено влияние модифицированных углеродных нанотрубок (P-CNT) и немодифицированных углеродных нанотрубок (CNT) на прочность на сжатие и трещиностойкость бетонных материалов в условиях фиксированного водоцементного соотношения. Результаты показывают, что при водоцементном соотношении 0,4, оптимальное содержание плазменных углеродных нанотрубок (P-CNT) составляет около 0,3 %; Плазменные углеродные нанотрубок могут равномерно распределяться в бетонном материале, механические свойства бетона при этом значительно улучшаются.

**Дослідження механічних властивостей нанобетона, модифікованого вуглецевими нанотрубками.** *Y.Zhang, L.Xia, S.Wang.*

Вивчено вплив модифікованих вуглецевих нанотрубок (P-CNT) і немодифікованих вуглецевих нанотрубок (CNT) на міцність на стиск і тріщиностійкість бетонних матеріалів в умовах фіксованого водоцементного співвідношення. Результати показують, що при водоцементному співвідношенні 0,4, оптимальний вміст плазмових вуглецевих нанотрубок (P-CNT) становить близько 0,3 %, відповідний вміст плазмових вуглецевих нанотрубок може рівномірно розподілятися у бетонному матеріалі, механічні властивості бетону можуть бути значно покращені.

## 1. Introduction

Cement concrete has currently the world's largest application among building materials, but due to its low tensile strength and poor impact strength, numerous cracks often occur in the construction; especially for the bridges, buildings and other large structures, there are many security risks [1, 2]. The invention of carbon nanotubes provides a more efficient strengthening method giving the properties of high yield strength, light weight, high heat resistance, large surface area, flexibility, large surface curvature; also the CNTs show excellent electrical conductivity; current throughput is 1000 times greater than that of metallic copper wire [3, 4]. However, the effect of carbon nanotubes on the conductivity of concrete and its use in the diagnosis of large structural defects is small.

Concrete materials based on carbon nanotubes require an increased plasma surface treatment of carbon nanotubes; this treatment removes the structure damages on the

Table 1. Chemical composition of Portland cement and fly ash

| Compositions | $SiO_2$ | $Al_2O_3$ | CaO | $Fe_2O_3$ | MgO | $SO_3$ | TOTAL |
|---|---|---|---|---|---|---|---|
| Cement | 21.58 | 4.45 | 62.8 | 2.79 | 3.39 | 3.38 | 98.39 |
| Flyash | 57.50 | 25.81 | 3.82 | 2.58 | 1.60 | 0.41 | 91.72 |

Table 2. Main physical parameters of carbon nanotubes

| Name | Pipe diameter, nm | Length, μm | Relative carbon content, % | Bulk resistivity, mΩ, cm |
|---|---|---|---|---|
| Carbon nanotube (CNT)50~90 | 5 ~ 10 | ≥96 % | 30.72 | carbon nanotube (CNT)50~90 |

surface of carbon nanotubes, improves the hydrophilicity of the surface, and improves their dispersion in the cement base material. Different proportions of the plasma modification of carbon nanotubes (P-CNT) and their effect on the mechanical properties of concrete were studied in [5–7].

## 2. Experimental

The strength grade of cement is PO42, 5-pass Portland cement. Fly ash provides density of 1.99 g/cm$^3$, 45 m cubic sieve allowance 20 % [8, 9]. The specific chemical composition of the cement and fly ash is shown in Table 1. Sand has the thickness of the module for 2.6. The apparent density is 2510 kg/m$^3$. The stone is 5 ~ 25 continuous graded gravel provided by Luquan stone factory, Shijiazhuang, with crushing value of 7.3. The content of needle-like particles was 4.0 %, apparent density was 2700 kg/m$^3$ [10, 11]. The additive is water-reducing agent of a polycarboxylic acid type in the content less than 1 %, the water-reducing rate is 30 %, and the solid content is 20 %.

The main physical parameters of carbon nano-tubes and the mix of the concrete are shown in Table 2.

Carbon nanotubes/concrete composites with different content (as a percentage of cement mass) were prepared by using the water cement ratio of 0.4. The content of P-CNT was 0. 0.05 %, 0.1 %, 0.3 %, 0.5 % and 1 %, respectively, and the contents of CNT were 0.5 % and 1 % [12, 13].

