Indian Journal of Science and Technology, *Vol 9(23), DOI: 10.17485/ijst/2016/v9i23/95869, June 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Self Sensing Concrete using Carbon Fibre for Health Monitoring of Structures under Static loading

K. S. Sathyanarayanan* and N. Sridharan

Department of Civil Engineering, SRM University, Chengalpattu, Kancheepuram District - 603203, Tamil Nadu, India; srm.kssn@gmail.com, nsridhar1949@gmail.com

Abstract

Background/Objective: To find an easy method to health monitor structures. **Method:** Self sensing or smart behavior has been observed in mortar or concrete with the addition of small amounts (0.2 to 0.5% by volume of cement) of short (5mm length) carbon fibres. It is seen that there is an increase in electrical resistance on loading upto crack propagation or fracture. On reaching the inelastic stage, the resistance change is not reversible. **Findings:** A method is developed which can be used in place of, often used strain gage technique or fibre optic technique for health monitoring of structures. There is an increase in resistance during fibre pull out in the elastic range. The change in elastic resistance was measured by a four probe method and was seen to be reversible for elastic deformation. Also, the crack propagation and fibre breakage of the specimen can be identified by irreversible resistance change. The stress vs strain and resistance vs strain graphs when plotted show similarity. **Application:** This phenomenon can be made use of to find the real time weight of vehicles in traffic and finding stress values of a loaded structure etc.

Keywords: Carbon Fibre, Health, Monitoring, Resistance-Strain, Sensor, Stress-Strain

1. Introduction

Engineers are often confronted with twin objects of identifying proper methods for the evaluation of stresses in structures and also to check that they are cost effective. The requirements to have smart materials and sensors for non destructive health monitoring are ever increasing due to the necessity to monitor in real time the critical structures like bridges, nuclear vessels, chemical storages etc[1–4].

The sensors are required to sense cracks in real time during static and dynamic loading for damage assessment[5–7] with consequent action plan for remedies. They are further required to be low cost for instrumentation of huge structures. The existing sensors like strain gauges, fibre optic gauges, piezo electric, acoustic emission, Bragg grating etc., are not only costly but also suffer from poor durability and the requirement of trained personnel, transportation and erection problems. They also require expensive peripheral equipment like electronic and laser equipment.

But in this present experimental programme with carbon fibre, carbon fibre itself is a sensor and does not require additional equipment except for a few simple instruments.

Voltage and current were measured from the loaded specimen from which the electrical resistance was computed. The instruments used were normally available voltmeter, ammeter and a regulated D. C. power supply. Dial gages were used for measuring the deflections. In this present experimental procedure, experiments were conducted by casting mortar cubes with an addition of 0.24% of carbon fibre for increasing electrical resistance along with methyl cellulose, silica fume[8] for enhancing fibre dispersion, silica fume for enhancing fiber matrix bonding and Water reducing admixture naphthalene sulfonic acid for enhancing workability since the usage of carbon fibre decreased the slump.

2. Review of literature

The influence of carbon fiber as a smart material was

** Author for correspondence*

developed by (1), the application of carbon fiber as a smart material for damage assessment and for static and dynamic loading (4) and carbon fiber reinforced cement as a strain sensing coating investigated[9].

3. Research Significance

Though the earlier authors studied carbon fibre concrete as a smart material[10], the relative performances of Latex, Methyl Cellulose and Silica Fume were not studied in detail. Hence the present work aims at their relative performances.

4. Objective and Scope

The objective and scope of the present work is to cast cubes and do the comparisons of 7, 14, 28 days curing, and study difference between 50mmx50mmx50mm and 70mmx70mmx70mm cubes, find the difference in winding copper wires along and perpendicular to the stress axis, study the effect of addition of methyl cellulose, carbon fibre and silica fume and get their stress Vs strain and Resistance Vs strain graphs and compare their performances.

5. Exerimental Work

5.1 Smart Behavior of Carbon fibre

Experiments were conducted to assess the smart behavior of carbon fibres. Unlike other sensors like strain gauges, fibre optic gauges etc. Carbon fibre due to its smart property namely to conduct electricity, acts as a self sensing material and senses resistance changes. Hence it senses elastic resistance change and inelastic failures. Also carbon fibre possesses high flexural strength which is an added advantage.

5.2 Experimental Programme

Cement mortar cubes were cast to characterize the effect of carbon fibre and its combinations with mortar.

Mortar with carbon fibre, Silica fume, methyl cellulose. (The carbon fibres used were of nominal length of 5mm and weighing 0.24% by volume of cement).

5.3 Mix Procedure

For the mortar containing methyl cellulose (0.4% by weight of cement), methyl cellulose was dissolved in water. After this, carbon fibre, the defoamer (0.13 volume percent) and the fibres were stirred by hand for 2 minutes. Then this mix, cement, sand, and water were mixed in the mixer for 5 minutes.

