Study of Strength Characteristics of Concrete by Using Carbon Nano-Fibre

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Abstract— Nanoscience and nanotechnology provide enormous opportunities to engineers the properties of materials by working in atomic or molecular level. It has not only facilitated to overcome many limitations of conventional materials, but also tremendously improved the mechanical, physical and chemical properties of the materials as well. Nanoscience has paved the way to tailor the properties of materials based on particular requirement by working in atomic or molecular level. In general, nanotechnology is not an isolated technology for certain purposes, but it is an enabling technology to achieve many goals by engineering a material at nano level. Similar to the fields like energy, medicine, electronics, etc., nanotechnology shows remarkable potentiality of its role to play by opening a new way to solve many of the perennial problems civil engineers do face every day. To develop high performance, multifunctional, ideal construction material, Cement composites with nano-additions have been vastly studied for their functional applications, such as strain and damage sensing. The capacity of a carbon nanofiber (CNF) cement paste has already been tested. However, this study is focused on the use of CNF cement composites as sensors in regular concrete samples. After reviewing various research papers, we found that carbon nano-fibre is a upcoming technology which is need to be used in construction. CNF with various percentages and its effect on the strength of structure is needed to be studied.

Key words: Carbon Nano Fbers (CNFs); Strain Sensing; Damage Sensing; Cement Composites

I. INTRODUCTION

The addition of specific particles to confer new properties is usually used to achieve additional functional applications to some materials. For several years, research interest has been focused on these so-called smart materials, i.e., materials which have the capability to respond automatically to certain external stimuli. Among these composites, cement-based materials have played a crucial role in construction and civil engineering industries. In the particular case of multifunctional cement composites, multifunctionality is achieved by taking advantage of the structural material itself to develop nonstructural functions, without the need of any type of external device. In order to obtain these multifunctional properties, cement materials should be combined with specific conductive admixtures that provide the new composite with a new range of functional applications, while mechanical properties are maintained or even improved. Hence, cost would be reduced, as design will be simplified minimizing the use of embedded devices. The present work is particularly aimed at the use of cement-based composites as strain or damage sensors in concrete elements. The strain sensing capacity of a material is determined by the response to its electrical resistivity in relation to the mechanical stresses applied to it. If a unidirectional compressive stress is applied, the electrical resistance in that direction is proportionally reduced. However, the electrical response would be the contrary if the material was tensioned, i.e., an increase in the resistance will be registered. Both effects are reversible in the material’s elastic range. Hence, electrical changes will be reversible if loads are removed. This application of cement composites is interesting for structural service state monitoring, room occupancy control, or vehicle weighing. On the other hand, a damage sensing mechanism begins at the yielding point, corresponding to the material’s plastic behaviour, and can be detected as irreversible changes in the electrical resistivity. The self-sensing properties (strain or damage) of cement composites have been studied for different carbon admixtures: carbon fibers, CNFs, CNTs, or graphene. The strain sensing response depends on the electrical conductivity of the composite, its water saturation degree, the type of electrical measure, or the curing age of the material. Besides all the characterization of the sensing phenomena made using small specimens, there are some studies that implement these cement sensors in full-scale structural elements. In order to implement these multifunctional composites in the structural monitoring system, a way is decided or derived. The concrete specimen should be moulded with mix containing 5% of CNF to introduce good conductivity and a simple designed circuit will be connected to it to measure the change in current and resistance. That will lead to the calibration of resistance to the load on the concrete. The aim of the present work is to study strain sensing and damage sensing properties on CNF cement pastes, which have already been proven useful for other applications. Sensors made in this CNF cement paste were attached to concrete elements, which were loaded only in compression. Therefore, the strain or damage level of the concrete was monitored by the electrical resistance changes in the CNF sensors. Another aim was to address different technical issues, the solutions of which are necessary for the practical implementation of this monitoring system. For example, the electrical resistivity changes related to different water saturation conditions are considered here. Finally, different experimental configurations to monitor the electrical resistivity of each sensor are evaluated.