The production process is as follows:

First, the right amount of dispersant and defoaming agent was put into a beaker containing a certain amount of water, stirred to dissolve, and then the carbon nanotubes were added and stirred until the carbon nanotubes were evenly dispersed for use [14]. Secondly, all kinds of raw materials (gravel, sand and cement) were added into the mixer, the materials were evenly mixed; ultrasonic dispersed carbon nanotubes and water were added in the mixing process and mixed for 2 min; all water was added and mixed for 2 min; then the mixture was poured out on the mixing plate and mixed evenly; the mixed concrete was poured into a mold with a mesh of copper wire electrodes. Finally, the mold was fixed on the vibration Table, and then the vibration Table 1 was opened. After demoulding for 5 min, 1 d was put into the specimen at the temperature of (20±2)°C, humidity was more than 95 % of the standard room value for aging maintenance [15, 16].

CNT concrete: the sand and cement were poured into the mixing barrel and then stirred for 1 min. Then the carbon nanotubes were put in half of the water to make an aqueous solution. The remaining water was poured into the pot and stirred again for 1 min.

Before the sample preparation, the quality of the test mold was checked, and the test mold with smooth and flat inner surface was select to prevent the leakage of the pouring mixture and uneven surface. After cleaning the test mold, mineral grease was applied in the test mold to facilitate demoulding, and a piece of white paper was put at the bottom of the mold. During the manufacturing process of the specimens, the concrete mixture should be loaded into the test mold once and placed on the vibration table for 30 sec [17]. After the vibration, the surface of the specimen should be smoothed with a spatula and quickly covered with a plastic film to prevent water evaporation. After 24 h, the sample should be removed from the mold.

## 3. Mechanical property tests

### 3.1. Compression test

The compressive strength of a concrete cube was tested on a hydraulic press. The loading speed was controlled at 0.5 to ~ 0.8 MPa/s.

Fig. 1. Compressive failure of normal concrete test block.

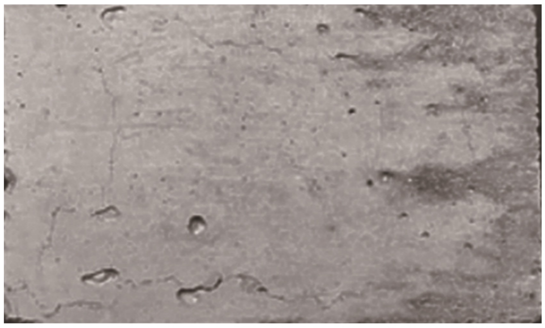

Fig. 2. P-CNT concrete specimen compressive failure.

Fig. 3. Crack resistance failure of normal concrete test block.

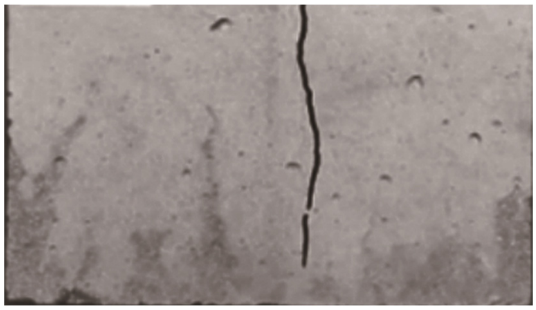

Fig. 4. P-CNT concrete specimen crack resistance failure.

The loading process was carried out in strict accordance with the requirements of the specification. In the concrete cube compressive strength test, when an ordinary concrete block is close to the ultimate load, the spalling of the concrete specimen surface occurs, the load reaches the peak after the specimen fracture. When the concrete modified by carbon nanotubes is close to the peak load, there are multiple longitudinal cracks on the specimen side, but the concrete remains relatively intact after damaging form, has a certain plastic. Fig. 1 and Fig. 2 are failure charts of compressive strength of the plain concrete and modified concrete respectively.

*3.2 Crack-test*

The splitting tensile strength was tested on the electro-hydraulic servo-controlled universal testing machine, and the loading speed was controlled at 1.00 kN/s. The loading process was carried out in strict accordance with the requirements of the specification. In the splitting tensile strength test, after the initial crack load is reached, the crack rapidly expands along the middle line of the test sample. When the ultimate load is reached, the test block is split in two parts near the middle line, resulting in brittle failure. However, the failure of the modified CNT concrete occurs when the load is very large and the surface crack width is very small. Fig. 3 and Fig. 4 show the crack resistance failure diagrams of ordinary concrete and modified concrete specimens respectively.

The data of mechanical tests are shown in Table 3. Fig. 5 are the influence curves of the content of the carbon nanotubes on the compressive strength of concrete. Fig. 6 show the influence of the content of the carbon nanotubes on the crack strength of concrete.

