Sensing Behaviour of Concrete with Smart Fillers

Jestine Augustine
Dept. of Civil Engineering
Saintgits College of Engineering
Kottayam, Kerala, India

Sneha M Varghese
Dept. of Civil Engineering
Saintgits College of Engineering
Kottayam, Kerala, India

***Abstract*— Self-sensing concrete has the capability to sense the conditions itself such as crack, damage, strain, deformation etc. through incorporating functional fillers or sensing component. It is also known as self-monitoring or self-diagnosing concrete. Here conductive fillers are going to be incorporated as additives to concrete. The conductive fillers using in this study are nanomaterials such as multi-walled carbon nanotube, carbon black. The preliminary test of cement and aggregates were done. Mix is fixed based on the workability tests and compressive strength tests as per IS 10262:2009. Electrical resistivity of concrete cube specimens with and without conductive fillers were measured. The cube specimens with conductive fillers showed good change in electrical resistivity response than control cube specimens, under the application of load. Electrical resistivity, change in electrical resistivity due to the application of load of specimens incorporated with different conductive fillers are to be evaluated.**

Keywords—self-sensing concrete, self-diagnosing, Graphene, electrical resistivity

I. INTRODUCTION

Structural Health Monitoring is relevant in Civil Engineering nowadays to ensure the health of the structures which has several applications which includes bridges, parking structures, buildings, nuclear facilities, grain terminals, hydro-electric structures and dams. It has various benefits such as early warning of future damages, proof of structure performance, extended life of structure, reduces maintenance costs etc. At present, it is done using external sensors attached on the structural elements which are connected to manipulating hardwares.

Self-sensing concrete is the type of smart concrete which can sense the failures in the structure by itself without the help of external sensors. Smart conductive fillers are incorporated in bricks, concrete etc. to self-sense the conditions inside it and environmental change including stress (or force), strain (or deformation), crack, damage, temperature, and humidity through incorporating functional fillers or sensing component. Early time sensing of cracks and damages increases the safety situations and service life of the concrete structures. Here, the use of external sensors can be avoided. Hybrid additives with different conductivity are used and the self-sensing concrete can be used in the field of traffic detection. The damages and Cracks can be easily found out during the entire life span of structures as the conductive fillers are used as additives. It is Multifunctional concrete which is beneficial in sensing as well as structural properties.

The self-sensing concrete is used over traditional NDTs in the recent years as it can be used in curved or arch shaped structures also it is used as a real time monitoring system in very damage prone or important areas.

The main objectives of the study were

• To measure the electrical resistivity of the specimens with conductive filler

• To assess the change in electrical resistivity due to the application of load.

II. MATERIALS USED

A. Cement

The cement used for the work is Portland Pozzolana Cement (PPC) – 53 Grade. The details are tabulated in Table 1 below.

Table 1: Properties of Cement

Properties	Results
Type of cement	PPC 53 grade
Standard Consistency (%)	29
Specific gravity	2.9

B. Fine Aggregate

Manufactured Sand (M-Sand) is used for the work which is conforming to the requirements of IS 383. It is having aggregate size ranging from 4.75mm to 150microns. The details are tabulated in Table 2 below.

Table 2: Properties of Fine Aggregate

Properties	Results
Type of fine aggregate	M Sand
Specific gravity	2.78
Zone	II

C. Coarse Aggregate

Coarse aggregate used for the work is conforming to the requirements of IS 383 and is having aggregate size ranging from 20 mm to 4.75 mm. The details are tabulated in Table 3 below.

Table 3: Properties of Coarse Aggregate

Properties	**Results**
Water Absorption	0.5
Specific gravity	2.5

D. Water

Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalies, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel. It is an important ingredient of concrete as it actually participates in the chemical reaction with cement termed as hydration of cement. Since it helps to form the strength giving cement gel, the quantity and quality of water are required to be looked into very carefully. Potable water is generally considered satisfactory for mixing concrete.

III. MIX DESIGN

As per IS 10262: 2009, a mix proportion is suitably designed based on the material properties of the ingredients in concrete such as specific gravity, water absorption of aggregates, cement and based on the minimum requirements of the final concrete.

The mix proportion obtained for M20 concrete is **1:1.879:2.6**. The details of mix design are tabulated in Table 4.