5.4 Curing Procedure

The specimen cubes were demolded after one day and allowed to cure at room temperature for 7 days[11–13].

5.5 Testing Procedure

For Compression testing, specimens were prepared by using 70mmx70mmx70mm and 50mmx50mmx50mm size. During compressive testing upto fracture the strain was measured by the cross head displacement in a Servo displacement controlled UTM 100T capacity (Figure 3). Voltage input from a Regulated Power Supply (R.P.S.) was given to the cube using four probe method (Figure 2) and the current output and voltage output were measured using a voltmeter and an ammeter and the fractional change in resistance computed at each loading stage. Prior to the test, cubes were painted in four layers with silver paint at a interval of 10 mm. Copper wires were wound around the layers and these were connected to the R.P.S., voltmeter and ammeter (Figure 1). The middle two copper wires from cube were connected to the two probes of the voltmeter. The positive end of ammeter was connected to positive end of R.P.S and negative end of R.P.S was connected to one end of cube. The negative end of ammeter was connected to another end of Cube. This is the four probe method of measuring resistance. From the voltage and current values obtained at each stage of loading, the resistance is calculated. The outer two contacts give the current value in ammeter and the middle two contacts in voltmeter give the voltage. Resistance was computed using

$$R=E/I \qquad (1)$$

Testing was performed in different cycles of loading in fractions of KN, upto failure and the readings were taken at each stage.

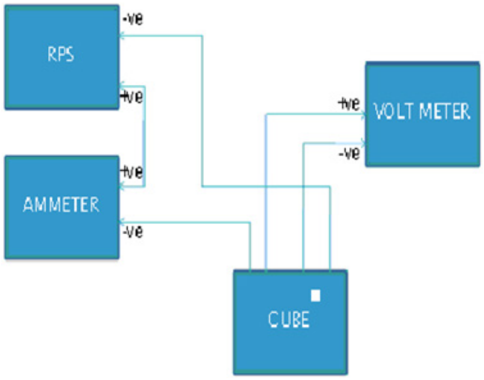

Figure 1. Compressive test of cube.

Figure 2. Four probe method.

Figure 3. Cube-compressive failure.

6. Results and Discussion

The results plotted are shown in Figures. 4, 5, 6, 7, 8, 9 and 10 from compression test for the cases of 1. Difference between 50 mmx50 mmx50 mm and 70 mmx70 mmx70 mm cubes 2. Copper wires are wounded in along and perpendicular to the stress axis. 3. Comparisons of 7, 14, 28 days curing. It is seen from the plots that the results in case 1. 50mm cube is much better than 70 mm cube because the cube size is minimum due to threshold value. In case 2. 50 mm cube with copper wires wounded along stress axis is better than wires wounded in perpendicular to stress axis. In case 3. 50 mm cube with 7 days curing is better than the 14 and 28 days curing. It essentially means that it is quite possible to predict the stress values in the field using the carbon fibre, silica fume and methyl cellulose combination It is also seen that once the stress vs strain and Resistance vs Strain (R-Ro/Ro where Ro is the initial resistance) graphs are drawn using a cube compression test, Field experiments can be conducted to get actual stress values. Thus health monitoring of structures can be carried out using this simple procedure.

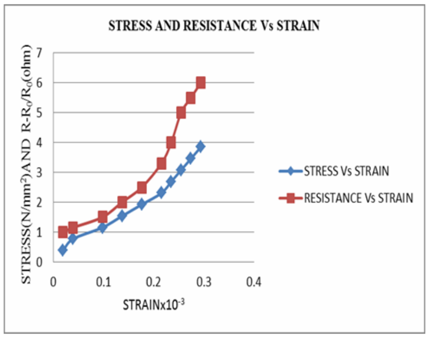

Figure 4. Carbon fibre, methyl cellulose and silicafume (50x50x50 mm).

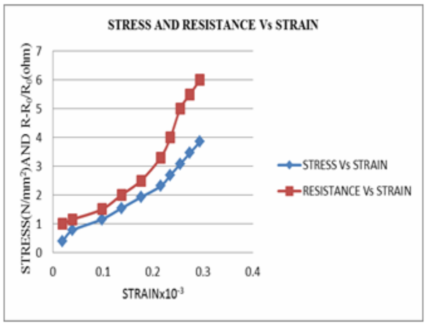

Figure 5. Carbon fibre methyl cellulose and silica fume (70x70x70mm).

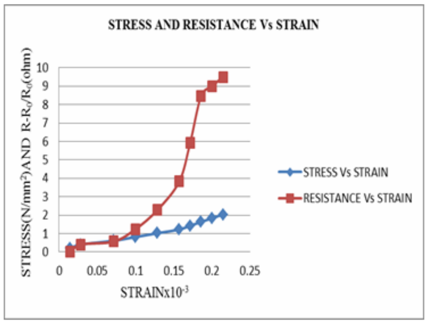

Figure 6. Carbon fibre, methyl cellulose and silica fume (along stress axis).

