Sensing Concrete using Hybrid Conductive Fillers for Structural Health Monitoring

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Abstract - *Sensing Concrete is a smart material which can monitor itself by its property of Electrical Conductivity. This multi-functional material finds different applications in the field of Structural Health Monitoring, Deicing of pavement etc. This study shows an experimental investigation on the effect of fillers like Steel fiber, Carbon powder and Graphite powder as a partial replacement (1%, 3%, 5%, and 7%) of fine aggregate on the conductivity of concrete. These fillers are added individually to each mix (Mono fiber composite) and the variation of conductivity and compressive strength for varying percentage of fillers are plotted. Apart from that, the variation of conductivity with the age of concrete is also represented and optimum quantity of filler required to convert a conventional concrete to a Sensing concrete is identified. Later the concrete is doped with combination of two and three types of fillers (Hybrid fiber composite) and the variation in results are studied. Finally variation of strain with change in resistance is also plotted.*

Key Words: **Compressive Strength, Conductive concrete, Hybrid filler, Carbon powder, Graphite powder, Steel fiber**

1. INTRODUCTION

Self-sensing concrete (SSC) refers to a multifunctional structural material that can monitor itself without any additional sensors [1]. By measuring electrical resistance of the SSC, the stress, strain, crack and damage can be in situ monitored on any existing structures [1]. The main inference from different literature study was that the size and distribution of the filler are more important than its conductivity and the volume of the filler affected the concrete conductivity [2]. A minimum filler content of 0.8% of concrete volume was required to attain good electrical conductivity [3]. This addition of filler will give concrete a piezoresistive property which helps to analyze stress or strain in a component by measuring its electrical resistivity [4], [5]. Hence it acts as an innovative method for structural health monitoring and thereby can avoid catastrophic failures.

2. RESEARCH SIGNIFICANCE

It was found that some studies included the measurement of electrical resistivity of concrete reinforced with single fiber and compared with concrete reinforced with two type of fiber [2]. Also some studies showed that with the increase in the filler content, the compressive and flexural strength was reduced beyond an optimum limit [3], [6]. Almost no study reported the effect of three types of filler in an electrically conductive concrete and its influence on the strength parameter. Since durability is a primary factor for producing structural concrete with desired service period, the scope of the work is that the potential of these hybrid conductive fillers might improve the conductivity without compromising the strength parameter of concrete.

3. EXPERIMENTAL WORK

3.1 Materials and Mix Proportion

Ordinary Portland cement (53 grade) which conforms to ASTM Type I was used in the study. Naturally crushed stone of nominal size 20 mm, specific gravity of 2.85, and absorption percentage of 0.25% was used as coarse aggregate. Fine aggregate used was artificially manufactured sand with specific gravity of 2.85. Concrete mix proportions are given in Table 1. The mixture was designed as per IS 10262: 2009 to have a 100mm slump and 28 days compressive strength of 30 MPa which represents a typical structural concrete grade. 15% of volume of cement is replaced with silica fume which act as a dispersing agent and a densifier [7]. The water cement ratio obtained was 0.48.

Table -1: Concrete mix proportion

Material	Quantity(kg/m^3)
Cement	335
Fine aggregate	721.27
Coarse aggregate	1279.07
Water content (water/cement ratio)	160.9 (0.48)
Silica fume	59.14

3.2 Preparation Procedure

There are mainly two ways to make conductive composition. One is conventional mixing and the other is slurry infiltration [8].

Fig. -1: Conductive Concrete Specimen

Here we make use of conventional mixing where, cement with 15% by weight replaced by silica fumes, fine and coarse aggregates are uniformly blended. To this filler of suitable proportion is added to form an even dry mix. Water with 2% superplasticizer is poured to dry mix and hand mixed thoroughly to get a uniform concrete mix. It is cast in to moulds and rammed and demoulded after 24 hours and cured for 28 days. Four numbers of copper electrodes are inserted to the mold while it is still in the plastic state as shown in the Fig. 1

3.3 Specimen and Electrical Setup

The experiments were performed on prismatic 150mm x 150mm x 150mm cement concrete samples using three different mixtures, varying the amount of carbon, steel fiber and graphite powder, as a partial replacement of volume of aggregate.

