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Investigating the Performance of Self Compacting Concrete Concrete Utilizing Micro Carbon Fibers as Sensing Agents

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ABSTRACT

While several structural health monitoring techniques exist, the use of smart concrete for this purpose is a relatively recent innovation. In this method, regular cement mortar or concrete is transformed into a self-sensing material by incorporating carbon fibers, enabling it to detect strains, stresses, and loads. To delve into this technique, the current research involves casting concrete cubes using self-compacting concrete measuring 15 cm, reinforced with varying dosages of carbon fibers. Numerous tests were conducted on an adequate number of specimens, encompassing stress and strain sensing detection. The results revealed a significant correlation between the properties of the concrete cubes and the change in fractional resistance (FCR). These findings indicated that a 1.5% dosage of carbon fibers in the specimen yields the strongest correlation between FCR and concrete cube properties. Additionally, this dosage was found to be optimal for stress sensing and crack/damage detection.

1. INTRODUCTION

Structural health monitoring (SHM) involves techniques used to identify and characterize damage or cracks in structures like bridges and buildings. Typically, devices like extensometers, strain gauges, load cells, and dial gauges are mounted internally within structural elements to monitor tension, compression, and other factors. However, this method does not provide accurate internal stress data for reinforced concrete elements and is limited in its ability to monitor the entire structure effectively.

To address this limitation, researchers have discovered that certain fibers such as carbon fibers, multiwall carbon nanotubes, nanotubes, and carbon black possess excellent self-sensory capabilities unlike other types of fibers. When these fibers are randomly distributed within cement or mortar composites, they activate the sensory properties of these materials. These fibers have the ability to promptly modify the electrical resistance of cement composites under various loads, enabling continuous health monitoring. Consequently, the concept of structural health monitoring (SHM) can be effectively applied by integrating internal sensors into concrete through this technique.

In recent literature reviews, various researchers have observed that when external compressive loads are applied to carbon fiber (CF) based cement specimens, the electrical resistance undergoes changes, either increasing or decreasing, in smart concrete or self-sensing concrete [1], [2]. Similarly, during flexural loading, the electrical resistance on compression surfaces decreases as the fibers move closer due to surface stretching. Conversely, during unloading at the tensile surface, the electrical resistance increases as the fibers are pulled away from each other [2], [3]. Several studies have investigated the behavior of cementitious composites with the introduction of CF [2], [4], [5]. Different research works have examined the impact of individual percentages of CF and carbon nanotubes (CNTs), as well as their combined effects, on cement composites for damage and strain sensing properties [6]. Additionally, some researchers have explored the practical applications of carbon fibers in traffic control when incorporated into cement composites [7], as well as in Structural Health Monitoring (SHM) [8].

2. EXPERIMENTAL INVESTIGATION

2.1 Materials Properties

The cement blend utilized in this study was composed of 43-degree Ordinary Portland Cement (OPC). Tap water, adhering to the specified water-cement ratio (w/c) of 0.4, was employed in the preparation of all samples. Additionally, a surfactant named Dedocylic benzene sulfonic sodium salt [7] was mixed in water to ensure effective dispersion of carbon fibers (CFs). The carbon fibers used in this study were SYC-TR-PU (supplied by Sanyung company, China) and were incorporated into self-compacting concrete (SCC) in various percentages, ranging from 0 to 2% with 0.5% step increments. Different doses of CFs were employed to investigate stress sensing behavior and to determine the percolation limit for further analysis. Table 1 provides the physical properties of the CFs utilized in this study. To enhance fiber dispersion and concrete workability, SCC was developed in this experimental study. To achieve SCC, a superplasticizer based on polycarboxylic ether (PCE) was added at one percent by weight of cement.

Table 1. Carbon Fiber Properties

Length	Mm	6
Carbon Content	%	95
Filament Diameter	µm	6.97
Density	g/cm^3	1.78
Tensile Strength	MPa	4,810
Density	g/cm^3	1.78
Tensile Modulus	GPa	225
Elongation	%	2.3
Electrical Resistivity	w.cm	1.54x10^{-3}

2.2 Specimen Preparation

Concrete cubes measuring 15 cm were produced with varying dosages of carbon fibers (CFs). To create fiber-based concrete, a solution comprising a mix of surfactant and water necessary for casting was prepared by blending the two using a shear mixer for twenty minutes. Carbon fibers were then added and mixed in the solution with the same mixer for an additional twenty minutes to ensure even distribution of CFs. This mixture was combined with dry concrete ingredients (already mixed in a dry state and kept in the mixer) along with a 1% superplasticizer to produce Self-Compacting Concrete (SCC). The resulting fresh concrete mixture was poured into metal molds and left at room temperature for 24 hours. After this period, the samples were demolded and submerged in fresh water for 28 days. The mix proportions for SCC, including material properties for 0.5% CF, are detailed in Table 2. For samples containing 1%, 1.5%, and 2% CF, the fiber volume was adjusted while keeping all other ingredients constant.

