THE EXPERIMENTAL STUDY ON DAMAGE DETECTION MEASUREMENT THROUGH PIEZORESISTIVITY OF CARBON NANO TUBE IN CEMENT MORTAR

J Viradiya[1], S Shah[1]

1. Marwadi Education Foundation, Rajkot, Gujarat, India

ABSTRACT. The work presented in this paper deals with the use of Nano technology in cement mortar. The Carbon Nano Tube (CNT) has piezoresistive property which has potential to measure the deformation. The use of CNT in this study is for strain measurement and thereby predicts the micro cracks early. To achieve this, the cement mortar (1:2) proportion is mixed with varying dosage of CNT by weight of the cement from 0.2 to 0.8 % with increment of 0.2%. Then the prism specimens are casted and tested for very low loading conditions to measure the deformation. The results of deflection and cracks obtained by CNT sensors will be compared with traditional strain gauges. It was found that CNT measured deformation is matching with 90% accuracy with those recorded by traditional dial gauge, however these experiments are very preliminary and numbers of repetition is required to check the sustainability and reproducibility.

Keywords: Piezoresistivity, Nano technology, Cement mortar, Carbon nanotube, Strain measurement.

Dr Siddharth G. Shah is a Professor and Head of the Civil Engineering Department, Faculty of PG studies & Research, Marwadi education foundation Rajkot. His research interest includes concrete technology and application of Nano technology along with soil-structure interaction and ground improvement techniques.

Jay Viradiya, ME Structure student at Marwadi Education foundation Rajkot.

INTRODUCTION

Durability of the concrete structure is expected to be around 100 years but due to numerous issues like Quality Control, Workmanship, Design mix, Carbonation, Alkali Silica Reactions Chloride ingress etc leads to corrosion of the reinforcement resulting in the spalling and cracking of the concrete and reduces its durability by 50-60%and the average life of concrete structure is only 30-40 years! Lifeline structures like bridge, dams, nuclear/thermal power plants and other many important public buildings cannot afford such degradation. Hence in such structures monitoring of the deformation and cracks as well as early detection is the key factor to ensure safety as well as serviceability. So there is a need to imbibe the strain gauges or similar devices in concrete structure which can measure and detects such deformation and cracks.

Resistivity is the property of material by virtue of which it offers resistance to current transmission through it. Resistivity is nowadays mostly used to calibrate with deformation and has become the promising feature of the next generation of smart cement-based materials. The concrete has a wide range of electrical resistivity. Mainly depends on the moisture content [1] temperature [2], the type of cement, the ratio of water to cement, and the amount and type of aggregates in the raw materials [3], admixtures and supplements. Most of the strain gauge and LVDT works on this principle of measuring the resistivity of the concrete to estimate the strain through calibrated relationships.

Nano technology and Nano materials have great potential to deal such problems and it has gained popularity amongst the Civil engineering research fraternity. Carbon Nano Tube (CNT) is slender particle with nanometre dimension of 1-2nm diameter and 10to 20nm length. The CNT has amazing physical and chemical properties. It tensile strength is almost 150 time more than that of steel and density is 1/6th of steel [7-13]. Some of the other properties of CNT which are useful in this study are listed in Table-1. CNT has one amazing property known as piezoresistivity by virtue of which the deformation measurements are possible when it is imbibed in cement mortar itself [19-20].

Table 1 Typical chemical and physical characteristics of carbon nano tube used in this study

PARAMETER	TYPE
Type	Multi-walled CNT
Production method	Chemical Vapour Deposition(CVD)
Available form	Black powder
Diameter	20-40 nm
Length	5-15 micrometer
Nanotubes purity	>98%
Amorphous carbon	<1%
Specific Surface area	40-300 cubic meter / gram
Bulk density	0.20-0.35 g/cm^3

