# MONITORING OF M35 GRADE STRUCTURAL CONCRETE BEHAVIOUR AND ITS HEALTH THROUGH SMART CONCRETE TECHNIQUE BY ADDING CARBON FIBERS

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**ABSTRACT**:

This project attempts to understand electrically conducting concrete, as provided the addition of short carbon fibers into concrete can function as a smart structure material that allows non-destructive electrical probes for the monitoring of construction & design flaws. The electrical signal is related to an increase in the concrete's volume resistivity during crack generation or propagation and a decrease in the resistivity during crack closure. The linearity between the volume resistivity change and compressive stress was good for mortar containing carbon fibers together with either methylcellulose or latex as dispersants.

Smart concrete structures that provide the capability of non-destructive flaw detection allow concrete structures to be repaired before it is too late. This capability is critically needed for highways, bridges and nuclear power plants. An intrinsically smart concrete is more versatile and more convenient to use than an extrinsically smart concrete. In particular, the carbon fibers in carbon fiber reinforced concrete serve to provide the smart action as well as improved structural performance. Furthermore, the addition of carbon fibers to concrete can be achieved by simply using the conventional stone concrete mixer.

This project also attempts to check the self adjusting and self-healing alongside self sensing Concrete that is itself a sensor of stress or strain. The sensing ability is not due to the embedment or attachment of sensors. The concrete has been modified through the use of admixtures so that it becomes a sensor. The sensing ability of smart concrete is based on the change of electrical resistance.

**KEYWORDS:** Sensibility of Concrete, Condition of Structure, Carbon Fibers, Silica Fume, Methylcellulose, Strain-Electrical Resistivity-Compressive Stress.

## INTRODUCTION

Concrete is a magic term in the human civilization of the construction field. Concrete always undergoes stress and strain when it is under loading that may be either static & dynamic [3] therefore it is necessary to identify what range of stress & strain it feels during the kind of loadings. There are several destructive & sensor devices to measure the stresses & stain but those are restricted to certain levels. Therefore coming with latest ideology of giving smartness to the concrete is more trustworthy and resourceful to identify the stress and strain at any required time interval and location also it won't take long time to provide the results like other destructive, nondestructive methods [1]

This particular experiment is done on the real time high strength concrete which is usually used for the highway bridges, nuclear power plant, giant size building structures, tunnels, precast concretes etc., where as in order to endowing the ability of smartness to the cementitious agents, so far the most of the researches are done on the cement-sand mortar with required ratio of water. The M35 grade of concrete was adopted to examine the same as mortar. Since cement is weak in conduction to pass the electricity through it therefore carbon fibers are added in order to receive the electrical signals and silica fume and methylcellulose are used to compensate for the strength parameters.

Smart Concrete attempts to understand the electrically conducting concrete [2], as provided by the addition of short carbon fibers (0.2-0.4 vol. % cement) to concrete. The motto of the smart concrete is to notice the stress-strain confronted whilst the kind of loadings, since the concrete is under compression the deformation of the bonding materials takes place such that the de-bonding condition will arise between the cementitious agents and carbon fibers therefore as more as the stress of concrete receives the more de-bonding of the carbon fibers and cementitious matrix. During the process of feeling/applying stress and strain the electrical resistance is measured with the help of suitable setup of electrical devices.

Confront strain-resistance-stress assessment [4] on structural elements upon testing through electrical resistivity is quite simple by using Ohm's law as shown in Fig.1 when the Fig.2 arrangements are done. It is as quiet as substituting the obtained readings of ammeter, voltmeter and RPS (Regulated Power Supply) in the Ohms equation as shown in Fig.3.

**LITERATURE REVIEW**

The motto of smart concrete technology is to detect the structural concrete flaws other than destructive tests and the smartness is given to the concrete by adding carbon fibers [1] which have the electrical conductivity by its nature and have the composite element in the concrete as short carbons and its unforeseen arrangements to connect each other with in the concrete matrix [2]. However the fundamental theorem of concrete is purely depends on the stress/strain tensors [3] in order to conclude the concrete condition whilst loading and unloading time period and the carbon fiber reinforced/elemental concrete as an intrinsically smart concrete for damage assessment [4] during static and dynamic loading on large highway live traffic structures.

It is likely to be possible to make the structural concrete damage self-sensing [5] with the method of electrical resistance of carbon fiber reinforced concrete also the effects of strain and damage on strain sensing ability [6][9][10] and the carbon fibers helps to converts the electrical resistivity into stress/strain parameters, the piezo resistivity-based strain sensing [7] in carbon fiber cement used for any structural concretes. The challenging phenomenon of using short carbon fibers in the concrete is their arrangement of how that happen inside the concrete body, the dispersion of short fibers in cement [8]. Concrete is casted as smartness achievable proportions of carbon fibers alongside other pertaining ingredients and how those materials responds and possessions during the curing period [11] is to be taken into account on the self-monitoring behavior of carbon fiber reinforced cement mortar/concrete mix also the effect of moisture on piezoresistivity of carbon fiber-reinforced cement paste [12], before the carbon fiber self-sensing smart concrete there were some sort of sensors available to bring the concrete into sensible condition [13].

This ideology is more appropriate to the precast concrete structures [14] which are becoming popular means of design and construction of concrete structures. Also, according to the American Society of Civil Engineers (ASCE) infrastructure report card, in the United States alone, 7.5% of bridges are structurally deficient state and many more are functionally obsolete [15] due to inadequate maintenance [16], huge bridge inventory and slow evolution of health monitoring methods of structures. Though all these inventions are come into practicality by pragmatism with the thorough investigations and implementations in the history of concrete that either plain or reinforced concrete [17][18]

**INSPIRATIONAL:**

The concept of giving ability to the high strength concrete on M35 grade of concrete is purely inspired [1] by the Professor Deborah Duen Ling Chung in university of Buffalo, State University, New York, USA.