The resistivity measurement method was based on adaption of Wenner method, using four embedded copper electrodes [9]. AC voltage is induced in order to reduce the effect of polarization which is high for DC voltage. From the voltage and current values obtained corresponding to 50Hz AC voltage, the resistance is calculated. Fig. 2 shows the circuit diagram of Four probe method.

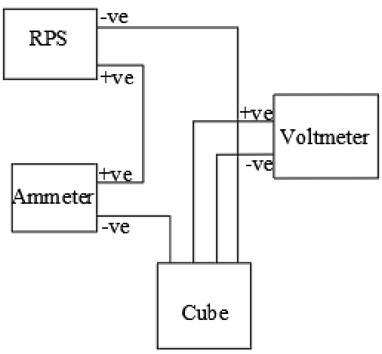

Fig. -2: Circuit diagram of Four probe method.

The electrical resistance, R, is determined by measuring the resultant drop in the voltage, V across the specimen

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

The resistivity of the material, $\rho = R\frac{A}{L}$

L and A are length and cross sectional area of the material

The conductivity of the material, $\sigma = \frac{1}{\rho}$

Fig. -3: Resistance measurement of sample concrete Specimen

4. MONO FIBER COMPOSITE

Mono fiber composites are made by doping fillers like carbon powder or steel fiber or graphite powder to the concrete composites by 1%, 3%, 5% and 7% as a partial replacement of fine aggregate.

Table -2 Mono fiber composite

Single fiber composite	Carbon Powder (CP) (% Vol)	Graphite Powder (GP) (% Vol)	Steel Fiber (SF) (% Vol)
1	1	0	0
	3	0	0
	5	0	0
	7	0	0
2	0	1	0
	0	3	0
	0	5	0
	0	7	0
3	0	0	1
	0	0	3
	0	0	5
	0	0	7

4.1 Results and Discussions of Mono Fiber Composites

Conductivity and Compressive strength for each of the Mono fiber composite cast and tested are shown in chart 1 and chart 2

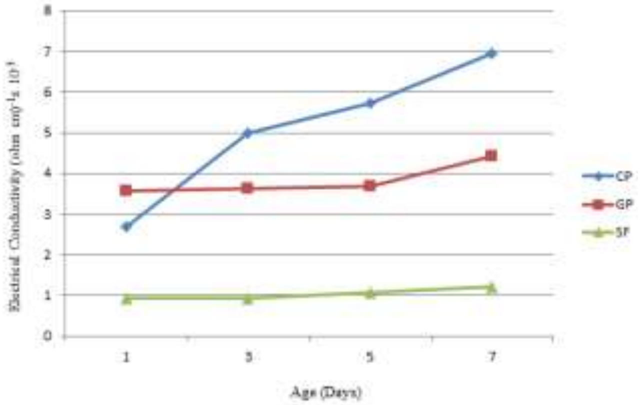

Chart -1: Electrical Conductivity of concrete mixtures with varying percentage of fillers

The above test result evidently shows that the conductivity of the specimen increases with increase in the fiber content. Carbon powder showed the highest improvement in the electrical conductivity of the concrete mixture. For 7% volume replacement using carbon powder the conductivity increased 2.5 folds more than 1% volume replacement. Similar improvements were observed for steel fiber and graphite powder.

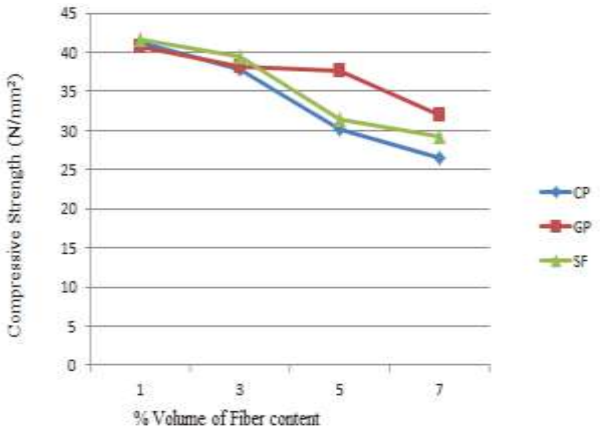

Chart -2: Compressive Strength of concrete mixtures with varying percentage of fillers

It is also clear from the above result that the strength decreased with increase in the filler replacement. Minimum reduction in strength occurred which is 21.6 % when graphite is used as the filler material. But, maximum reduction in strength is obtained when carbon powder is used as filler which is by 35.6 %.