II. TEST TO BE CONDUCTED

A. Strain gauge test on concrete

The installation of strain gauges for concrete structures presents several unique challenges to the installer, whether measurements are made on the concrete surface or within the concrete, or on reinforcement bars within the structure. For example, special preparation is required to ensure that strains on the irregular surface of the concrete are fully transmitted to the strain gauge provisions are necessary to protect the installation from mechanical damage during fabrication and from the hostile environment of the concrete itself. Normal procedures should be followed for bonding the gauge to the prepared gaging surface. Special notice should be paid to several points, however. First, the gauge length of strain gauges used on concrete should be at least 5 times the diameter of the largest aggregate in the concrete. This often results in the use of patterns with gauge lengths of 1 in (25 mm) or more. Strain Gauge Installations for Concrete Structures strains in aggregate materials, and is fully encapsulated in a polymer concrete material to closely match the mechanical properties of typical structural concrete, guard against mechanical damage, and to protect against moisture and corrosive attack.

B. *Concrete compression test*

Cubical moulds of size 15cm x 15cm x 15cm are commonly used. The concrete is poured in the mould and tempered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are kept in water for curing. The top surfaces of these specimens are made even and smooth. It is done by putting cement paste and spreading smoothly on whole area of specimen. When the specimen completes its curing period, those cubes are taken for compression test with whole setup. The specimen was kept under UTM and system is taken online. Then the load is allowed to increase. Before this all data needed for result are entered. Then system senses the load and the maximum load where the cube cracked. With this process, in parallel the strain test and the reading of circuit are taken.

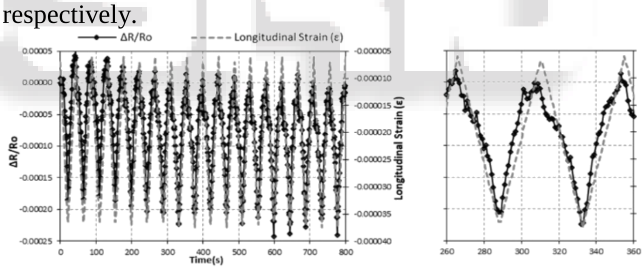
C. *Electric resistivity*

Considering any conductor which have free electron to flow and allow electricity to pass through it, defines its property of conductance. A conductor offers a fix resistance in a constant environment but with the change of temperature or pressure the free electron goes under changes in its state of energy which disturbs the resistance offered by it. When the concrete specimen goes under compression the pressure increases and the resistance offered by CNF reduces and it eases the flow of electricity. These fluctuations are happening on a very small scale which may be observed in mA and mV. In this, the arrangement of circuit is so simple we were just recording the changes in current while the supply was constant (AC). In this we will we recording the changes in resistance/current with the change in load.

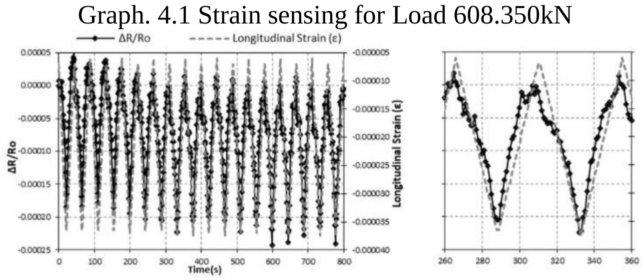
III. EXPERIMENTATION

A. *Strain Sensing Tests*

The maximum load and the longitudinal strain (ε) of the concrete sample are included. The maximum load applied was applied, was 608.350 kN and 625.500 kN for Graph 4.1, 4.2 respectively. The strain-sensing 608.350 kN and 625.500 kN for Graph 4.1, 4.2 respectively. The strain-sensing capacity of the capacity of the sensors (at different loading levels) is confirmed by the similarities between both sensors (at different loading levels) is confirmed by the similarities between both curves. Figure 4.1, Fig 4.2. Strain sensing tests results, resistance change, and longitudinal strain curves (7th & 8th cycles cycles zoom on the right) for compression cycles up to 608.350 kN and 625.500 kN for Figure 4.1, 4.2 respectively.