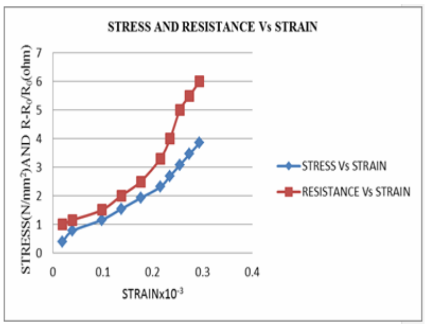

Figure 7. Carbon fibre, methyl cellulose and silica fume (perpendicular to stress axis).

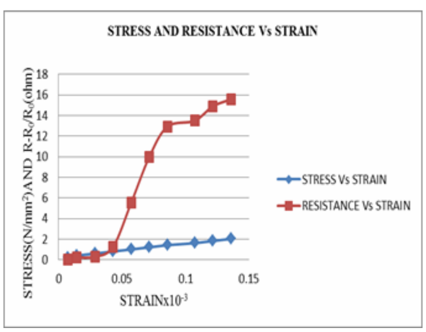

Figure 8. Carbon fibre, methylcellulose and silica fume (7 days curing).

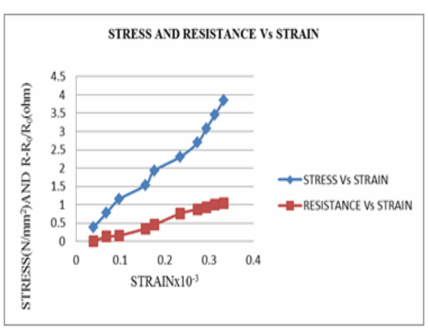

Figure 9. Carbon fibre, methyl cellulosen and silica fume (14 days curing).

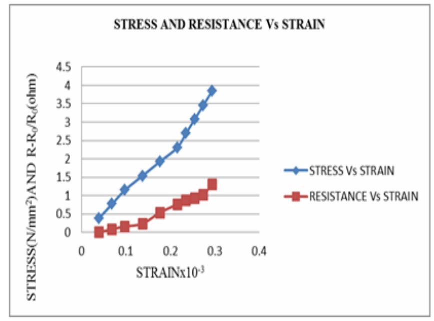

Figure 10. Carbon fibre, methyl cellulose and silica fume (28 days curing).

6. Conclusion

By investigating the Case (1), Case (2), Case(3), 50 mm cube with copper wires wounded in along the stress axis and also with 7 days curing is better than the other mixes.

7. Acknowledgement

The first author wishes to express sincere thanks to “SRM University” for providing all the facilities to carry out this work.

8. References

1. Chen PW, Chung DDL. Carbon fiber reinforced concrete for smart structures capable of non-destructive flaw detection.Smart Mater. Struct. 1993; 2:22–30.
2. Chen PW, Chung DDL. Improving the electrical conductivity of composites comprised of short conducting fibers in a conducting matrix: The addition of a non-conducting particulate filler. Journal of Electronic materials. 1995; 24(1):47–51.
3. Chen PW, Chung DDL. Concrete as a new strain/stress tensor. Composites. 1996; PartB(27B):11–23.
4. Chen PW, Chung DDL. Carbon fiber reinforced concrete as an intrinsically smart concrete for damage assessment during static and dynamic loading. ACI Materials Journal. 1996 Jul-Aug.
5. Wen S, Chung DDL. Electrical resistance-based damage self-sensing in carbon fiber reinforced cement. Carbon. 2007; 45(4):710–6.
6. Wen S, Chung DDL. Effects of strain and damage on strain sensing ability of carbon fiber Cement. Journal of materials in civil Engineering. ASCE. 2006 May/Jun; 18(3):355–60.
7. Wen S, Chung DDL. Piezo resistivity-based strain sensing in carbon fiber-Reinforced cement. ACI Materials Journal. 2007 Mar-Apr.
8. Chung DDL. Dispersion of short fibers in cement. Jour-

nal of Materials in Civil Engineering ASCE. 2005 Jul-Aug; 17(4):379–83.

9. Chung DDL. Carbon fibre reinforced cement as a strain sensing coating. Cement and Concrete Research. 2001; 31:665–7.
10. Wang X, Fu X, Chung DDL. Strain sensing using carbon fiber. Journal of Materials Research. 1999 Mar; 14(3):790–802.
11. Fu X, Chung DDL. Effect of curing on the self monitoring behavior of carbon fiber reinforced mortar. Cement and Concrete Research. 1997; 27(9):1313–8.
12. Wen S, Chung D D L. Effect of moisture on pisoresistivity of carbon fiber-reinforced cement paste, ACI Materials Journal. 2008 May-Jun; 105(3):274–80.
13. Li H, Ou J. Smart concrete sensors and self-sensing concrete structures. Key Engineering Materials. 2009; 400–2:69–80.