From the above two results it is inferred that 7 % GP gives strength of 32 N/mm^2 where as its conductivity is only 4.41 x 10^{-3}(ohm cm)$^{-1}$. But for 5 % CP, it gives a satisfying strength of 30.2 N/mm^2 and an Electrical conductivity of 5.73 x 10^{-3} (ohm cm)$^{-1}$ which is 30% more than GP and 81.15% more than SF. So among the twelve composites of conductive concrete mixture with different fillers, 5% of CP is taken as the optimum quantity to convert conventional concrete to a sensing concrete.

5. HYBRID FIBER COMPOSITE- TYPE 1

The effect of fillers on conductivity can be magnified if the used fillers were of different sizes and shapes such that each type of filler will improve the conductivity network at different level which will result in producing continuous conductive path. The combination of more than one type of fillers will enhance electrical properties without compromising the strength criteria.

Table -3 Hybrid Fiber Composite – Type 1

Carbon Powder (CP) (% Vol)	**Graphite Powder (GP) (% Vol)**	**Steel Fiber (SF) (% Vol)**
2	3	0
3	2	0
2.5	2.5	0
0	2	3
0	3	2
0	2.5	2.5
2	0	3
3	0	2
2.5	0	2.5

5.1 Results and Discussions of Hybrid Fiber Composite – Type 1

Among the different hybrid composites of Type 1, concrete mixture with carbon and graphite powder in the ratio 3:2 gives better conductivity of 10.7 x 10^{-3} (ohm cm)$^{-1}$ than the remaining mixture. Also, since the concrete hardens with age, conductivity is found to decrease with time.

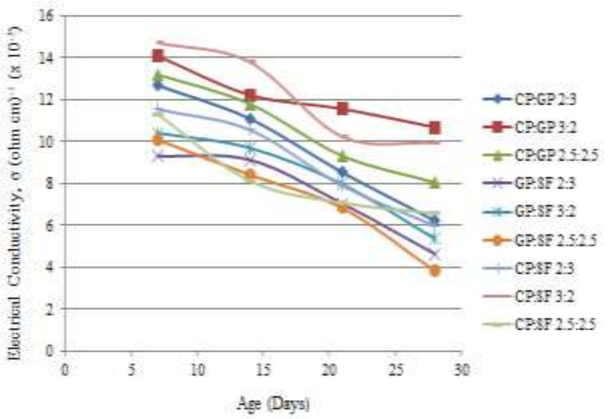

Chart -3: Variation in Conductivity of Hybrid Composite – Type 1 with age

The entire specimen satisfied the strength criteria. While Comparing to single fiber composite, conductivity increased by 86.5% and strength increased by 24.8%. Concrete doped with carbon and steel fiber also shows comparable results with the carbon and graphite powder embedded concrete.

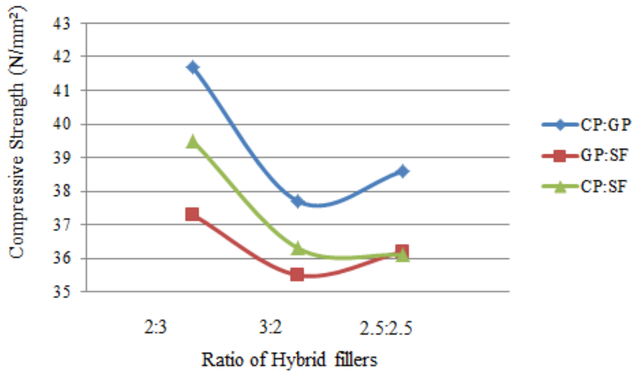

Chart -4: Variation of Compressive strength with Ratio of Hybrid filler – Type 1

From chart 3 it is clear that, electrical conductivities of most of the tested Hybrid composites were magnified compared to that of the Single fiber Composites. Hence the test results proved that the Hybrid fiber composite can replace the single fiber composite in every manner.