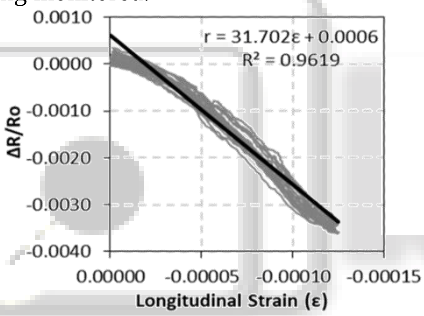
Graph. 4.1 Strain sensing for Load 608.350kN



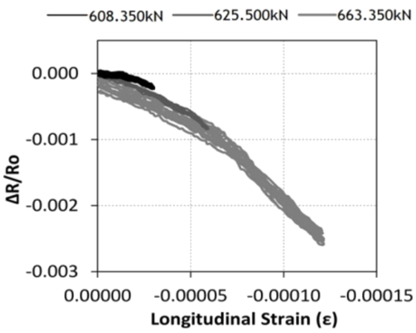
Graph. 4.2 Strain sensing for Load 625.500kN
Source :Nanomaterials 2017, 7, 413 Paper [7]

$$K = \frac{\frac{\Delta R}{R_o}}{\varepsilon} \approx \frac{\frac{\Delta \rho}{\rho_o}}{\varepsilon}.$$

The results of the sensing tests were plotted as resistance change vs. strain curves (instead of time history) the curves are shown in Graph 4.3. Each curve in Figure 4.3.1 represents different nanomaterial cycles up to a certain stress level. Similar trends can be observed regardless of the results of the sensing tests were plotted as resistance change vs. strain curves (instead of the actual maximum stress. For comparison purposes, the sensitivity of these sensors can be defined the results of the sensing tests were plotted as resistance change vs. strain curves (instead of time history functions), and the curves are shown in Graph 4.3. Each curve in Graph 4.3.1 represents by the gage factor (K) as the ratio between the fractional resistance change (ΔR/Ro) and the strain (ε), time history functions), and the curves are shown in Graph 4.3. Each curve in Figure 5a represents different cycles up to a certain stress level. Similar trends can be observed Equation (2), in which resistance or resistivity (Δρ/ρo) changes can be considered equivalent, as stated different cycles up to a certain stress level. Similar trends can be observed regardless of the actual maximum stress. For comparison purposes, the sensitivity of these sensors equivalent, as stated in previous research [1]. Graph 4.3.2 includes all experimental results obtained by the same sensor after testing under different loading. However, in these tests, strain gages were also attached to the sensors themselves, showing differences between electrical behaviour was observed, as in the aforementioned tests with constant amplitudes. However, in these tests, strain gages were also attached to the sensors themselves, showing differences between strain levels on the concrete specimens and CNF sensors. The size of the sensors (1 cm thick and 10 cm long).Therefore, sensor strains were 40% lower than the actual strain values of the concrete sample being monitored.



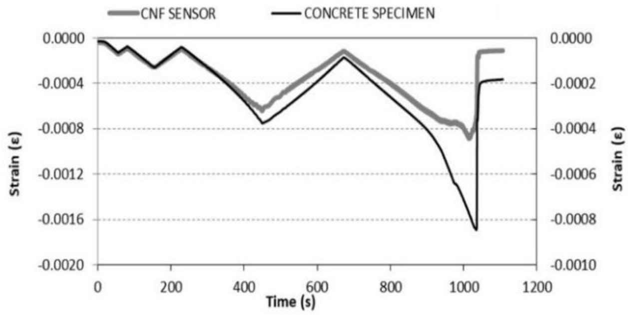
Graph. 4.3.1 R vs Long. strain



Graph4.3.2 Curves and linear regression for sensors

B. Compression Test

Graph 4.4 shows the stress–strain curves for two different damage tests, where stress was applied to the concrete specimen in accordance to the setup detailed in the Material and Methods section above. Concrete specimen strain was registered every second during the tests by means of two strain gages adhered to the concrete surface. In black, the elastic range (the first two cycles and part of the third) is denoted, as well as the equation obtained by regression analysis and R2 value. As expected, after the elastic range, hysteresis can be clearly observed.