EXPERIMENTAL PROCEDURE

In this study an attempt was made to reveal the potential of the dispersed CNT in cement mortar to act as sensor and detect the cracks in early stage. For this, CBR apparatus was fixed to test the prism specimen's small dimensions and less load rate. Three points bending test was performed on specimen mixed with cement mortar. The cement mixtures with CNT, each with different CNT loading, were prepared for measurement of resistivity. The dimension of the block is kept 15x5x5 cm. They were fabricated by keeping wooden partition in traditional cube mould. The Mortar Mixture contained ordinary Portland cement, water, natural sand and multi-walled carbon nanotubes. Water to cement ratio was maintained at 0.4 while the CNT were added at varying concentrations of 0.2, 0.4, 0.6and 0.8 %, by weight of cement and a reference mixture without nano-inclusions was prepared. To measure the resistivity the conductivity was measured through electrodes of copper wire of 2mm. inserted in prism specimen as shown in Figure 1.

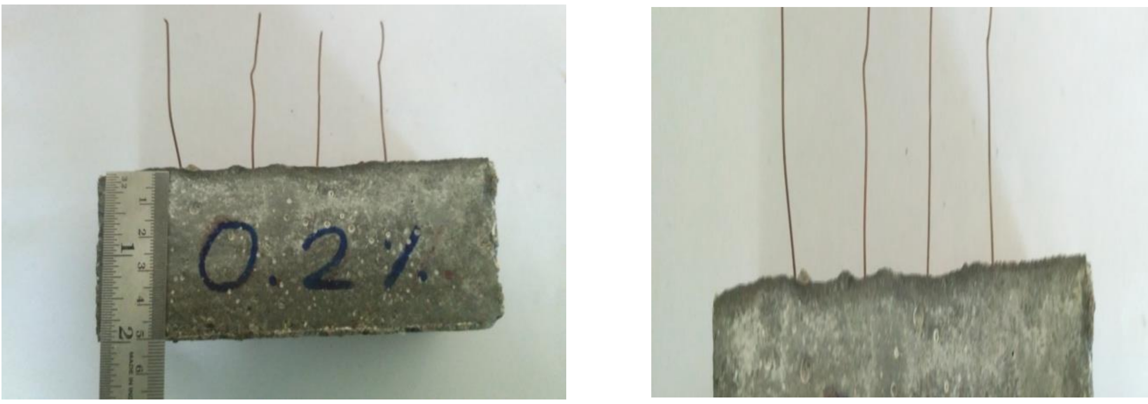

Figure 1 Embedded electrode configuration in the CNT/cement prismatic mortars

Preparation of nano modified mortars

The fabrication procedure of prism of cement mortars was divided into three steps. First water and CNT mixed with appropriate dispersing agents like sodium dodecyle. and then cement and the sand suspension was mixed for 5min hand mixing than the immediately after mixing, the fresh mortar was poured into oiled wooden molds of inner dimensions 5x5x15 cm and was left to set for 24 hours before dismantling of moulds.

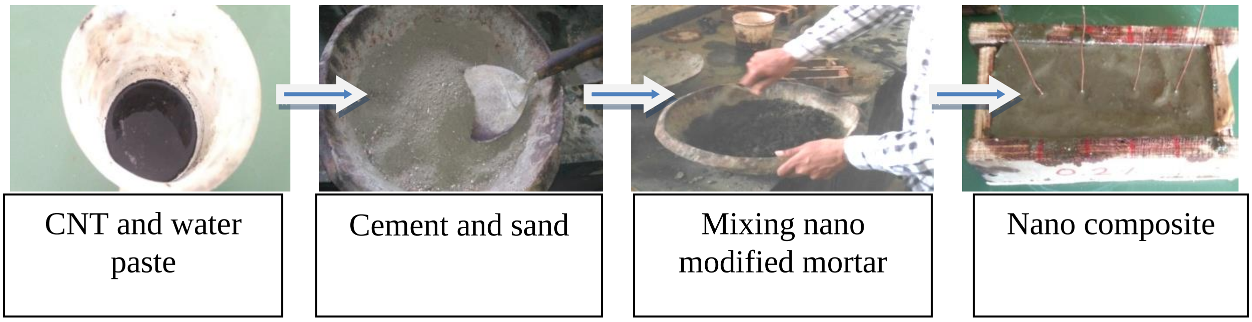

Figure 2 Schematic representation of the nano-modified mortars manufacturing process