As can be seen from Fig. 5, the compressive strength of concrete cubes with P-CNT contents of 0.05 %, 0.1 %, 0.3 %, 0.5 % and 1 % increased by 3.6 %, 4.7 %, 5.8 %, 4.7 % and 1.4 %, respectively, compared with ordinary concrete. The crack strength for concrete mixed with P-CNT in the contents of 0.05 %, 0.1 %, 0.3 %, 0.5 % and 1 % was, respectively, 8.2 %, 9.6 %, 13.5 %, 9.6 % and 9.2 % higher than that of ordinary concrete.

Fig. 5 and Fig. 6 show that P-CNT incorporation can significantly improve the compressive strength and crack resistance of the concrete; with the increase of plasma carbon nanotube (P-CNT) content, the compressive strength and crack resistance of the concrete also increase gradually, but when the content reaches 0.3 %, the con-

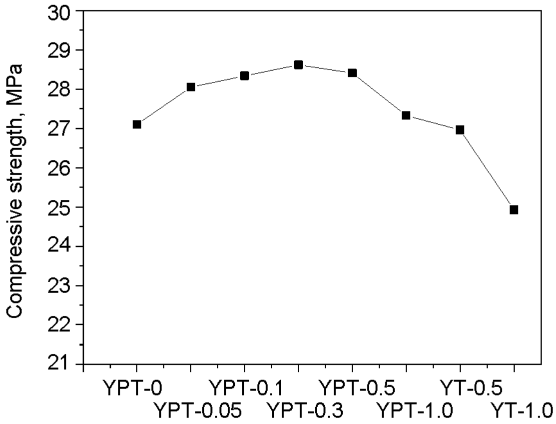


Fig. 5. Influence of carbon nanotube content on compressive strength.

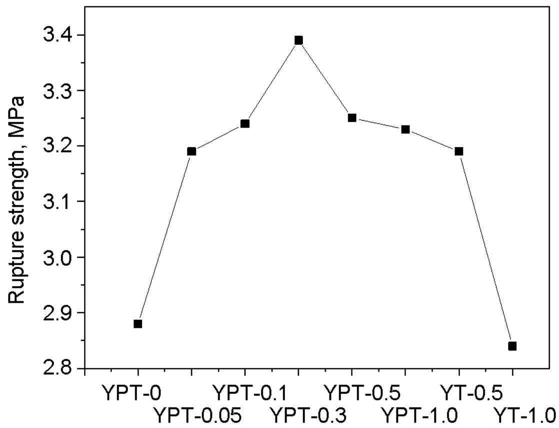


Fig. 6. Influence of carbon nanotube content on crack strength.

crete compressive strength and crack resistance reach the peak, then the downward trend presents. As can be seen, when the content of P-CNT is from 0.3 % to ~ 1 %, the compressive strength decreases gradually, and the crack resistance decreases first and then tends to be flat, indicating that there is an excess of P-CNT; and the excess P-CNT cannot be dispersed in it, resulting in the reduction of the compressive strength and crack resistance of concrete.

As can be seen from Fig. 6, when untreated carbon nanotubes are added, the compressive strength of concrete decreases slightly compared with that of ordinary concrete when the CNT content is 0.5 %, but the crack strength increases by 7.9 %. In particular, the compressive strength of concrete decreased by 8.3 % when the CNT content reached 1%. This is because the untreated CNT cannot be fully dispersed in water, agglomerations are formed easy; this affects the compressive strength of concrete. It can be seen from Fig. 5 that, when the P-CNT content is 0.5 % or 1 %, the compressive strength of P-CNT concrete is 5.7 % and 10.5 % higher than that of CNT concrete, respectively. When the content was 0.5 %, the crack strength of P-CNT concrete was not significantly improved compared with that of CNT concrete. When the content of P-CNT was 1 %, the crack strength increased by 11 %. The main reason is that well-dispersed P-CNT in concrete can cure the micro-cracks caused by cement matrix shrinkage and reduce their size; and the bridging and pulling out effects of P-CNT delay and prevent the growth of micro-cracks in the matrix, so as to achieve the toughening effect. Moreover, because P-CNT can react with cement hydration products, the interaction force between CNT and cement-stone interface is mainly chemical force, and the interface performance is good, and the macroscopic mechanical properties of the corresponding CNT concrete material are also greatly improved.