Graph 4.4 Resistance change and longitudinal strain for sensing test

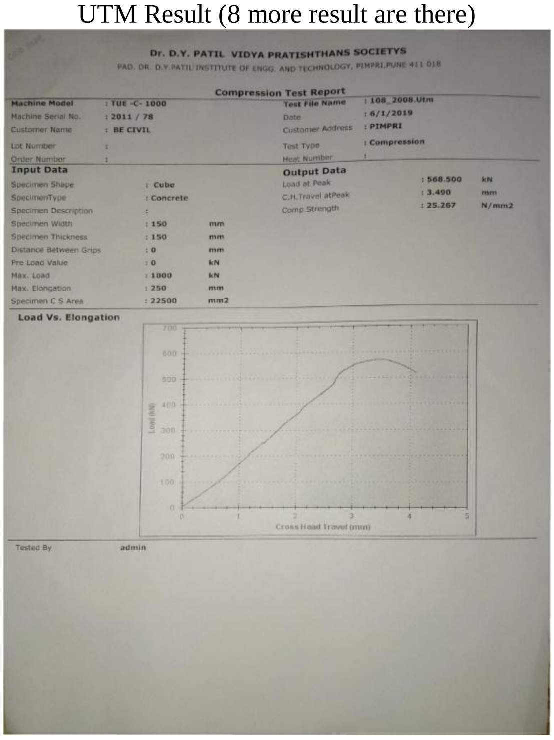
Source research paper[7]

The strain axis ranges have been modified so that the correspondence of both results can be easily observed. As expected, the deformation of the concrete specimen was transmitted to the sensor and as the Young's modulus is different, both strains are proportional during the elastic range. After surpassing the elastic range, strains do not proportionally match. As observed in the strain sensing tests, the strain of the sensor is approximately 60% of the concrete specimen during the elastic range (first and second cycles and part of the third

Age in days	Weight In kg	Load in KN	Strength In N/mm2	Avg In N/mm2
	8.28	608.1	27.03	
	8.65	625.0	27.80	
7	8.79	625.5	27.77	27.53
	8.86	663.3	29.48	
	8.28	663.9	29.90	
14	8.91	568.5	25.26	28.21
	8.76	688.1	30.58	
	8.69	568.5	25.26	
28	8.80	688.1	30.58	28.80

Table No. 1 Details of specimen with compression

UTM Result (8 more result are there)


Dr. D.Y. PATIL VIDYA PRATISHTHANS SOCIETYS
PAD. DR. D.Y.PATIL INSTITUTE OF ENGG. AND TECHNOLOGY, PIMPRI,PUNE 411 018

Compression Test Report

Machine Model	: TUE -C- 1000	Test File Name	: 108_2008.Utm
Machine Serial No.	: 2011 / 78	Date	: 6/1/2019
Customer Name	: BE CIVIL	Customer Address	: PIMPRI
Lot Number	:	Test Type	: Compression
Order Number	:	Heat Number	:

Input Data

Specimen Shape	: Cube	
SpecimenType	: Concrete	
Specimen Description	:	
Specimen Width	: 150	mm
Specimen Thickness	: 150	mm
Distance Between Grips	: 0	mm
Pre Load Value	: 0	kN
Max. Load	: 1000	kN
Max. Elongation	: 250	mm
Specimen C S Area	: 22500	mm2

Output Data

Load at Peak	: 568.500	kN
C.H.Travel atPeak	: 3.490	mm
Comp.Strength	: 25.267	N/mm2

Load Vs. Elongation

Load (kN)
Cross Head Travel (mm)

