The Investigation Thermal Efficiency of High Performance Fiber Reinforced composites with additive Single-Wall Carbon Nanotubes

Materials Chemistry Scientific Research Research Article

Adar Karagoz

AVA construction, The Graduate School of Natural and Applied Sciences, Dokuz Eylul University, Paris, France

Submitted : March 23rd, 2020
Accepted : April 8th, 2020
Published : April 10th, 2020

Correspondence author
Adar Karagoz
AVA Construction
The Graduate School of Natural and Applied Sciences
Dokuz Eylul University
Paris
France
E-mail : adarkaragoz@gmail.com

Abstract

We are experiencing the beginning of a new industrial revolution based on the development of a new level of scientific and technological progress. Nano-scale modified materials have significantly improved mechanical, electrical and thermal properties compared to micro and macro scales. This research studies the self-heating of Single Wall Carbon Nano Tube (SWCNT) reinforced cementitious composites by application of an electric. Experiments were tested for a total of eight weeks, once every week. During the tests, the top surface temperature, the voltage supplied and the current were recorded. The temperature increase and temperature increase rate power consumption were determined. Mortar having SWCNT ratio showed a superior heating performance for 8 weeks. In this study, the bearing elements of the buildings and roads are intended to be a heater. The thermal efficiency of the high performance fiber reinforced composites were investigated.

Keywords: **Self-Heating, Multifunctional Smart Material, Electrical Heating, Cement, Multi-Wall Carbon Nanotube**

Introduction

Nowadays, renewable energy increases its importance. Making intelligent buildings and producing energy from renewable sources is of great importance for the future of the world. In many regions of the world, natural gas and electricity are used for heating purposes. Natural gas has limited reserves. A central heating installation requires a labor-intensive, costly and time-consuming furnace, water pipes and radiators. In addition to natural gas and coal, the central heating system also uses electricity to pump water. During the lifetime of the building, the cost of service and repair of central heating is costly. In addition, it is an advantage that the heating element is not outside to make the buildings look more aesthetically pleasing. The fact that the heater element is a part of the building and that this energy source is taken from the solar cells aims to be a building that is a smart and renewable energy source.

The basic application of concrete is a structural material. Non-conductive cement, conductive additives (carbon fibers, nano fibers or nanotubes, graphite powder, steel fibers, etc.) are becoming a good electrical conductor [1]. Similarly, many properties such as electrical conductivity of cementitious materials are affected by micro and nano behaviours [2]. The addition of micro- and nano-fibers to the cementitious matrices allows the modification of the properties of the materials [3, 4]. Fiala et al. reported that carbon black and alkali-activated aluminosilicates could be developed for the self-heating material technology [3]. Kim et al. stated that cement composites with CNT less than 0.6% by weight are suitable for self-heating.

Conventional cementitious materials are not electrically conductive. Resistance is too high to effectively heated. Resistance can be reduced with carbon fibers, steel fibers and graphite etc. such as electrically conductive materials [1-4].

In recent years, carbon nanotubes (CNTs) have shown very good mechanical, thermal and electrical performance. Carbon materials have high thermal conductivity (but not as much as metal) and are also very resistant to abrasion. All these properties are desirable in multifunctional cement composites and as a result, carbon materials are suitable as conductive materials. Carbon based materials have excellent mechanical, electrical and thermal properties and are used successfully in polymer matrices [5].

Fiala et al. reported that alkali-activated aluminosilicates with carbon black can be improved for self-heating material technology. Kim et al. (2016) stated that cement composites with CNT less than 0.6% by weight is appropriate for self-heating [6]. Galao et al. stated that shotcrete of carbon nano fiber reinforced cement paste (5% by cement mass) had electrical heating performance.

High performance Cement-based composites, which are, contain a high amount of steel fiber and have better mechanical properties than traditional concrete and mortar. The concept of high performance means not only high mechanical properties but also high durability [7].

Materials and Method

Cem II 42,5R type cement and the fine aggregate (0-5mm) were used. In the mixture, plasticiser was used. Stainless steel wire mesh was used as electrode. Steel fiber was used as conductive additive. Single walled carbon nano tube was also used as conductive additive.