**AIM**: The current exercise aims to recognize the characteristic behavior (strain-resistivity-stress) and its health (condition of concrete specimens) of M35 grade concrete with adding of variable of carbon fiber content 0.2% & 0.3% of Volume of cement when it is under the circumstance of different kind loads.

**PART-1: MATERIALS & METHODOLOGY (DESIGN MIX FOR M35 GRADE OF CONCRETE)**

**1. M35 grade of Concrete**

The design mix for M35 grade concrete is done with locally available resource materials [8] duly tests are done on prior to confirm the mix design proportions.

**1.1 Cement**: 53 grade Ordinary Portland Cement (OPC) is used throughout the study. The various tests like Fineness, Normal consistency, Initial & final setting time, Soundness, Specific gravity on cement is carried out by following IS: 12269-1987at constant room temperature. The results are presented in Table 1.

**Table.1 Characteristics of Cement**

| S. No. | Characteristics | Observed Value |
|---|---|---|
| 1 | Fineness | 8.06% |
| 2 | Normal consistency | 32% |
| 3 | Initial setting time | 60minutes |
| 4 | Final setting time | 350 minutes |
| 5 | Soundness | 6 mm |
| 6 | Specific gravity | 3.14 |

**1.2 Fine aggregate:** The clean sand in the vicinity which is free from organic matter and various physical properties like fineness modulus, sand type, grade zone and specific gravity were tested. Test results are mentioned in Table 2.

**Table.2 Characteristics of Fine Aggregate**

| S. No. | Characteristics | Observed Value |
|---|---|---|
| 1 | Fineness modulus | 2% |
| 2 | Type | Coarser |
| 3 | Grade zone | II |
| 4 | Specific gravity | 2.45 |

**1.3 Coarse Aggregate**: Crusher / Hand broken in the proximity coarse aggregate of two sizes were used (60% of 20mm size & 40% of 12.5mm size aggregates) for the current study. This was done because to avoid voids in the concrete and standard tests like specific Gravity, Abrasion value, Impact value and shape test on coarse aggregates are presented in Table 3.

**Table.3 Characteristics of Coarse Aggregate**

| S. No. | Characteristics | Observed Value |
|---|---|---|
| 1 | Specific gravity | 2.70 |
| 2 | Abrasion Value | 8% |
| 3 | Impact Value: | 12.6% |
| 4 | Shape test | 17.36 % (flakiness index)<br>36.48% (elongation index) |

**1.4 Water**: Potable water consists of pH ranges from 6.5 to 8.5

**TESTING SPECIMENS:**

**1.5 Mix proportion**

Three trial mixes were done to attain the target mean strength of M35 grade of concrete [15], raw materials are weighted as required according to design ofM35 grade of concrete mix and then the materials are dumped in to the mechanical mixer drum one after other following 60seconds of minimum time to mix up.

**1.6 Compressive strength test**

The cube specimens of size 150mm x 150mm x 150mm were casted [14], immense cured in water tank, and after 3 days, 7 days and 28 days the samples were tested, illustrated in Fig.2. Results of the concrete compressive strength tabulated in table.4 and its graphical representation shown in Fig.1

**Table.4 Results of Compressive Strength of Concrete at Various Ages**

| S.No | Age of Conc. | Concrete Prop. (1:1.67:2.5) | Mean Strength (MPa) | Concrete Prop. (1:1.53:2.29) | Mean Strength (MPa) | Concrete Prop. (1:1.4:2.08) | Mean Strength (MPa) |
|---|---|---|---|---|---|---|---|
| | | Trial Mix-1 | | Trial Mix-2 | | Trial Mix-3 | |
| 1 | 3 Days | 16.40 | 16.89 | 16.80 | 17.13 | 18.95 | 20.36 |
| 2 | | 17.01 | | 17.09 | | 21.56 | |
| 3 | | 17.26 | | 17.50 | | 20.56 | |
| 1 | 7 Days | 26.20 | 26.92 | 27.60 | 28.12 | 29.15 | 29.90 |
| 2 | | 27.36 | | 27.86 | | 28.22 | |
| 3 | | 27.20 | | 28.90 | | 28.88 | |
| 1 | 28 Days | 39.59 | 40.23 | 42.90 | 42.95 | 47.08 | 47.23 |
| 2 | | 40.01 | | 42.89 | | 46.56 | |
| 3 | | 41.09 | | 43.06 | | 48.05 | |

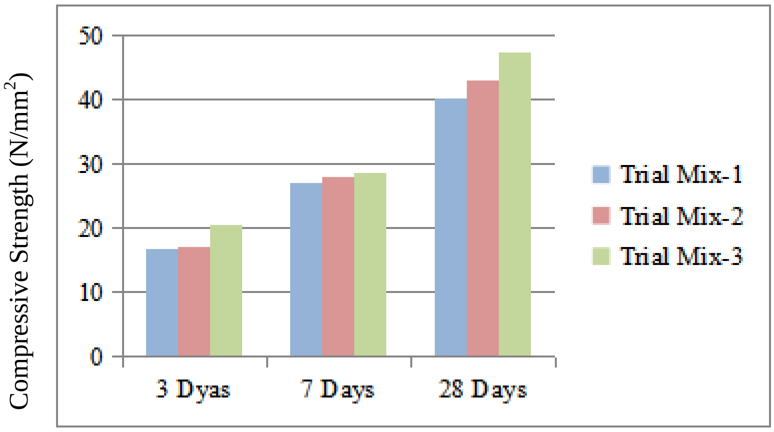



**Fig.1. Comparison of Conventional Concrete Compressive Strength Values**

**Fig.2. Compression Testing of Control Mix at CTM**

### 1.7 Adoption of Mix Proportion

For the present investigation designed, the mix proportion used is 1:1.40:2.08 at water cement ratio 0.42 and cement quantity of 480 kg/cu.m since the mentioned proportion acquires the adequate results.