6. HYBRID FIBER COMPOSITE- TYPE 2

Hybrid fiber composite of Type 2 is prepared by simultaneously incorporating three types of fillers in to the conventional concrete mix. The combination chosen for the study is shown in Table 4

Table -4 Hybrid Fiber Composite – Type 2

Carbon Powder (CP)(% Vol)	Graphite Powder (GP)(% Vol)	Steel Fiber (SF)(% Vol)
2	1.5	1.5
1.5	2	1.5
1.5	1.5	2

6.1 Results and Discussion of Hybrid Fiber Composite Type 2

As shown in the chart 5 maximum conductivity was exhibited by the specimen with hybrid filler in the ratio 1.5:1.5:2 (CGS – CP: GP: SF). This evidently shows that the conductivity can be improved by enhancing the conductive networks that is possible by using fillers of different properties simultaneously.

Maximum conductivity of Type 2 specimen at 28th day was 11.01 x 10^{-3}(ohm cm)$^{-1}$ while that of Type 1 specimen was only 10.7 x 10^{-3}(ohm cm)$^{-1}$ which is 2.89% more.

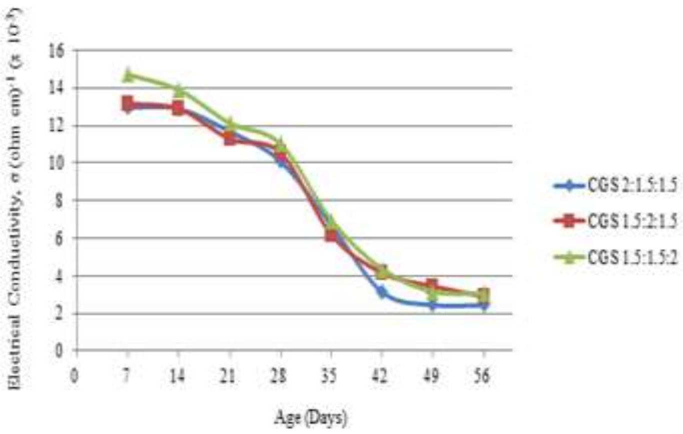

Chart -5: Variation in Conductivity of Hybrid Composite – Type 2 with age

All the specimens satisfied strength criteria and the compressive strength was comparable with hybrid fiber composite of Type 1.

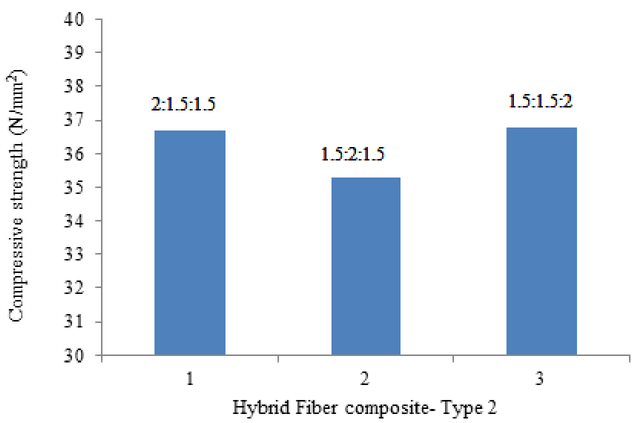

Chart -6: Variation of Compressive strength with Ratio of Hybrid filler – Type 2

7. STRAIN V/S RESISTANCE VARIATION OF HYBRID FIBER COMPOSITE - TYPE 2

The variation of resistance with increase in loading was performed on different cement concrete composition of Hybrid fiber composite Type 2. The resulting graph enables us to identify various relationships between strain and resistance. It is this relation which helps for structural health monitoring of structures.

Fig. -4: Resistance measurement on a typical specimen

For the above test load is applied at an increment of 50kN until it reaches ultimate breaking load. Specimen is kept in such a way that four probes of the specimen is placed facing the person who is doing the experiment. Load is applied perpendicular to the direction of casting. To prevent leakage of current through the body of machine, a plastic sack is provided on top and bottom of the specimen.