Table 4: Details of Mix Design

Description	**Results**
Design Mix	1:1.9:2.6
Water-Cement Ratio	0.49
Cement (kg/m^3)	390
Fine Aggregate (kg/m^3)	733
Coarse Aggregate (kg/m^3)	1015
Water (l/m^3)	191

IV. TEST ON FRESH AND HARDENED CONCRETE

Test results on fresh and hardened concrete are shown in table 5.

Table 5: Test Results of Fresh and Hardened Concrete

TESTS ON FRESH CONCRETE	
Slump Value	100 mm
Compaction Factor	0.8
TESTS ON HARDENED CONCRETE	
7th day Average Compressive Strength	18.89 N/mm²
14th day Average Compressive Strength	24.8 N/mm²

V. EXPERIMENTAL INVESTIGATION

Cube specimens with different conductive fillers at different percentages were casted as per the mix design and tested to find the optimum percentage which shows good resistivity response

A. Mixing

For proper mixing of fillers with cement and to avoid agglomeration of nano-materials mechanical mixer was used. Manual mixing imparts agglomeration of nanomaterials. Planetary mixer used for the mixing is shown in Figure 1.

Fig. 1: Planetary Mixer used for mixing

B. Specimen Details

Cube specimens with size 150 mm x 150 mm x 150 mm were casted. Copper rods with 6 mm diameter were used as electrodes.

Fig. 2: Cube Specimens

i. Control Specimens

Cube specimens without any conductive fillers were casted and tested.

ii. Multi-Walled Carbon Nanotube (MWCNT) Specimens

Cube specimens with different percentages of MWCNT were casted and tested. The specimen notations of MWCNT specimens is shown in Table 6

Table 6: MWCNT added Cube Specimens

NOTATION	MWCNT Percentage with respect to weight of cement (%)
A1	0.2
A2	0.3
A3	0.4
A4	0.5
A5	0.6

iii.Carbon Black (CB) Specimens

Cube specimens with different percentages of CB were casted and tested. The specimen notations of CB specimens are shown in Table 7.

Table 7: CB added Cube Specimens

NOTATION	CB Percentage with respect to weight of cement (%)
B1	0.5
B2	1
B3	2
B4	3
B5	4
B6	5
B7	6
B8	7

iv. Hybrid Specimens

Cube specimens with different optimum percentages of MWCNT and CB were casted and tested. The specimen notations of hybrid specimens are shown in Table 8.

Table 8: Hybrid Cube Specimens

NOTATION	CB (%)	MWCNT % w.r.t wt. of cement
C1	2	0.5
C2	2	0.6
C3	4	0.5
C4	4	0.6

C. Test Setup

Compression Testing Machine was used for the testing of concrete cubes. LCR meter was used for the measurement of resistance of specimens. The test setup is shown in Figure 3.

Fig. 3: Test Setup using LCR meter

VI. RESULTS AND DISCUSSIONS

A. Control Specimens

The load v/s resistance graph obtained for control specimens are plotted in Figure 4.

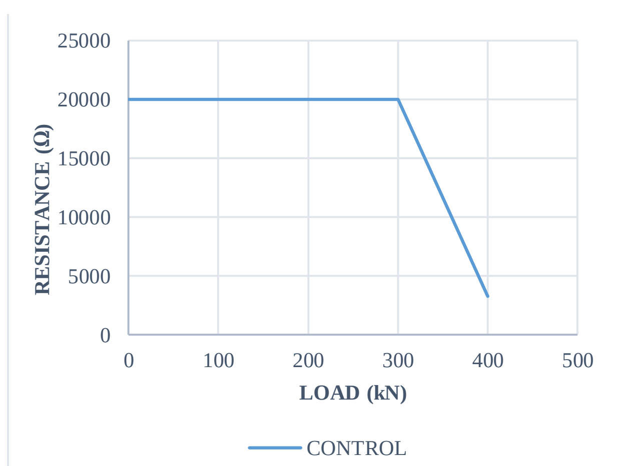

Fig. 4: Control Specimen load v/s resistance graph

B. MWCNT Specimens

Specimens were tested after 7 day curing and the results obtained for MWCNT specimens are plotted in Figure 5.