## PART-2: MATERIALS & METHODOLOGY (EXPERIMENTAL WORK-SMART CONCRETE)

### 2. Smart Concrete Constituents

After adopting the best control mix of M35 grade of concrete the following admixtures (keeping carbon fiber as variable constituent) were added in order to bring the sensing ability to the concrete alongside **Cement:** As mentioned in 1.1, **Fine aggregate:** As mentioned in 1.2, **Coarse aggregate:** As mentioned in 1.3, **Water:** As mentioned in 1.4

- ✓ Contain short carbon fibers, typically 6mm in length
- ✓ Carbon Fiber content is 0.2% Volume of Cement (Trial-1)
- ✓ Carbon Fiber content is 0.3% Volume of Cement (Trial-2)
- ✓ Silica fume content is 12% by weight of cement
- ✓ Methylcellulose content is 0.55% by weight of cement

### 2.1 Carbon Fibers

The physical properties and its specification of carbon fibers are given in Table.5

**Table.5 Carbon fiber specifications**

| | |
|---|---|
| Fiber length | 6mm ,12mm |
| Carbon content (%) | >98 |
| Fiber type | T300 |
| Filament diameter (um) | 7 |
| Fiber length (mm) | 2 |
| Tensile strength (MPa) | 3600-3850 |

| | |
|---|---|
| Tensile modulus (GPa) | 220-245 |
| Elongation (%) | 1.5 |
| Density (g/cm3) | 1.76 |
| Volume resistivity (cm) | 1.5x10- |

**2.2 Silica Fume**

Silica fume is also known as micro silica. The following are the physical & chemical properties of the Silica Fume.

*Physical Properties*

- ✓ Diameter is about 0.1 micron to 0.2 micron
- ✓ Surface area about 30,000 $m^2/kg$
- ✓ Density varies from 150 to 700 $kg/m^3$
- ✓ When its density is about 550 $kg/m^3$ it is the best suited as concrete additive

*Chemical Composition*

- ✓ Contains more than 90 percent silicon dioxide
- ✓ Other constituents are carbon, sulphur and oxides of aluminium, iron, calcium, magnesium, sodium and potassium

**TESTING SPECIMENS:**

**2.3 Mixing & Preparation of test specimen of Smart Concrete**

The constituents of smart concrete are 53 grade ordinary portland cement, fine and aggregates, carbon fibers (variable constituent) 6mm long 0.2% & 0.3% of volume of cement, silica fume 12% of weight of cement, methylcellulose 0.55% of weight of cement with water cement ratio of 0.42. Two different M35 grade of concrete are mixed by adjusting carbon fibers 0.2% and 0.3% of volume of cement, the dry constituents are mixed in a mechanical mixer adding one after another and water is added until it gets a homogeneous mix. The thorough mixture was poured in to cubes 150 x 150 x150 mm cube moulds of required numbers i.e. 7 sets each set contains 3 cubes, 3 sets for 0.2% carbon fiber, 3 sets for 0.3% carbon fiber and another 1 set for control mix (M35 grade of concrete) and left for final setting of the concrete later moulds are strike and specimens are put in the water tank for immense curing for required time [5].

**2.4 Compressive Strength of Smart Concrete**

The cube specimens of size 150mm x 150mm x 150mm were casted, immense cured in water tank, and after 7 days, 14 days and 28 days the samples were tested, illustrated in fig.2. Results of the concrete compressive strength tabulated in table.6 and its graphical representation shown in fig.3

**Table.6 Compressive Strength of Smart Concrete at Various Ages**

| S.No | Age of Concrete | Control Mix (MPa) | Mean Strength (MPa) | Concrete with 0.2% Carbon (MPa) | Mean Strength (MPa) | Concrete with 0.3% Carbon (MPa) | Mean Strength (MPa) |
|---|---|---|---|---|---|---|---|
| 1 | 7 Days | 29.15 | 28.75 | 28.98 | 28.93 | 29.65 | 29.90 |
| 2 | | 28.22 | | 28.16 | | 30.50 | |
| 3 | | 28.88 | | 29.66 | | 29.56 | |
| 1 | 14 Days | 36.65 | 36.75 | 37.22 | 37.67 | 38.25 | 38.90 |
| 2 | | 37.15 | | 38.24 | | 38.88 | |
| 3 | | 36.45 | | 37.55 | | 39.58 | |
| 1 | 28 Days | 47.08 | 47.23 | 48.56 | 47.87 | 49.59 | 49.07 |
| 2 | | 46.56 | | 49.50 | | 47.53 | |
| 3 | | 48.05 | | 45.56 | | 50.10 | |

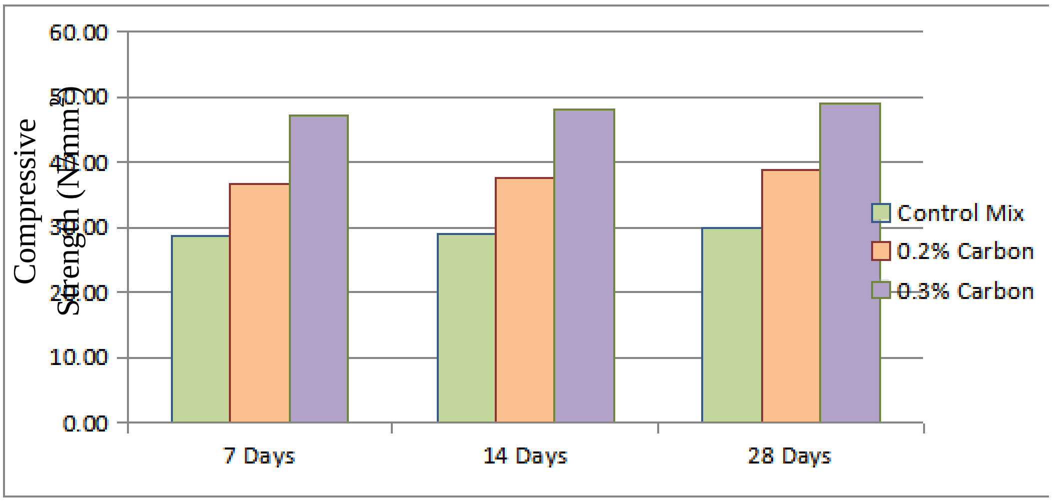



**Fig.3. Comparison of Smart Concrete Compressive Strength Values**

**2.5 Split tensile test for Smart Concrete**

The cylinder specimen of size 150mmdiameter x 300mm long were casted [14], immense cured in water tank, and after 7 days, 14 days and 28 days the samples were tested as shown in fig.5. Results of the concrete compressive strength tabulated in table.7 and its graphical representation shown in Fig.4