DC surface electrical resistivity measurements

Surface resistivity was determined according to Ohm’s law, by measuring the current as a result of the application of a voltage potential across the surface of the sample. All specimens were tested at each composition. Figure 3 shows the types of electrical resistivity data which were collected electrical current in amperes as a function of test time in seconds and surface resistivity in Ohms per square as a function of readings count at the indicated voltage.

Figure 3 Different cement mortar specimen with different electrical resistivity

Piezoresistive behavior

The piezoresistive behavior of nanomodified mortars was assessed by measurement of their electrical response during mechanical load in the direction perpendicular to the embedded electrodes, during the loading the electric current of the specimen under a constant voltage. And then the change in DC electrical resistance on loaded specimen was calculated.

Damage detection under three-point bending

Damage and crack formation and propagation in the mortars during loading lead to the collapse of the electrically conductive network, hence also to resistivity increases. Three-point bending tests were performed with simultaneous electrical resistance change measurements using the four-probe method as shown in Fig the tests were performed under crosshead while an applied voltage of 05 V was used.

Figure 4 Cement/CNT during three points bending testing with simultaneous electrical resistivity measurement

RESULTS AND DISCUSSION

In this study important task was to check the effectiveness of CNT mixed mortar to measure the strain on its own, then to validate the results with the actual displacement records. For this, it was key to establish the relationship between the loading applied to the specimen v/s the resistivity of prism specimens. The behavior observed in Figure 5 shows a significant effect of CNTs the existence of resistivity values of nano-modified the control value (ordinary specimen) increased with the tube concentration from 0.4 to 0.6 wt. of cement and so on. An electric current is passed through the substance ion current to establish a continuous. The conductive network structure of carbon nanotubes is in its volume.

Damage sensing under bending

Three-point bending test of 0.2%, 0.4%, 0.6%, 0.8% by weight of cement. The resistivity penetration results are given in Figure 3 depicts typical resistance changes measured in-situ during three-point bending Loading; load-displacement characteristics of mortar are also included in the figure. Electric-based trends the resistance curve, the material response can be divided into three major systems. The first system extends from the origin to 0.022mm displacement and involves small-scale Resistance in the elastic range increases and reaches a maximum load. The second regime occupies a narrow displacement range between 0.022 and 0.03 mm, where the sudden monotonic increase in resistance is approximately one order of magnitude occurs. Mechanical response of internal materials after the maximum load is usually associated with multiple loads; this mechanism is a smooth load drop Crack formation and propagation. The last regime extended from displacement 0.03 mm to the final failure and involves a small to insignificant increase Resistivity. The inheritance of these three regimes proves this Induced potential damage of embedded nanotubes, which suddenly increased resistance can provide early warning of material disasters.