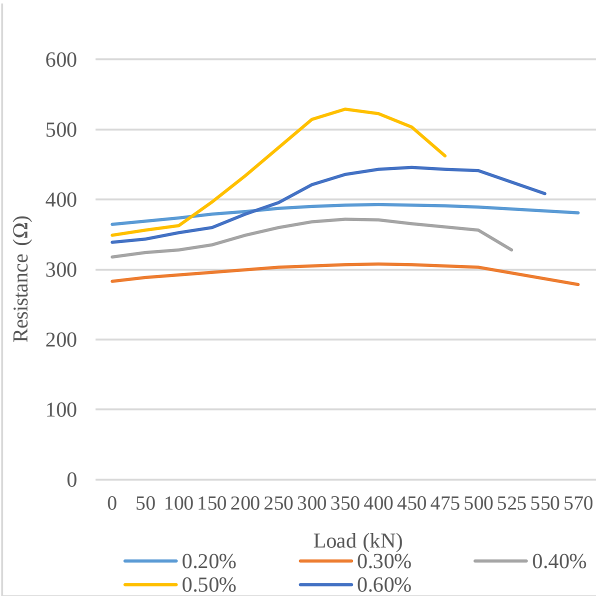

Fig. 5: MWCNT Specimens load v/s resistance graph

C. CB Specimens

Specimens were tested after 7 day curing and the results obtained for MWCNT specimens are plotted in Figure 6.

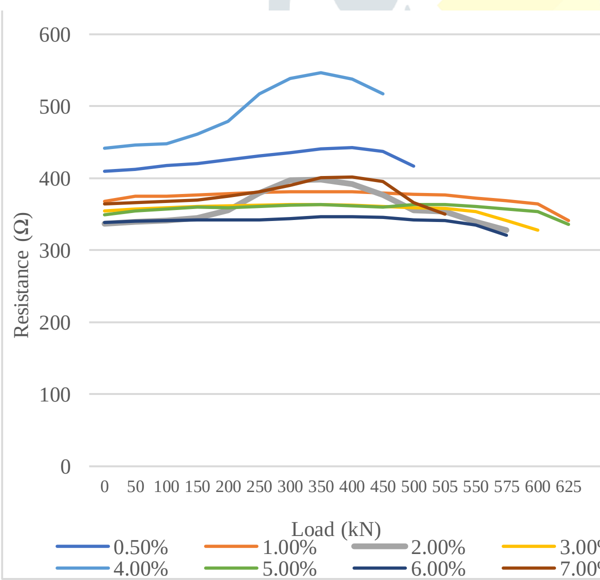

Fig. 6: CB Specimens load v/s resistance graph

D. Hybrid Specimens

Specimens were tested after 7 day curing and the load v/s resistance obtained for MWCNT specimens are plotted in Figure 7.

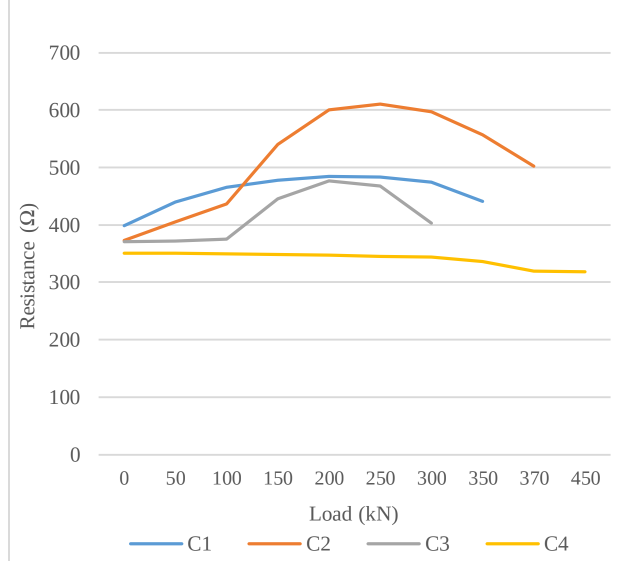

Fig. 7: Hybrid Specimens load v/s resistance graph

VII CONCLUSIONS

Basic tests were carried out for the raw materials such as cement, fine and coarse aggregates and based on these results, the mix design for M20 concrete was done. Several trials were conducted to fix the mix proportion so as to obtain sufficient workability.

- Cubes with MWCNT content of 0.5 % by weight of cement shows good resistivity response than other percentages.
- Cubes with Carbon Black content of 4 % by weight of cement shows good resistivity response than other percentages
- In hybrid specimens, cubes with 2% CB and 0.6 % MWCNT shows good resistivity response than other percentages.

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