**Table.7 Split Tensile Strength of Smart Concrete at Various Ages**

| S.No | Age of Concrete | Control Mix (MPa) | Mean Strength (MPa) | Concrete with 0.2% Carbon (MPa) | Mean Strength (MPa) | Concrete with 0.3% Carbon (MPa) | Mean Strength (MPa) |
|---|---|---|---|---|---|---|---|
| 1 | 7 Days | 3.15 | 3.02 | 3.10 | 3.19 | 3.09 | 3.24 |
| 2 | | 3.05 | | 3.20 | | 3.33 | |
| 3 | | 2.85 | | 3.28 | | 3.31 | |
| 1 | 14 Days | 3.35 | 3.34 | 3.64 | 3.41 | 3.56 | 3.47 |
| 2 | | 3.21 | | 3.15 | | 3.41 | |
| 3 | | 3.45 | | 3.45 | | 3.44 | |
| 1 | 28 Days | 4.06 | 4.08 | 4.12 | 4.09 | 4.15 | 4.14 |
| 2 | | 4.09 | | 4.09 | | 4.08 | |
| 3 | | 4.10 | | 4.06 | | 4.18 | |

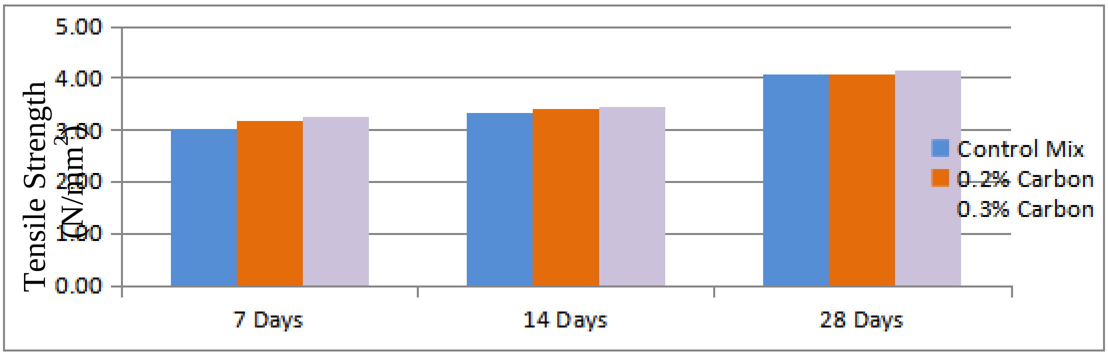



**Fig.4. Comparison of Split Tensile Strength Values**

**Fig.5. Split Tensile Test**

### 2.4 Sensibility checking of test specimens by Electrical Resistance

The test samples were tested in two batches (Batch-1 for 0.2% carbon fiber & Batch-2 for 0.3% of carbon fiber) each batch contains 3 sets of cubes to test at 7 days, 14 days and 28 days and each set contains 3 cubes. The specimens are taken out from the curing tank and dried it at 50*C until it have the surface dry state soon later circumference of 150mm cubical specimen is marked equal spacing leaving 30mm from the both the ends and silver paint is applied before and after fasten the tight enough copper wire which leave a small projection to act as a probe, see fig.6 for pictorial illustration. The projections are connected with the [9] ammeter, voltmeter and RPS (Regulated Power Supply) the arrangement of such setup was illustrated in Fig.7. The whole setup concrete test cube specimen is placed in Digital Compression Testing Machine (CTM) as shown in the Fig.1 in order to apply the load increasing gradually in every 5kN interval until the breaking of test cube specimen and every load interval the readings are recorded from ammeter, voltmeter to find out the resistance by substituting in the Ohms law equation as shown in Fig.1. The stress values are calculated using the Load/Area method at every interval of loading since the area of specimen is 150mm x 150mm however these inputs were given to the Compression Testing Machine (CTM) which has the digital screen to display the direct stress value. Strain is measured with the help of strain gauges and readings are recorded at every 5kN loading interval [10]. All the values are noted at every loading interval and tabulated for further calculations

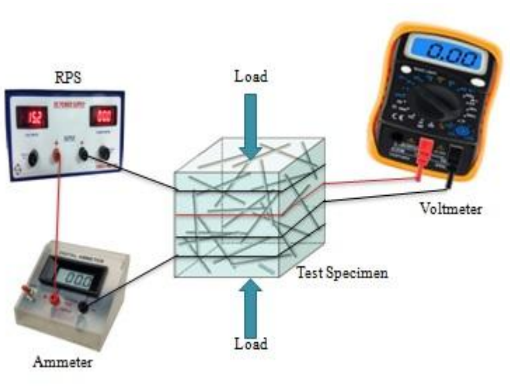



**Fig.6. Probe Method of Electrical Resistance @ Compression Testing Machine**

**Fig.7. Electrical Devices Setup for Compression Test**

### 2.5 Germane Tests carried-out on Smart Concrete

The following tests [1] were conducted to confirm the arrangement of cementecious and admixture constituents in smart concrete matrix and their proportions to meet the design criteria.

