Journal of Material Sciences & Engineering
ISSN: 2169-0022

Short Communication Open Access

# The Electrical Heating Performance of Multi-Walled Carbon Nanotubes (MWCNT) Reinforced Mortar

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**Abstract**

Multi-walled carbon nanotubes (MWCNT) have been investigated in this research as being an electrical heating material in mortar. This research studies the self-heating of conductive mortar pastes with MWCNT materials by the application of an electric current. The main parameters studied are: percentage of MWCNT materials, electrical resistance, power consumption, increased temperature per minute and maximum temperature rise.

Three MWCNT reinforced cement based mixtures and reference mortar were designed. Four samples were cast and cured. Afterwards, tests were run under equal currents and the temperature of the specimens was registered. During this time, temperature increase per minute and maximum temperature rise was calculated.

**Keywords:** Self-heating; Multifunctional smart material; Electrical heating; Cement; Multi-wall carbon nanotube

## Introduction

In our big cities, natural gas and electric energy are mostly used for heating purposes. Natural gas has limited reserves. The installation of a central heating requires a furnace, water pipes and radiators which is labor intensive, costly and time consuming. Besides natural gas and coal, central heating system uses electricity also to pump water. In the life time of the structure, the service, repair costs of central heating are great. In this study, "Electrical heating mortar" will be manufactured to heat buildings. The basic application of concrete is a structural material. Non-conductive cement, conductive additives (carbon fibers, nanofibers or nanotubes, graphite dust, steel fibers, etc.) are becoming a good electrical conductor [1].

Self-heating cement directly relates to the increase in thermal and electrical conductivity of the composite [1]. Carbonaceous materials have a high thermal conductivity and are highly resistant to corrosion. This allows them to make good practices for thermal applications of multifunctional cementitious composites, such as heating buildings or preventing the freezing of highways and airports [2].

Recently, carbon nanotubes (CNTs) have demonstrated very good mechanical, thermal and electrical performance. Carbon materials have a high thermal conductivity (but not as much as metal) and are very resistant to wear at the same time. All these properties are desirable in multifunctional cement composites, and as a result, carbon materials are suitable as conductive additives. The new generations of carbon nano-filaments has excellent mechanical, electrical and thermal properties and are successfully used in polymer matrices [3].

## Materials and Methods

Cem II 42,5R type cement and the fine aggregate (0-5 mm) were used. In the mixtures, plasticiser and silica fume were used. Pure copper wire mesh was used as electrode. Brass fiber was used as conductive additive. Multi-walled carbon nanotube was also used as conductive additive.

According to the information given by the producer, MWCNT was manufactured using catalytically carbon vapour deposition method. Characteristic properties of MWCNT are presented in Table 1, as obtained from the producer and SEM image is shown in Figure 1.

| Property | Unit | Value | Measurement method |
|---|---|---|---|
| Average diameter | nanometer | 9.5 | TEM |
| Average length | micrometer | 1.5 | TEM |
| Purity of carbon | % | 90 | TGA |
| Metal oxide | % | 10 | TGA |
| Unit weight | $g/cm^3$ | 0.2-0.35 | HRTEM |
| Surface area | $m^2/g$ | 250-300 | BET |

**Table 1:** Multi-walled carbon nanotube characteristic properties (supplier data).

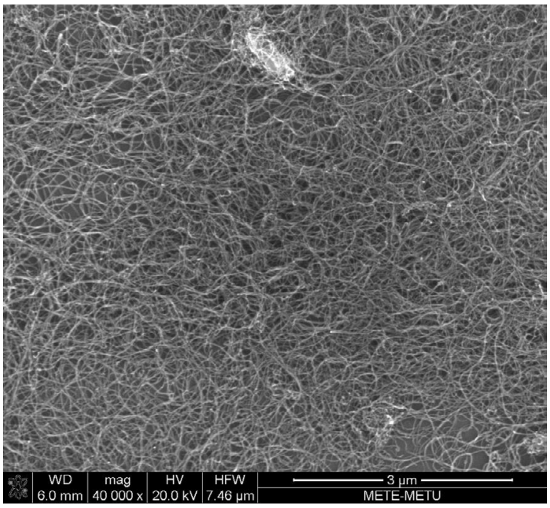


**Figure 1:** SEM image of MWCNT.

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**Received** April 13, 2019; **Accepted** April 23, 2019; **Published** April 30, 2019