Table 2. Mix Propertion

S. No.	Materials	Remarks	Quantity in kgs /m3 of concrete
1	Cement	43 Grade OPC	475
2	Carbon Fibre	Electrically conductive	2.37
3	Fine Aggregate	FM-2.56 and Zone-III	653.4
4	Water	Tap water having pH 7.1	203.4
5	Coarse Aggregate(of maximum size 10 mm)	FM- 6.88	1174
6	Surfactant	Dedocyl Benzenesulphonic acid sodium salt (SDBS)	0.32
7	Superplastizer	PCE based	8.7

FM-Fiennes modules, PCE- Polycarboxylic ether

2.3 Testing Procedure

A Universal Testing Machine (UTM) with a capacity of 1000 kN was employed for all the tests conducted in the experiment. The UTM was utilized to measure load and stress, while a Digital Multimeter (DMM) was used to assess changes in electric resistance. In preparation for the tests, an electrically conductive paint was applied to the surface of all concrete samples. Copper wires were wound perpendicularly to the direction of load application over this conductive paint. To record changes in resistance during loading, the DMM was connected to these copper wires.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Ultimate Strength

In evaluating the peak load carrying capacity of three specimens for each carbon fiber dosage, compressive strength tests were conducted. This step was crucial to ensure that the applied load during stress/strain sensing tests remained within the material's elastic limit. Additionally, it aimed to understand the impact of adding carbon fibers (CFs) to the concrete mixture.

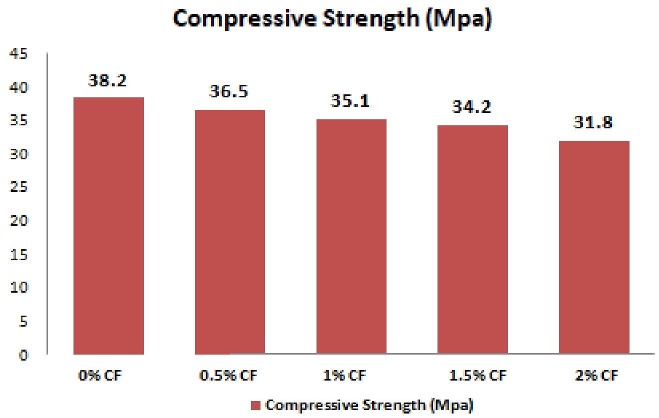

Fig.1. Compressive strength of all the specimens

The results of these compressive strength tests are illustrated in Figure 1. The figure indicates that the peak stress slightly decreases with an increasing quantity of fibers. This phenomenon can be attributed to the higher presence of carbon fibers, leading to reduced strength due to the formation of small air pockets within the material. Specifically, compared to specimens without fibers, a decrease in strength of 1.67%, 6.4%, 8.6%, and 11.6% was observed for CF dosages of 0.5%, 1%, 1.5%, and 2%, respectively.

3.2 Stress sensing Results

specimens were subjected to a peak load of 260kN (within the elastic range) after 28 days of curing. For each dosage of carbon fiber, plots illustrating Fractional Change in Resistance (FCR) and stress were created over time. During the testing process, strain and load on the cube were measured using the Universal Testing Machine (UTM), while changes in resistance were recorded using a digital multimeter. By utilizing the formula "load upon area," stress values were calculated. The time-related data depicting stress and FCR findings are presented in Figure 2.