#### 2.5.1 Scanning Electron Microscopy (SEM)

SEM analysis was done and it produces a two-dimensional image of 10μm, 20μm, 50μm, 100μm and reveals the information about the sample, including external morphology (texture), chemical composition, when used with the EDS feature, and orientation of materials making up the sample. Fig.8 shows the illustration of SEM

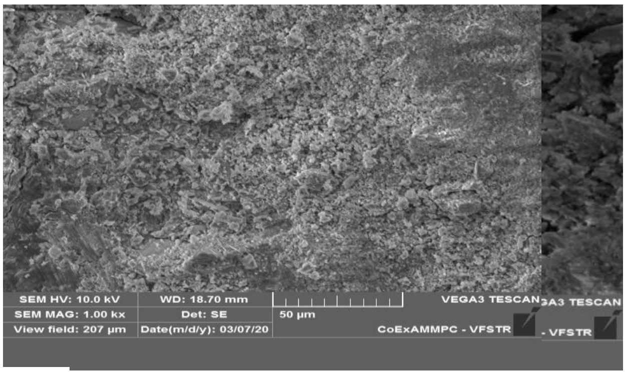


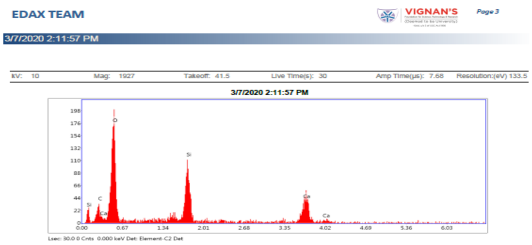

**Fig.8. SEM Analysis two-dimensional Image at 20µm & 50 µm**

### 2.5.2 Energy Dispersive Spectroscopy (EDS)

EDS analysis is performed to determine the composition of elements present in the sample. Any smaller size particles can be analyzed at large magnification using EDS. Fig.9 Illustrate the constituent's composition.

### 2.5.3 X-Ray Diffraction (XRD)

X-Ray Diffraction analysis is performed to determine the silica phase of the powder concrete samples. The samples are scanned by an X-Ray diffractometer. Fig.10 Shows the Pictorial representation of X-Ray Diffraction.




| Element | Weight % | Atomic % | Net Int. | Error % | Kratio | Z | R | A | F |
|---|---|---|---|---|---|---|---|---|---|
| C K | 3.70 | 6.84 | 4.13 | 30.07 | | | | | |
| O K | 42.97 | 59.62 | 47.35 | 11.36 | | | | | |
| SiK | 16.93 | 13.38 | 28.35 | 7.97 | | | | | |
| CaK | 36.40 | 20.16 | 18.37 | 11.11 | | | | | |

**Fig.9. Energy Dispersive Spectroscopy Analysis for composition of material**

The Peak Value (2 theta / theta) = **26.56 degree**

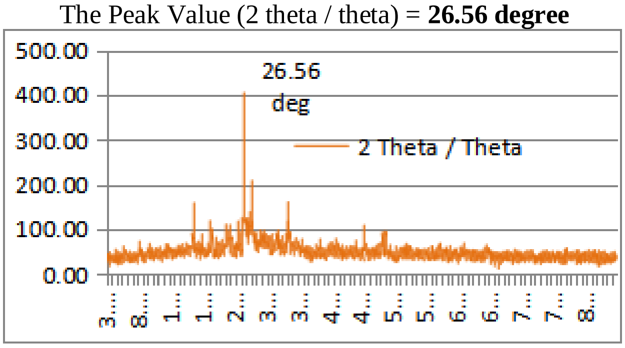


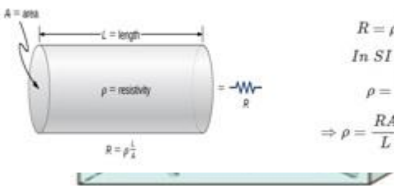

**Fig.10. X-Ray Diffraction Analysis**

**RESULTS & DISCUSSION**:

The prediction was comes true that the self arranging of carbon fibers [11] 6mm long are spread all over the volume of specimen and get in contact to each other as shown in Fig.11 which made experiment successful by allowing the electricity in to it in the mass of concrete when the copper wires are fasten over the circumferential of cube specimen with the application of silver pain which brings the contact to the carbon fibers and electrical devices these copper wires acts as probes in this circumstance.

| Quantity | Symbol | Unit of Measurement | Unit Abbreviation |
|---|---|---|---|
| Current | I | Ampere ("Amp") | A |
| Voltage | E or V | Volt | V |
| Resistance | R | Ohm | Ω |

$$R = \frac{E}{I}$$




$$R = \rho\frac{L}{A} \Rightarrow \rho = \frac{RA}{L}$$

*In SI System of Unit*

$$\rho = \frac{R\,\Omega \times A\,m^2}{L\,m}$$

$$\Rightarrow \rho = \frac{RA}{L}\ \frac{\Omega - m^2}{m}\ or\ \Omega - m$$

**Fig.11. Tentative Expectation of Arrangement of Carbon Fibers in concrete specimen.**

**Fig.12. Ohms law Equations for Resistance & Resistivity**

The appropriate setup of electrical devices which connects to the test specimen helps to obtain the readings from voltmeter, ammeter and RPS (regulated Power Supply) whilst applying the gradually increasing load on the compression testing machine (CTM). The CTM is assigned to apply the load intervals 5kN, 10kN, 15kN, 20kN, 30kN, 35kN, 40kN and so on until the test specimen breaks. All readings from electrical devices and CTM are recorded in tabulated format and substitute them in the Ohm's law equation in order to obtain the resistance and resistivity Fig.12 Provides the conversion of readings into required state. R= Resistance (Ω) and ρ = Resistivity (Ω-m).

The stress and strain values are recorded simultaneously with resistance readings shown in Table.8, 9 & 10 and plotted them in graphs, Fig.13, 14 and 15 explains the sensitivity of concrete containing carbon fiber content of 0.2% of volume cement. During the application of loading on 7days age specimen which might not adjusted the molecules of concrete felt more stress therefore the volume of electrical resistivity is increased and 14 days age specimen pretended the stresses as compared with the previous and the volume of electrical resistivity is quite less and coming to the 28days age specimens are matured and have the ability of more stress pretend therefore the deformation of cementitious molecules are deformed much therefore it occupies the less volume of electrical resistivity [12]. Nevertheless it indicates that the non linier fluctuations of volume of electrical resistivity due to insufficient volume of carbon fibers.