**Citation:** Karagöz A, Demircilioğlu E, Karademir C (2019) The Electrical Heating Performance of Multi-Walled Carbon Nanotubes (MWCNT) Reinforced Mortar. J Material Sci Eng 8: 519.

Distilled water was used in concrete mixes. Molds were made of steel. Mold size was 5 × 5 × 2.5 $cm^3$. On the sidewalls of the mold, two slots which have width of 2 mm and height of 45 mm were opened. 25 mm thick board was placed under the mold and the copper electrodes were inserted in the mortar molds.

The mixtures were designed according to TS 802 "*Design of Concrete Mixtures*" standard. In this study, the reference mixture was, which has no copper fiber and MWCNT. Three different mixtures were designed which had 1% volume of brass fiber and MWCNT of 0.115%-0.23%-0.35%, by volume.

The mortars are: CnT0 which does not have any conductive materials; CnT1b had 0.115% MWCNT and 1% brass fiber volume ratio; CnT2b had 0.23% MWCNT and 1% brass fiber volume ratio; CnT3b had 0.35% MWCNT and 1% brass fiber volume ratio.

Cement and aggregates were put in mixer. Water and plasticizer were weighed in separate cups then mixed in a cup. Water, plasticizer and MWCNT mix were added to dry aggregate and cement in three stages and mixed every time.

During the preparation process of the mixtures with carbon nanotube additive, the additive was dispersed in distilled water. After mixing the pure water and the plasticizer in a glass beaker by WiseStir MSH-20D magnetic stirrer for 5 minutes at 1500 rpm, MWCNT was added to the mixture and the mixing process was continued 30 minutes more. Then, an ultra-sonication process was carried out by Mercurial ultrasonic cleaner for 30 minutes. During this process, the Van der Waals' bonds between MWCNT and MWCNT particles were broken in order to prevent agglomeration. After this process the mixture was mixed again on a magnetic stirrer for 30 minutes at 1500 rpm, so that the MWCNT was dispersed in water and plasticizer. The dispersion process is shown in Figure 2.

All mixtures were cast into the molds in 2 stages. The mix was rodded 10 times for each stage. Molds with mixture were vibrated on a vibration table for 30 seconds. After 24 hours, samples were demolded and cured in 20°C water for 28 days. Samples are shown in the Figure 3.

Three 5 × 5 × 2.5 cm prismatic samples from each mixture were tested. Experiments of the samples were made on 35th of production. A thermocouple was placed on the sample upper surface to monitor temperature change during the experiment. DC electrical potential was applied to each sample for 20 minutes. The test diagram is presented in Figure 4. During the electrical heating test, direct current was supplied from the two electrodes to the sample with the DC source. To measure the electrical resistivity of the samples, the sample potential differences (Vs) were measured from both electrodes. Current passing through the circuit (I) and the potential difference (Vs) was recorded at 1 Hz. The instantaneous electrical resistance (Rs) of the sample using Ohm's law was calculated by using eqn. (1).

$$R_s=(V_s)/(I) \quad (1)$$

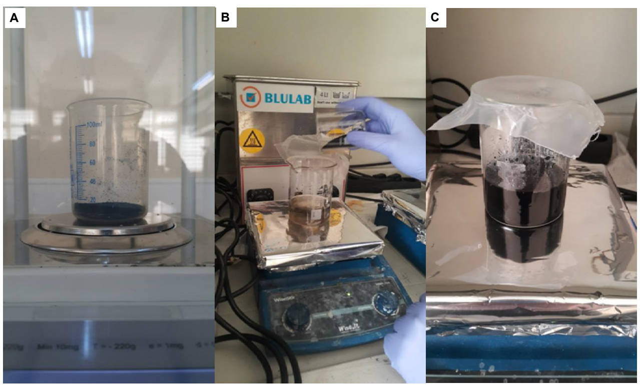


**Figure 2:** Process of dispersion. **(a)** Accurately weighted MWCNT; **(b)** Pure water, plasticizer and nano material mixed at 1500 rpm, and **(c)** MWCNT with distilled water.