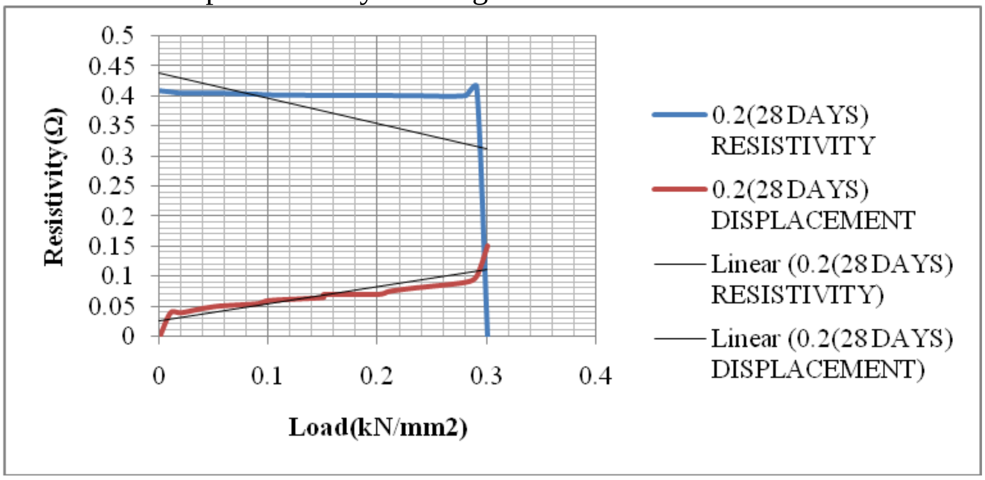

Figure 5 Change in electrical resistance under crosshead displacement control three-point bending in a mortar with 0.2% wt. of cement CNT

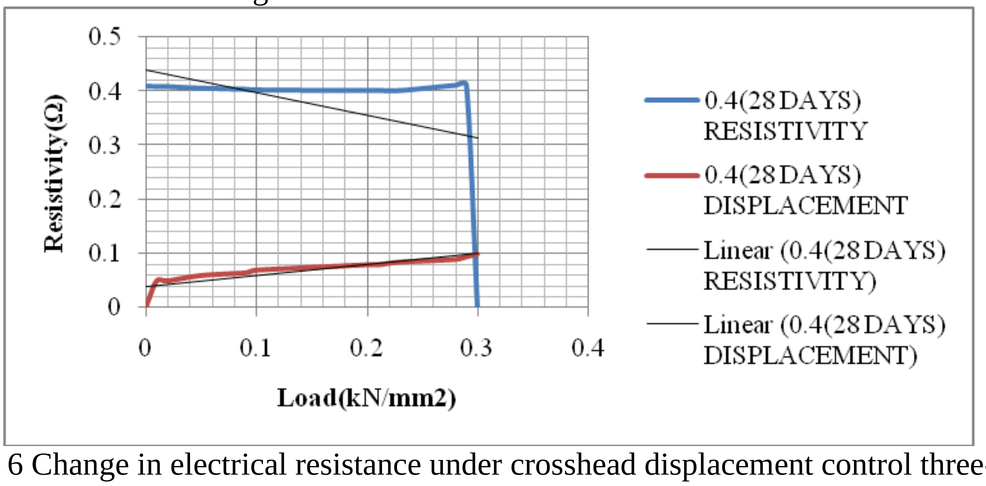

Figure 6 Change in electrical resistance under crosshead displacement control three-point bending in a mortar with 0.4% wt. of cement CNT

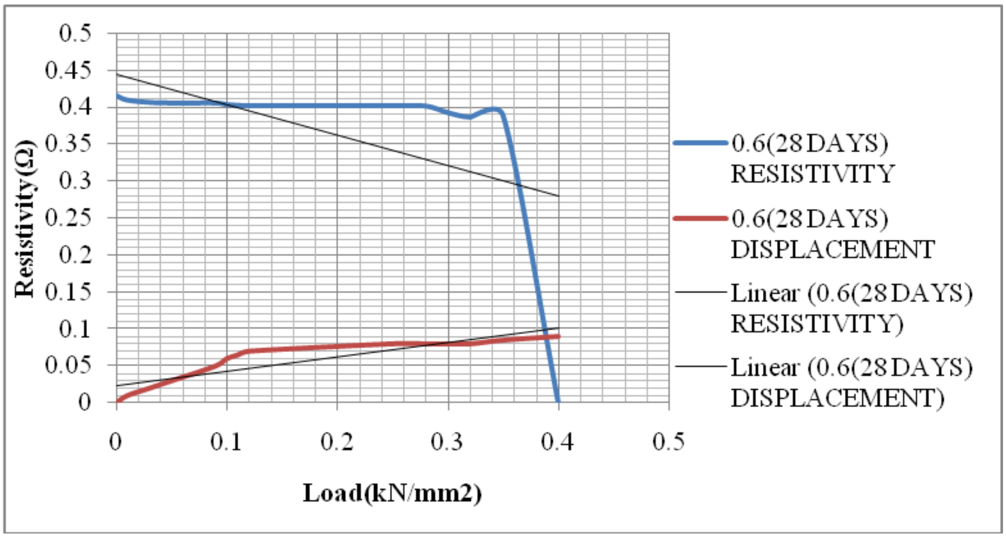

Figure 7 Change in electrical resistance under crosshead displacement control three-point bending in a mortar with 0.6% wt. of cement CNT