Table 3. Results of compressive strength tests

| Specimen number | Compressive strength, MPa | | Specimen number | Compressive strength, MPa | |
|---|---|---|---|---|---|
| | Experimental values | Mean value | | Measured values | Mean of measured values |
| YPT-0-1 | 26.90 | | LPT-0-1 | 4.12 | |
| YPT-0-2 | 27.35 | 27.13 | LPT-0-2 | 3.01 | 3.03 |
| YPT-0-3 | 34.72 | | LPT-0-3 | 3.04 | |
| YPT-0.05-1 | 27.88 | | LPT-0.05-1 | 3.31 | |
| YPT-0.05-2 | 26.77 | 28.10 | LPT-0.05-2 | 3.03 | 3.28 |
| YPT-0.05-3 | 29.64 | | LPT-0.05-3 | 3.49 | |
| YPT-0.1-1 | 29.19 | | LPT-0.1-1 | 3.37 | |

However, there is a critical value. As can be seen from Fig. 5 and Fig. 6, when the content of P-CNT exceeds 0.3 % and carbon nanotubes are added, the compressive strength and crack strength of the composites decrease. The reason is that after the carbon nanotubes are treated by plasma, when the content of plasma carbon nanotubes is relatively low, there is sufficient space in the mixture to disperse them, and agglomeration is not easy to occur, so that the distribution is more uniform in concrete. However, with the increase of P-CNT content, the mass of water is constant under condition of the fixed water-cement ratio, and there is no enough space to disperse P-CNTs. Moreover, when P-CNTs are stirred, the nanotubes easy entangles with each other and form agglomerations. At the same time, a large number of bubbles are introduced into the matrix to form honeycomb, micro-holes and other defects, so that the mechanical properties of concrete decrease.

## *4. Conclusions*

Through the above research, the main conclusions are as follows:

When the water-cement ratio is constant, the compressive strength and crack strength of the concrete composite increase with the increase of the content of carbon nanotubes. After being treated by plasma technology, hydrophilic groups were grafted on the surface of the carbon nanotubes. Compared with untreated carbon nanotubes, the treated carbon nanotubes had good dispersion in water.

When the water-cement ratio is constant and the content of P-CNT is less than 0.3 %, the compressive strength and crack strength show an upward trend with the increase of the P-CNT content. When the P-CNT content is greater than 0.3 %, the compressive strength and crack strength decrease instead of increase; that is, the best enhancement effect is achieved when the P-CNT content is 0.3 %.

## *References*


1. D.R.Kauffman, D.C.Sorescu, D.P.Schofield, *Nano Lett.*, **10**, 958 (2010).
2. M.Mazaheri, D.Mart, Z.R.Hesabi, *Composites .Sci. Technol.*, **71**, 939 (2011).
3. M.K.Yeh, N.H.Tai, J.H.Liu, *Carbon*, **44**, 1 (2006).
4. O.Mendoza, G.Sierra, N.J.I.Tob, *Constr. Build. Mater.*, **47**, 771 (2013).
5. F.Azhari, N.Banthia, *Cement and Concrete Composites*, **34**, 866 (2012).
6. N.T.Selvan, S.B.Eshwaran, A.Das, *Sens. Actuat. A: Physical*, **239**, 102 (2016).
7. M.Liu, *Functional Materials*, **26**, 567 (2019).
8. G.Y.Li, P.M.Wang, X.Zhao, *Cement and Concrete Composites*, **29**, 377 (2007).
9. B.Han, L.Zhang, S.Sun, *Composites, Part A: Appl. Sci. Manufact.*, **79**, 103 (2015).
10. F.Shaikh, S.Supit, *Constr. Build. Mater.*, **99**, 208 (2015).
11. M.Ormellese, M.Berra, F.Bolzoni, *Cement and Concrete Res.*, **36**, 536 (2016).
12. G.Qiao, B.Guo, Z.Li, *Constr. Build. Mater.*, **134**, 388 (2017).
13. G.Li, L.Wang, C.Leung, *RSC Advances*, **5**, 70229 (2015).
14. F.T.Isfahani, W.Li, E.Redaelli, *Cement and Concrete Composites*, **74**, 154 (2016).
15. G.Y.Li, P.M.Wang, X.Zhao, *Carbon*, **43**, 1239 (2005).
16. K.K.Chew, K.K.Low, Z.S.H.Sharif, *J. Mechan. Behavior Biomed. Mater.*, **4**, 331 (2011).
17. T.Nochaiya, A. Chaipanich, *Appl. Surf. Sci.*, **257**, 1941 (2011).