Fig.16, 17 and 18 explains the sensitivity of concrete containing carbon fiber content of 0.3% of volume cement which observations are recorded in Table.11, 12 & 13. During the application of loading on 7days age specimen which might not adjusted the molecules of concrete felt more stress therefore the volume of electrical resistivity is increased and 14 days age specimen pretended the stresses as compared with the previous and the volume of electrical resistivity is quite less and coming to the 28days age specimens are matured and have the ability of more stress pretend therefore the deformation of cementitious molecules are deformed much therefore it occupies the less volume of electrical resistivity. At this condition it indicates that the linear fluctuations of volume of electrical resistivity due to sufficient volume of carbon fibers [13].

Moreover the same test is conducted on the conventional concrete and the readings are recorded in Table.14 which is free from admixtures at the age of 28 days it clearly proves that there is no sensitivity to the concrete the volume of electrical resistivity has no change during the loading and is abnormal when the specimen is broken which indicates the electricity can occupy in the broken spaces**.** Fig.19. shows the illustration.

**Table.8 Data for Carbon fiber 0.20% at 7 Days**

| Load (kN) | Voltage (E) | Current (I) | Resistance (Ω) R = E / I | Length of Specimen (L) cm | Area of Specimen (A) cm² | Electrical Resistivity (Ω-cm) ρ = R*A / L |
|---|---|---|---|---|---|---|
| 5 | 1 | 0.25 | 5000 | 15 | 225 | 75000 |
| 10 | 3 | 0.48 | 5333 | 15 | 225 | 80000 |
| 15 | 3 | 0.35 | 8000 | 15 | 225 | 120000 |
| 20 | 5 | 0.46 | 10667 | 15 | 225 | 160000 |
| 25 | 6 | 0.44 | 14000 | 15 | 225 | 210000 |
| 30 | 7 | 0.4 | 18667 | 15 | 225 | 280000 |
| 35 | 11 | 0.45 | 23333 | 15 | 225 | 350000 |
| 40 | 15 | 0.45 | 33333 | 15 | 225 | 500000 |
| 45 | | | | | | |

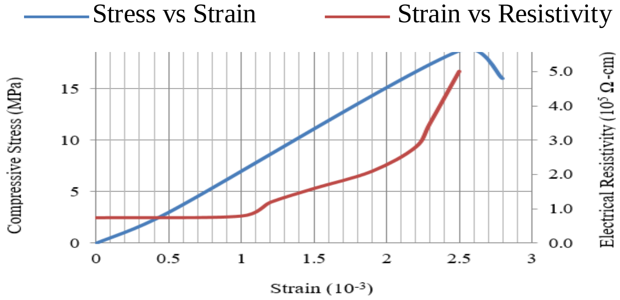



**Fig.13. Relationship b/w Stress-Strain-Resistivity for Carbon fiber 0.2% at 7 Days**

| Load (kN) | Voltage (E) | Current (I) | Resistance (Ω) R = E / I | Length of Specimen (L) cm | Area of Specimen (A) cm² | Electrical Resistivity (Ω-cm) ρ = R*A / L |
|---|---|---|---|---|---|---|
| 5 | 1 | 0.25 | 5000 | 15 | 225 | 75000 |
| 10 | 3 | 0.48 | 5333 | 15 | 225 | 80000 |
| 15 | 3 | 0.35 | 8000 | 15 | 225 | 120000 |
| 20 | 6 | 0.46 | 13333 | 15 | 225 | 200000 |
| 25 | 8 | 0.44 | 17333 | 15 | 225 | 260000 |
| 30 | 9 | 0.4 | 22667 | 15 | 225 | 340000 |
| 35 | 12 | 0.45 | 26667 | 15 | 225 | 400000 |
| 40 | 14 | 0.45 | 32000 | 15 | 225 | 480000 |
| 45 | | | | | | |

**Table.9 Data for Carbon fiber 0.20% at 14 Days**

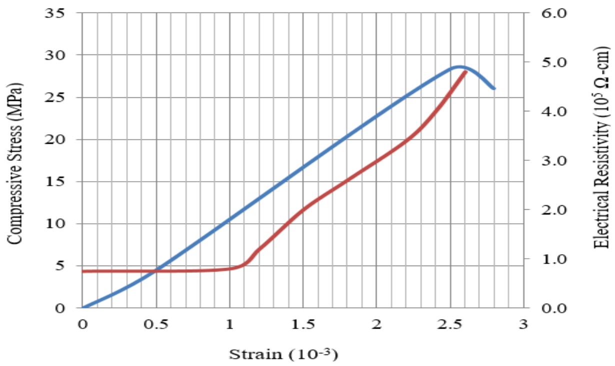



**Fig.14. Relationship b/w Stress-Strain-Resistivity for Carbon fiber 0.2% at 14 Days**

**Table.10 Data for Carbon fiber 0.20% at 28 Days**

| Load (kN) | Voltage (E) | Current (I) | Resistance (Ω) R = E / I | Length of Specimen (L) cm | Area of Specimen (A) $cm^2$ | Electrical Resistivity (Ω-cm) ρ = R*A / L |
|---|---|---|---|---|---|---|
| 5 | 1 | 0.25 | 5000 | 15 | 225 | 75000 |
| 10 | 3 | 0.48 | 5333 | 15 | 225 | 80000 |
| 15 | 4 | 0.35 | 10667 | 15 | 225 | 160000 |
| 20 | 7 | 0.46 | 15333 | 15 | 225 | 230000 |
| 25 | 9 | 0.44 | 20333 | 15 | 225 | 305000 |
| 30 | 9 | 0.4 | 22667 | 15 | 225 | 340000 |
| 35 | 13 | 0.45 | 28000 | 15 | 225 | 420000 |
| 40 | 14 | 0.45 | 32000 | 15 | 225 | 480000 |
| 45 | | | | | | |