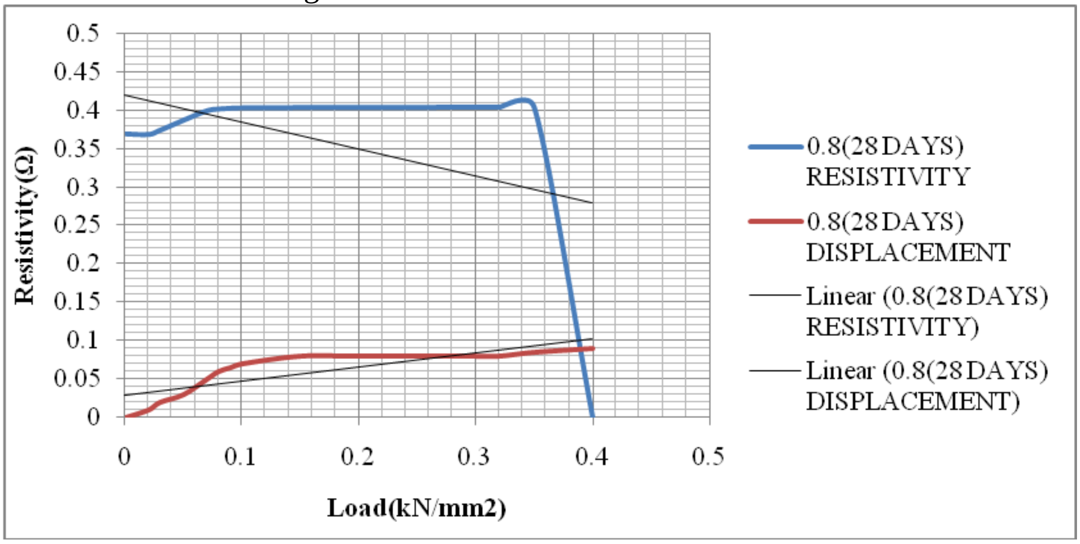

Figure 8 Change in electrical resistance under crosshead displacement control three-point bending in a mortar with 0.8% wt. of cement CNT

Various graphs show the corresponding change in electrical resistance along with the instantaneous three-point bending response, for mortars modified with carbon nanotubes at 0.2 %, 0.4%, 0.6%, 0.8% wt. of cement, respectively. Compared with CNT modified mortars, it has also been found that the sharp increase in resistance is related to reaching the maximum load carrying capacity of the material, thereby predicting the occurrence of catastrophic damage that leads to the final failure and the most recent result with the same type Nanotubes show high efficiency to improve bending response and resistivity response in mortar.

CONCLUDING REMARKS

The piezoresistive property of CNT/cement mortar was investigated in this study. Experimental studies on three points bending test reveals that CNT‘s damage sensing capability of embedded in mortar due to the sharp increase in resistivity. As the deflection increases the resistivity also increase. Just before the initiation of the crack the resistivity values are increasing abruptly which can be considered as the valuable warning signs to detect the deformation and damage. However, this study has limitation of dimensions, durability and small loading rate.

REFERENCES

[1] D. A. WHITING, M. A. NAGI, Electrical Resistivity of Concrete—A Literature Review," Portland Cement Association, Skokie, Illinois, USA.

[2] O. SENGUL, Use of electrical resistivity as an indicator for durability" Construction and Building Materials, Vol.73, 2014.pp , 434-441.

[3] F. RAJABIPOUR, J. WEISS, "Electrical conductivity of drying cement paste" Materials and Structures, Vol.40(10), 2007. pp 1143-1160.