## Results and Discussion

In the tests, besides the reference mortar and 3 multi-walled carbon nanotube (MWCNT), included mortars, having different MWCNT ratios, were used. As it can be seen in Figure 5, the average resistance for a mortar, which has no conductive additives, is 14611.4 Ohms on the 30V and in average 13806.3 Ohms on 60V. One of the most important parameters for heating a material is the electrical resistance of the

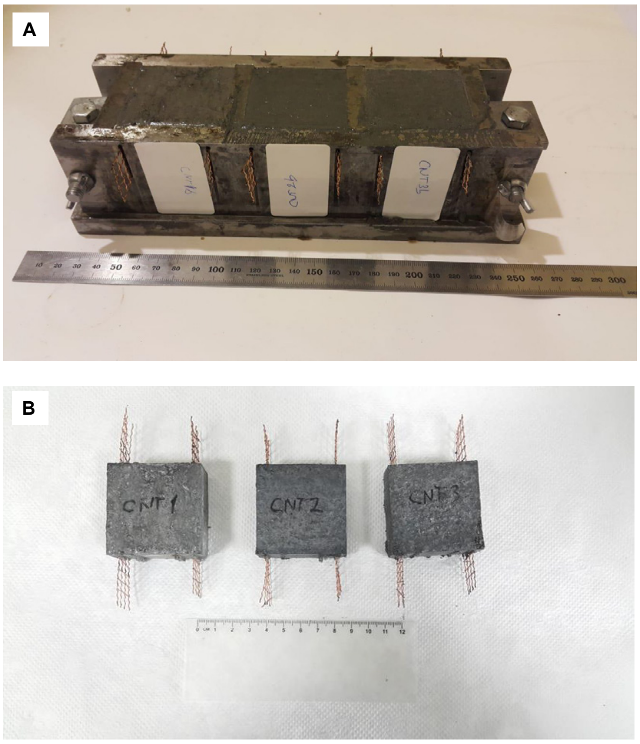


**Figure 3: (a)** After casting wet and **(b)** Dry.

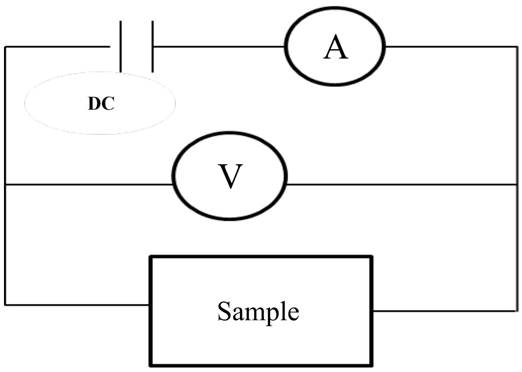


**Figure 4:** Circuit diagram.

material. The mortar must be capable of providing both a current and a specific resistance to it. As shown in Figure 6, there was a large decrease in the resistance of the material as it contained more additives. The average electrical resistances of CnT1b, CnT2b, CnT3b were calculated under 30V are 1354.7, 399 and 304.7 Ohms, respectively. Under 60V, the average electrical resistances of CnT1b, CnT2b, CnT3b are 1236.4, 398.9 and 325.6 Ohms, respectively. It is clear on the resistance graphs that as MWCNT ratio increased, resistances decreased and the mortars became more conductive.