Tested By admin

IV. OBSERVATIONS FROM THE TESTS CONDUCTED

A. *Strain Sensing Tests*

Strain sensing sensitivity of CNF cement pastes has been previously studied in standard samples. The main results of this work highlighted an influence of the maximum load the composite's sensitivity to its own strain. Gage factors were measured in the range between 15 and in the composite's sensitivity to its own strain. Gage factors were measured in the range between 50 depending on the CNF dosage and the maximum stress applied. This effect has also been observed been Both functions became steeper for increasing strain values, and gage factors consequently presented lower slope values (i.e., lower gage factor, hence lower sensitivity) if strains were lower increased. Therefore, the gage factor differences between results in Figure 8 (stress up to 10 MPa) and then 25 με. Both functions became steeper for increasing strain values, and gage factors consequently Figure 2 (stress lower than 5 MPa) can be explained by this stress effect on the sensing capability of increased. Therefore, the gage factor differences between results in Figure 8 and Figure 2 (stress lower than 5 MPa) can be explained by this stress effect on the sensing capability of these composites. These results point to a proper performance of the sensors, as their general behaviour matches previously detected trends in CNF paste specimens axially loaded. However, for a real application of these sensors, some issues should first be addressed. For example, strain differences between the monitored element and the sensor are indicated in Figures. Therefore, a particular calibration of each sensor for the service structure should be made prior to putting the system in motion. Nevertheless, the fore mentioned results present good linear regressions despite the exact gage factor value, which will depend on relative sensor–structure proportions and geometries or bonding properties. The possibility of embedding the sensors may be an alternative for the real application of these sensors in concrete elements. This technique may solve the strain transmission problems and guarantee more stable humidity conditions. Thus, the resistivity changes due to humidity changes in CNF pastes (as shown in Table 1) can be controlled.

B. *Compression Tests*

After the feasibility of 5% CNF cement paste as sensors capable of sensing the deformation of structural elements (cube concrete specimen with dimension of 15 cm× 15 cm x 15 cm, placed with its axis in a vertical plane), the capability of sensing structural damage was analysed as sensors capable of perceiving structural damage (by simple compression loads). The variation in the electric resistance change of the sensor is proportional, in the elastic range, to the strain of the sensor and to the strain of the concrete specimen. Similar to other studies, after the elastic range was overpassed, the electric resistance change (ΔR/Ro) changed from a straight line to a curve, whose curvature increases as stress increases. This phenomenon was also observed in, where a strain up to 0.008 at the moment of rupture was observed, whereas in our study of adhered sensors, rupture strain was around 0.000400. Obviously, the Young's modulus of the sensor is lower than that of the concrete specimen. This behaviour is important as it could be used to determine, not only the shift from the elastic range to the plastic range but also the proximity to rupture. In any case, due to this strain difference between sensor and structure, CNF sensors did not show great changes in their resistivity, as have other CNF or carbon fibre cement composites at higher strain levels. Therefore, these attached sensors can practically measure the strain of the support directly, even for states close to the material's failure, even though no damage sensing mechanism is triggered.

C. *Some of the Advantages from the Above Results*

a) This project will offer a way to estimate the strength of the structure under load condition practically and easily.
b) This setup will show the change in strength of columns without destroying the structure.
c) This project introduces a new way of compression test in real time option.
d) Reduction in size and weight of the conventional devices
e) Give a better result in 5% CNF

V. CONCLUSION

Under uniaxial compression loads sensors were working properly with 5% CNF cement pastes, capable of sensing the strain of the structure, in the elastic range. It is also necessary that such sensors should be previously calibrated due to problems of strain transmission to the concrete structure. After all these experiment and study of other research papers, the regression analyses using third degree polynomials, compared to the linear gauge factor, result in a more accurate approach to the strain sensing of cement pastes. However, a more complex physical interpretation is required. This system will must result properly when a proper circuit system will be designed and the the property of conductance offered by CNF would be used more properly. The calibration was a hard part of the result recording, which should be done more carefully.

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