[4] A. N. HANNA, "Concrete Ties for U.S. Railroads - An Update" Special Publication, 93. 2006.

[5] W. YEAH, J. J. CHANG, "A study on the efficiency of electrochemical realization of carbonated concrete" Construction and Building Materials, Vol. 19(7), 2005.pp 516-524.

[6] B. J. CHRISTENSEN, T. COVERDALE, R. A. OLSON, S. J. FORD, E. J. GARBOCZI, H. M. JENNINGS, T. O. MASON, "Impedance Spectroscopy of Hydrating Cement-Based Materials: Measurement, Interpretation, and Application" Journal of the American Ceramic Society,Vol.77(11), 1994,pp 2789-2804.

[7] S. IIJIMA, "Helical microtubules of graphitic carbon" Nature, Vol.354(6348), 1991, pp56-58.

[8] R. SIDDIQUE, A. MEHTA, "Effect of carbon nanotubes on properties of cement Mortars" Construction and Building Materials,Vol.50, 2014, pp116-129.

[9] A. G. RINZLER, J. H. HAFNER, P. NIKOLAEV L. LOU, "Unraveling Nanotubes: Field Emission from an Atomic Wire" Science, Vol.269(5230), 1995. pp1550-1553.

[10] N. S. LEE, D. S. CHUNG, I. T. HAN, "Application of carbon nanotubes to field emission displays" Diamond and Related Materials, Vol.10(2), 2001, pp265-270.

[11] R. ROSEN, W. SIMENDINGER, C. DEBBAULT, H. SHIMODA, L. FLEMING, B. STONER, O. ZHOU," Application of carbon nanotubes as electrodes in gas discharge tubes" Applied Physics Letters, Vol.76(13), 2000.pp1668-1670.

[12] H. SUGIE, M. TANEMURA, V. FILIP, K. IWATA, K. TAKAHASHI, F. OKUYAMA," Carbon nanotubes as an electron source in an x-ray tube,‖ Applied Physics Letters, Vol.78(17), 2001. pp.2578-2580.

[13] R. H. BAUGHMAN, A. A. ZAKHIDOV, W. A. HEER, ―Carbon Nanotubes-the route toward applications" Science, Vol.297 (5582), 2002. Pp.787-792.

[14] S. P. WU, X. M. LIU, Q. S. YE, L. I NING, “Self-monitoring electrically conductive asphalt-based composite containing carbon fillers” Transactions of Nonferrous Metals Society of China, Vol.16, 2006, pp512-516.

[15] B. HAN, G. QIAO, H. JIANG, “Piezoresistive response extraction for smart cement-based composites/sensors” Journal of Wuhan University of Technology-Mater. Sci. Ed., Vol.27 (4), 2012,pp 754-757.

[16] S. WEN, D. D. L. CHUNG, “Double percolation in the electrical conduction in carbon fiber reinforced cement-based materials” Carbon, Vol.45(2), 2007. Pp.263-267.

[17] S. WEN, D. D. L. CHUNG, “Damage monitoring of cement paste by electrical resistance measurement” Cement and Concrete Research, Vol.30(12), 2000, pp1979-1982.

[18] D.-M. BONTEA, D. D. L. CHUNG, G. C. LEE, “Damage in carbon fiber-reinforced concrete, monitored by electrical resistance measurement” Cement and Concrete Research, Vol.30(4), 2000, pp 651-659.

[19] Q. BARODAWALS, S. SHAH & S. SHAH, Modifying the strength and durability of self Compacting concrete using carbon nanotubes. Proceedings of International Conference on Advances in Construction Materials and Structures (ACMS-2018) IIT Roorkee, Roorkee, Uttarakhand, India, March 7-8, 2018, pp 120.

[20] Q. BARODAWALS, S. SHAH & S. SHAH Effects of Multiwall CNT on strength and durability properties of SCC Indian Concrete Journal, Vol.91, No4, 2017,pp 81-86.