According to the information given by the producer (LANXESS), Characteristic of SWCNT Rhenofit® CNT-3 is a water-based dispersion of single wall carbon nanotubes (SWCNT) which can be used directly for production of formulations. The dispersion is highly homogeneous and stabilized and the applied process ensures non-destructive dispersing of carbon nanotubes under mild conditions. Characteristic properties of SWCNT are presented in table as obtained from the producer:

Composition: 0.2 wt% single wall carbon nanotubes 0.4 wt% low molecular weight dispersing agent 99.4 wt% water

- Appearance: Black dispersion
- Odour: No odour
- Compatibility: Can be mixed with liquid systems and appropriate polar organic solvents
- pH value: Neutral to slightly basic (approximately pH = 7-9).

Cement and aggregates were put in mixer. Water with SWCNT and plasticizer were weighed in separate cups then mixed in a cup. Water and plasticizer mix were added to dry aggregate and cement in 3 stages and mixed every time.

Mixture was cast into the molds in 2 stages. The mix was rodded 10 times. Mold with mixture were vibrated on a vibration table. After 24 hours, sample was demolded and cured in room temperature (20°C) water for 28 days. Mold size was 10 × 10 × 3.5 cm^3.

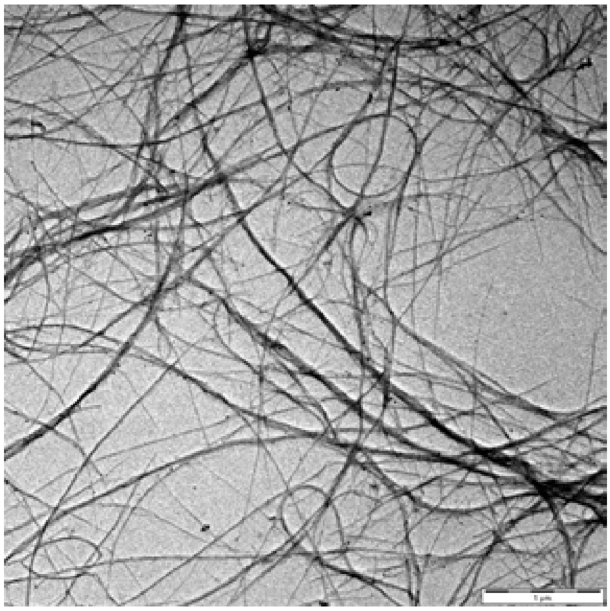

Figure 1: SEM image of SWCNT (Scale is 1 μm)

The mixtures were designed according to TS 802 “Design of Concrete Mixtures” standard. In this study, concrete were designed which had 3% volume of steel fiber.

Three 10 × 10× 3.5 cm prismatic sample from each mixture were tested. Experiments of the sample was made on 35th of production. A thermal camera was recorded during the experiment. A direct current source was used. The test diagram and experiment are presented in Figure 2, 3. 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. The instantaneous electrical resistance (Rs) of the sample using Ohm’s law was calculated by using Equation 1.

$$Rs = (Vs) / (I) \quad (1)$$

The Power consumed during the heating test was calculated by Eq. 2.

$$P = \int I \times Vdt \quad (2)$$

Where; I: current, R is the resistance, t the time.

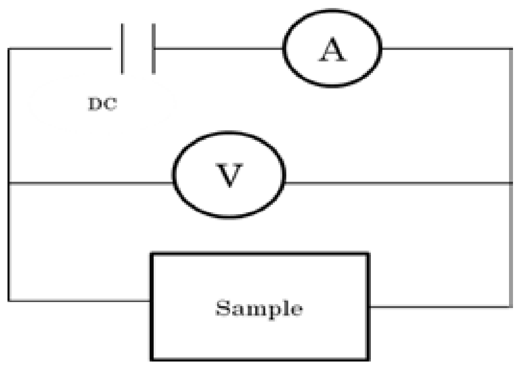

Figure 2: Circuit diagram

Figure 3: Schematic of Experiment (different weeks)

Results and Discussions

This experimental study is trying to solve the heating problem by means of a concrete system that can be heated by electricity. The concrete was tested once a week for a total of 8 weeks under 112V voltage. In addition, total experiment time was determined as 5 minutes and the results were recorded. It has been observed that a sample reached high temperature in a very short time. While testing the sample, piece of ice about 5 cm thick were poured and it was seen that the ice melted completely during the experiment. Temperature-time curves which were obtained from the 8 weeks of electrical heating tests are presented in Figure 4. As it is shown on the graphs Figure (4-6), there is a linear increase in the temperatures by time while 8 weeks. Mortar having SWCNT ratio showed a superior heating performance. For 8 weeks, we observed that the maximum temperature of the sample reached almost the same points within the same period.