The temperature-time curves obtained from the 30V and 60V electrical heating tests are as shown in the graphs (Figures 7 and 8).

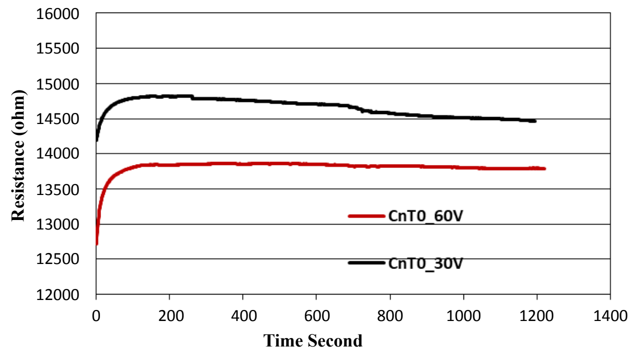


**Figure 5:** Reference mortars resistance.

During under the 30V test, it was observed that there was almost a linear relation among the temperature increase and time with respect to the MWCNT volume ratio. As the MWCNT ratio increased, the temperature increase was faster.

In the experiment performed under 60V, the temperature rise rate is proportional to the MWCNT ratio, but mixtures containing MWCNT of 0.2% and 0.35% by volume have similar temperature increases which are 34°C.

Also during 'under the 30V' test, it was observed that there was a relation among the temperature increase rate (°C/minute) and temperature increase with respect to the MWCNT volume ratio (Figure 9).

In the experiment performed under 60V, the temperature rise rate is proportional to the MWCNT ratio, but mixtures containing MWCNT of 0.2% and 0.35% by volume have similar temperature increase rates. Relevant literature are listed [4-6].

## Conclusions

In this study four different cement matrix composites were designed. Except for one sample were all designed with different percentages of MWCNT and 1 percent of brass fiber. Four samples were prepared, cured and tested. The effects of electrical conductivity, the amount of temperature increase per minute were experimentally tested. Important results are presented as bellow:

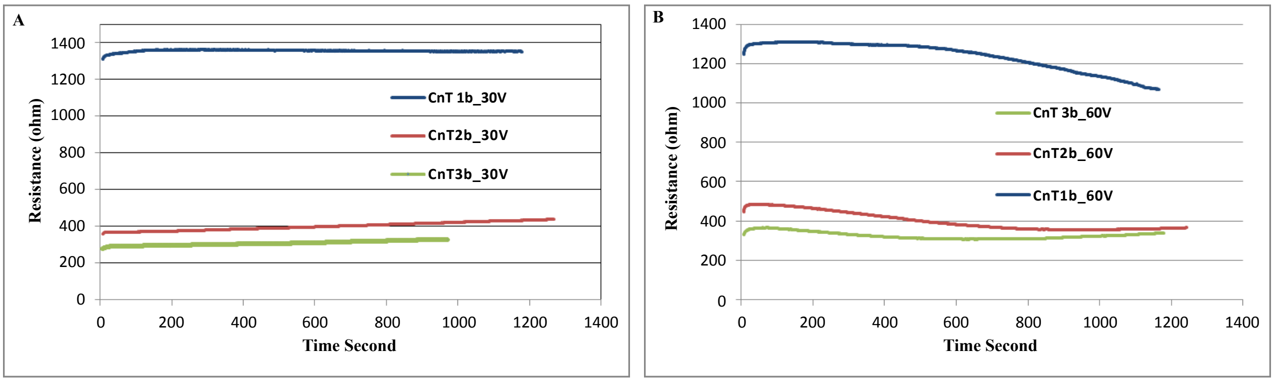


**Figure 6:** With MWCNT mortars resistance; **(a)** 30V and **(b)** 60V.

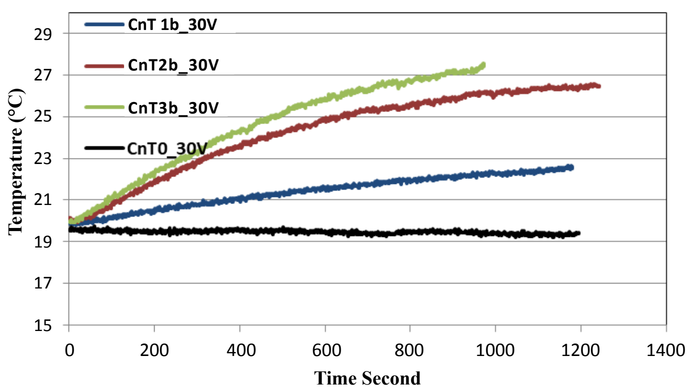


**Figure 7:** Temperature increase (under 30V).

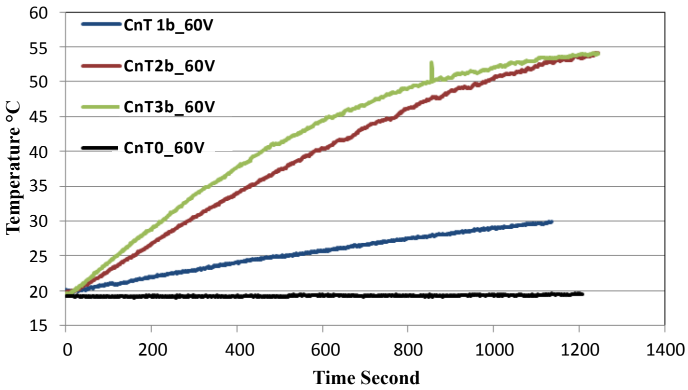


**Figure 8:** Temperatures increase (under 60V).

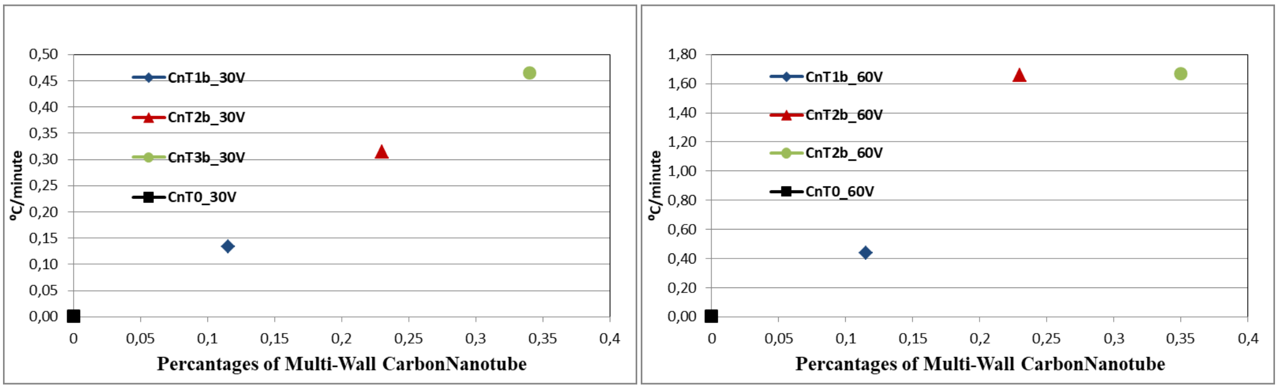


**Figure 9:** Temperature increase rate per minute.

1. The reference sample without conductive material has a very high resistance to other mixtures. Since there was no conductive material in the mixture, a temperature increase or a significant current transition was not observed.
2. The resistance decreased as the MWCNT ratio increased in the mixture.
3. Under the 60V, the CnT2b and CnT3b, the temperature increase and temperature increase rates are very close to each other.
4. Under the 60V, the CnT2b and CnT3b, temperature increases are 35°C in 20 minutes The MWCNT cement can be used as electrical-heating cement. The results are contribution of develop electrical-heating cement based materials. This study is a contribution for smart multifunctional electrical heating cement composites.

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