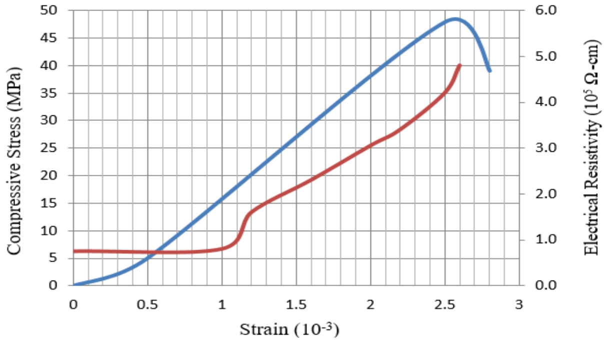



**Fig.15. Relationship b/w Stress-Strain-Resistivity for Carbon fiber 0.2% at 28 Days**

**Table.11 Data for Carbon fiber 0.30% at 7 Days**

| Load (kN) | Voltage (E) | Current (I) | Resistance (Ω) R = E / I | Length of Specimen (L) cm | Area of Specimen (A) $cm^2$ | Electrical Resistivity (Ω-cm) ρ = R*A / L |
|---|---|---|---|---|---|---|
| 5 | 1 | 0.25 | 4667 | 15 | 225 | 70000 |
| 10 | 4 | 0.48 | 7333 | 15 | 225 | 110000 |
| 15 | 3 | 0.35 | 7333 | 15 | 225 | 110000 |
| 20 | 5 | 0.46 | 10333 | 15 | 225 | 155000 |
| 25 | 7 | 0.44 | 16000 | 15 | 225 | 240000 |
| 30 | 9 | 0.4 | 21333 | 15 | 225 | 320000 |
| 35 | 14 | 0.45 | 30000 | 15 | 225 | 450000 |
| 40 | 14 | 0.45 | 32000 | 15 | 225 | 480000 |
| 45 | | | | | | |

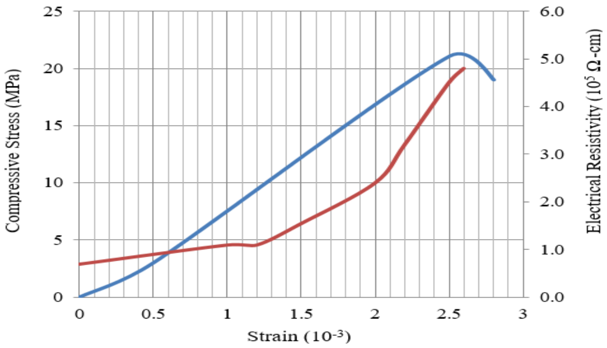



**Fig.16. Relationship b/w Stress-Strain-Resistivity for Carbon fiber 0.3% at 7 Days**

**Table.12 Data for Carbon fiber 0.30% at 14 Days**

| Load (kN) | Voltage (E) | Current (I) | Resistance (Ω) R = E / I | Length of Specimen (L) cm | Area of Specimen (A) $cm^2$ | Electrical Resistivity (Ω-cm) ρ = R*A / L |
|---|---|---|---|---|---|---|
| 5 | 1 | 0.25 | 5000 | 15 | 225 | 75000 |
| 10 | 4 | 0.48 | 8000 | 15 | 225 | 120000 |
| 15 | 4 | 0.35 | 10667 | 15 | 225 | 160000 |
| 20 | 6 | 0.46 | 14000 | 15 | 225 | 210000 |
| 25 | 9 | 0.44 | 21333 | 15 | 225 | 320000 |
| 30 | 10 | 0.4 | 25333 | 15 | 225 | 380000 |
| 35 | 14 | 0.45 | 30000 | 15 | 225 | 450000 |
| 40 | 15 | 0.45 | 33333 | 15 | 225 | 500000 |
| 45 | | | | | | |

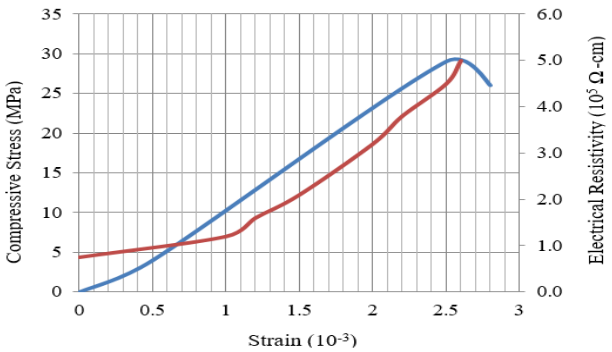



**Fig.17. Relationship b/w Stress-Strain-Resistivity for Carbon fiber 0.3% at 14 Days**

**Table.13 Data for Carbon fiber 0.30% at 28 Days**

| Load (kN) | Voltage (E) | Current (I) | Resistance (Ω) R = E / I | Length of Specimen (L) cm | Area of Specimen (A) $cm^2$ | Electrical Resistivity (Ω-cm) ρ = R*A / L |
|---|---|---|---|---|---|---|
| 5 | 1 | 0.25 | 5000 | 15 | 225 | 75000 |
| 10 | 4 | 0.48 | 8000 | 15 | 225 | 120000 |
| 15 | 4 | 0.35 | 10667 | 15 | 225 | 160000 |
| 20 | 6 | 0.46 | 14000 | 15 | 225 | 210000 |
| 25 | 9 | 0.44 | 21333 | 15 | 225 | 320000 |
| 30 | 10 | 0.4 | 25333 | 15 | 225 | 380000 |
| 35 | 14 | 0.45 | 30000 | 15 | 225 | 450000 |
| 40 | 15 | 0.45 | 33333 | 15 | 225 | 500000 |
| 45 | | | | | | |