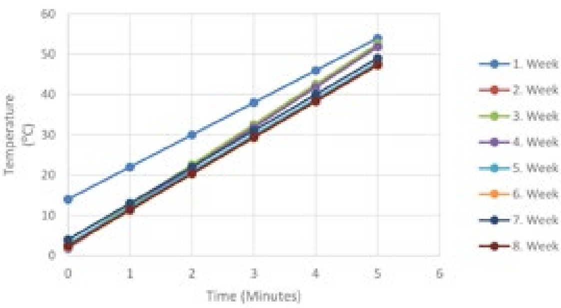

Figure 4: Temperature-Minute Graphs

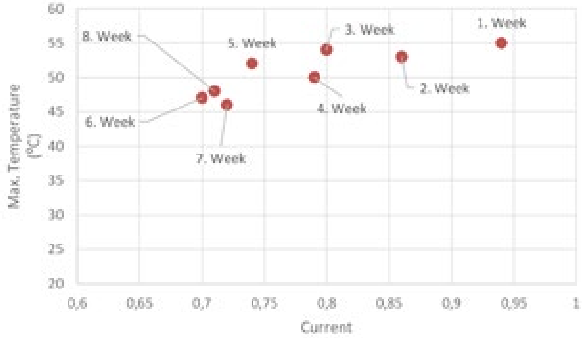

Figure 5: Max. Temperature-Current Graphs

During the 8 weeks tests it was observed that there was almost a same relation among the temperature increase rate (Vt ºC/minute).

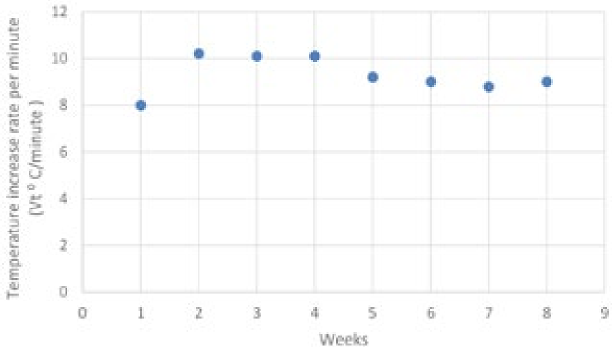

Figure 6: Temperature increase rate per minute – Weeks graphs

Power is calculated by multiplying of current and the voltage for one hour. Power consumption is calculated based on the amount of energy spent in 1 hour.

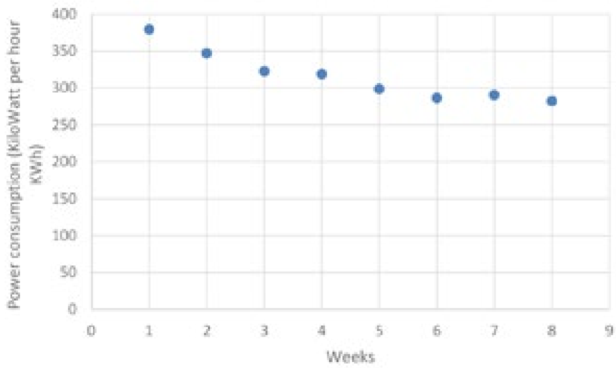

Figure 7: Power (KWh)-Weeks graphs

Conclusions

In this study cement matrix composite was designed. Designed with SWCNT and 3 percent of steel fiber. Sample was prepared, cured and tested [7-10]. The effect of electrical conductivity, the amount of temperature increase per minute were experimentally tested. Important results are presented as bellow;

The temperature-time curves obtained from the 112V electrical heating tests are given in

- There was almost a linear relation among the temperature increase and temperature increase is the same every week.
- The temperature rise is the SWCNT ratio, have similar temperature increases every week which are 50 ºC.
- The temperature rise rates are the SWCNT ratio, have similar temperature increases every week, which are around 10 ºC.
- The mixture of SWCNT, the temperature increase and temperature increase rates are very close to each other every weeks.
- The mixture's temperature increases are around 50 ºC in 5 minutes.
- Power consumption is calculated based on the amount of energy spent in 1 hour. The average cost of 1 KWh power consumption of industrial pricing in France is about 0, 0580 €. Accordingly, if the electrically heated concrete works continuously for 1 hour, the amount consumed will be approximately 20 €.