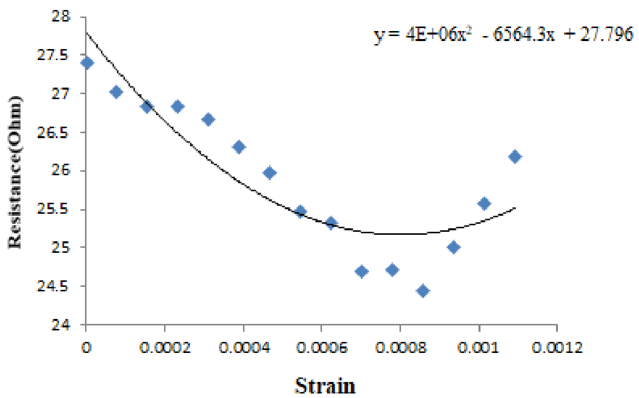

Chart -7: Strain v/s Resistance of Hybrid fiber composite – Type 2 (CP: GP: SF – 2:1.5:1.5)

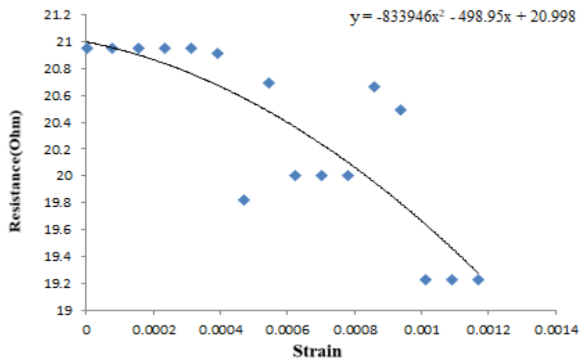

Chart -8: Strain v/s Resistance of Hybrid fiber composite – Type 2 (CP: GP: SF – 1.5:2:1.5)

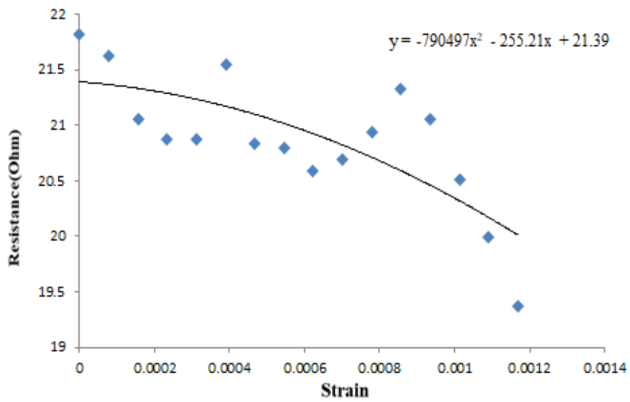

Chart -9: Strain v/s Resistance of Hybrid fiber composite – Type 2 (CP: GP: SF – 1.5:1.5:2)

From the above charts it is evident that the resistance decreases with increase in compression for each sample due to the close proximity of fibers. It should be also noted that the resistance variation showed a different trend line for each composition tested. In chart 7 we can see that the resistance is again increasing beyond a limit. This is due to the development of micro and major cracks within the composite which causes a discontinuity in the conductive path. But for chart 8 and 9 the resistance value decreases with increase in strain.

CONCLUSIONS

- Electrical Conductivity of concrete can be improved by incorporating different types of conductive fillers like carbon powder, graphite powder and steel fibers as a partial replacement of fine aggregate.
- Carbon and graphite powder affects the workability of mixture which compelled the use of superplasticizer.
- Compressive strength of concrete reduced with increase in volume of filler content.

- Among the twelve Mono fiber Composite mixture, with varying percentage of fillers, 5% of CP is taken as the optimum quantity to convert conventional concrete to a sensing concrete with satisfying strength.
- Experimental investigation proved that Hybrid filler overcomes the drawbacks of Mono fillers.
- All the designed combination of Hybrid fiber composite satisfied the strength criteria.
- For Type 1 composites maximum conductivity is obtained for specimen with fillers, CP and GP in the combination of 3:2 and it was increased by 1.8 times fold which is 86.7% more than 5% CP incorporated concrete mixture.
- Among Type 2 composite, CGS in the ratio 1.5:1.5:2 gives maximum conductivity which 2.89% more than Type 1 composite.
- The analysis of variation in electrical conductivity with strength using software is an area which requires further study.
- The strain v/s resistance graph plotted for Type 2 composites proved that the conductivity increases with increase in strain. This is because of the close proximity of fillers under compression.
- Any increase in resistance during loading is due to the formation of cracks within the composite.

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