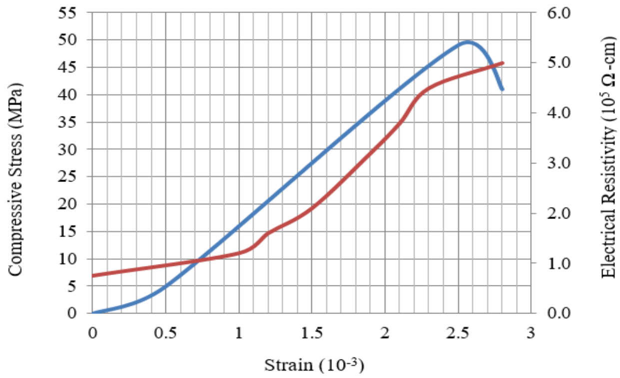



**Fig.18. Relationship b/w Stress-Strain-Resistivity for Carbon fiber 0.3% at 28 Days**

**Table.14 Data for Control mix at 28 Days**

| Load (kN) | Voltage (E) | Current (I) | Resistance (Ω) R = E / I | Length of Specimen (L) cm | Area of Specimen (A) cm² | Electrical Resistivity (Ω-cm) ρ = R*A / L |
|---|---|---|---|---|---|---|
| **5** | 1 | 0.25 | 5333 | 15 | 225 | 80000 |
| **10** | 3 | 0.48 | 5333 | 15 | 225 | 80000 |
| **15** | 2 | 0.35 | 5667 | 15 | 225 | 85000 |
| **20** | 3 | 0.46 | 6333 | 15 | 225 | 95000 |
| **25** | 3 | 0.44 | 7333 | 15 | 225 | 110000 |
| **30** | 3 | 0.4 | 8000 | 15 | 225 | 120000 |
| **35** | 4 | 0.45 | 8667 | 15 | 225 | 130000 |
| **40** | 17 | 0.45 | 37333 | 15 | 225 | 560000 |
| **45** | | | | | | |

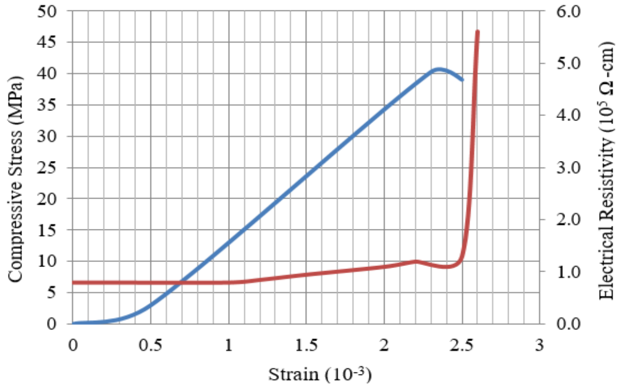



**Fig.19: Relationship between Stress-Strain-Resistivity for Control Mix at 28 Days**

## CONCLUSIONS:

The electrical resistance to the smart concrete is whilst applying compressive loads are tremendously changing as the stress increases the volume of electrical resistivity is drastically increasing by which it is predictable that the concrete has the internal fracture since it absorbs the more volume electric resistivity. Apart from several destructive, non-destructive and sensor devices to find out stress and strain in concrete an ideology of providing smartness to concrete in this 21st century to identify stress and strain at any time interval as well as it is most trustworthy and less duration to know the stress and strain. Construction of any concrete structure by using smart concrete it is quite easy to identify the construction flaws and monitoring of structural health at periodical intervals and can assess the condition of a structure that may be a Building, Bridge, Dam, Dome, Atomic Chambers, Power Plants etc.

Sensibility can be given to the concrete by adding carbon fibers (3% volume of cement), silica fume (12% weight of cement) and methylcellulose (0.55% weight of cement). The trial is done with carbon fibers variability of 0.2% & 0.3% of volume of cement, the best result is obtained with 0.3% of volume of cement additives, since our test is carried out to the concrete mix with the grade of M35 (1:1.40:2.08:0.42), Where the nominal size of aggregates are used is 20mm. The mixing proportion of carbon fibers, methyl cellulose and silica fume was up to the mark which is proved by the SEM analysis, EDS test and XRD test conducted at Vignan University, Vadlamudi-Guntur Dist.

Preparation and pouring of smart concrete is easy as conventional concrete. The test procedure is damn easy to conduct at every point of the field with some simple hand tools and AC/DC power supply and also it can be considered as a non-destructive test hence no damage is given to concrete. The cost is 30% more than the normal concrete but when it comes to eventual cost including periodical checking of concrete strength and other parameters with different equipment mobilization at site to carry out is almost the same.

The experiment is not promising the capability of identifying the direction of crack which occurs inside the concrete matrix, but this study is confirms only to find out the volume of crack happened in internal layers of cube made with M35 grade concrete the method involved is to find out electrical resistivity (Ohm-cm) for variable stresses and strains applied over a concrete cube prepared by M35 grade using carbon fibers and arranged in a manner shown in Fig.11., and results and results (shown in Table.8 to 13) are obtained through the testing machines and meters are shown in Fig.13 to 18.

This study focuses on the qualitative rather than quantitative through Fig.13-18., but it would like to convey that the electrical resistivity (Ohm-cm) observed gives/provide the volume of crack due to mechanical stress and strain. As stress increases the electrical resistivity is increasing which indicates decrease of strength in concrete. As a future work the amount of electrical resistivity can have a relationship with strength of concrete which will be a quantitative parameter.

## ACKNOWLEDGEMENTS:

The authors are grateful towards the CoEAMMPAC for conducting the tests of X-Ray Diffraction (XRD) analysis, Energy Dispersive Spectroscopy (EDS), Scanning Electron Microscopy (SEM) and also thankful to Vignan's Foundation for Science, Technology and Research, Vadlamudi-Guntur, Andhra Pradesh for the support and Structural Engineering Research (SER) lab and ECE lab amenities for the better conduction of research work.

**CONFLICTS OF INTEREST:**

None.

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18. IS 456 - 200: Plain and Reinforced Concrete Code of Practice.