As a result, the roads are hard work and long work for countries where snowfall is very intense and the temperature frequently falls below 0 degrees. If the roads can automatically solve the icing problem, we will save time and less chemicals. As we know, France ranks 4th in the world ranking in terms of production and use of wind turbines. In this way, roads that can be heated with renewable energy can be designed [11-17].

The SWCNT 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.

Acknowledgements

I would like to thank to LANXESS Company for supplying Single Wall Carbon nanotube and Multi Wall Carbon nanotube.

References

1. Amini B, Tehrani SS (2014) "Simultaneous effects of salted water and water flow on asphalt concrete pavement deterioration under freeze-thaw cycles". Int Jour of Pavement Engineering 15: 383-391.
2. Chung DDL (2004) "Self-heating structural materials". Smart Materials and Structures 13: 562-565.
3. Feng D, Yi J, Wang D, Chen LL (2010) "Impact of salt and freeze-thaw cycles on performance of asphalt mixtures in coastal frozen region of China". Cold Regions Science and Technology 62: 34-41.
4. Fiala L, Jerman M, Rovnanik P, Cerny R (2017) Basic Physical, Mechanical and Electrical Properties of Electrically Enhanced Alkali-Activated Aluminosilicates. Materials and Technology 51: 1005-1009.
5. Galao O, Baeza FJ, Zornoza E, Garcés P (2014) Self-heating function of carbon nanofiber cement pastes. Materiales de Construcción 64: 1-11.
6. Galao O, Banon L, Javier BF, Carmona J, Garcés G (2016) "Highly Conductive Carbon Fiber Reinforced Concrete for Icing Prevention and Curing". Materials 9: 281.
7. Gomis J, Galao O, Gomis V, Zornoza E, Garcés P (2015) "Self-heating and deicing conductive cement. Experimental study and modeling". Const Build Mater 75: 442-449.
8. Gopalakrishnan K, Ceylan H, Kim S, Yang S, Abdualla H (2015) "Electrically Conductive Mortar Characterization for Self-Heating Airfield Concrete Pavement Mix Design". Int J Pavement Res Technol 8: 315-324.
9. Hassan Y, El Halim AOA, Razaqpur AG, Bekheet W, Farha MH (2002) "Effects of runway deicers on pavement materials and mixes: Comparison with road salt". Jour of Transportation Engineering-ASCE 128: 385-391.
10. O Galao, FJ Baeza, E Zornoza, P Garcés (2014) Self-heating function of carbon nanofiber cement pastes. Materiales Contruccion 64: 314.
11. Kim GM, Naeem F, Kim HK, Lee HK (2016) Heating and heat-dependent mechanical characteristics of CNT-embedded cementitious composites. Composite Structures 136: 162-170.
12. Mehta PK, Monteiro PJM (2006) Concrete: Microstructure, Properties, and Materials. 3rd Edition. McGraw-Hill, New York
13. Ozgan E, Serin S, Gerengi H, Arslan İ (2013) "Multi-faceted investigation of the effect of de-icer chemicals on the engineering properties of asphalt concrete". Cold Regions Science and Technology 87: 59-67.
14. Shi X (2008) Impact of Airport Pavement Deicing Products on Aircraft and Airfield Infrastructure. Washington D.C: Transportation Research Board.
15. Tang N, Sun CJ, Huang SX, Wu SP (2013) "Damage and corrosion of conductive asphalt concrete subjected to freeze-thaw cycles and salt". Materials Research Innovations 17: 240-245.
16. Wang S, Wen S, Chung DDL (2004) "Resistance heating using electrically conductive cements". Advances in Cement Research 16: 161-166.
17. Zhang K, Han B, Yu X (2011) "Nickel particle based electrical resistance heating cementitious composites". Cold Regions Science and Technology 69: 64-69.