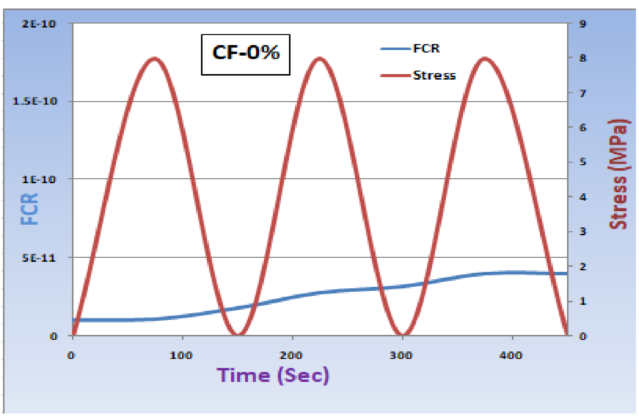

Fig. (a) CF 0%

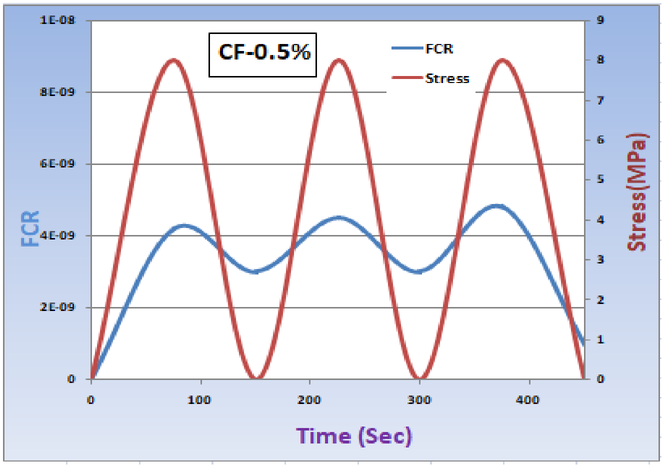

Fig. (b) CF 0.5%

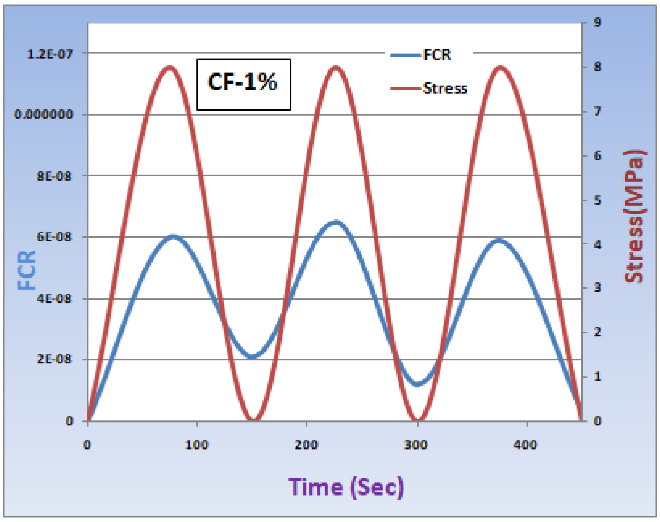

Fig. (c) CF 1.0%

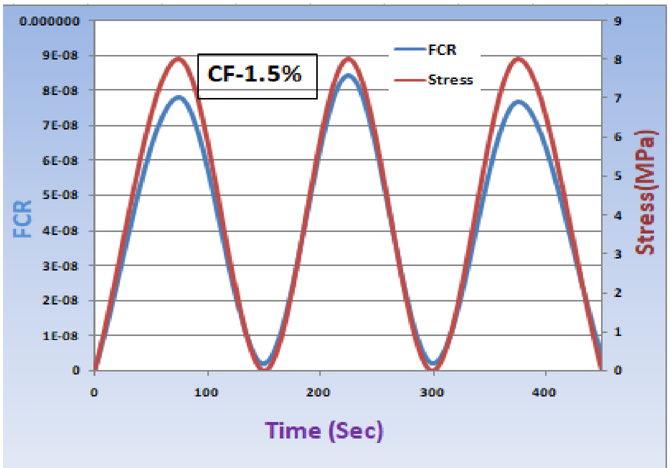

Fig. (d) CF 1.5%

The results obtained indicate that there is a noticeable difference in the correlation between stress and Fractional Change in Resistance (FCR) in specimens without carbon fibers, as shown in Figure 2-a. In these specimens, FCR is considerably lower than in those containing embedded carbon fibers, with a maximum order of 4x10-5. Moving from Figure 2-b to 2-e, as the dosage of fibers increases, a clear and strong correlation between FCR and stress is evident, especially during cyclic loading. This trend aligns with previous studies [9] and highlights a reversible relationship between FCR and stress as fiber dosage increases.

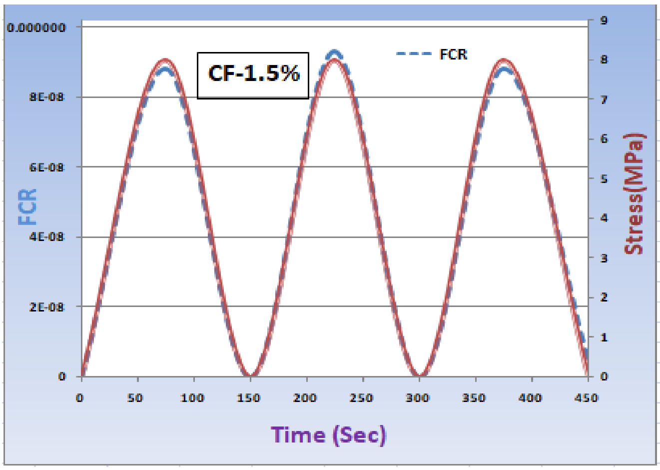

Fig. (e) CF 2.0%

Fig.2 (a to e): Strain Sensing Behavior of all the samples with different dosages of CF

The average improvement in electrical resistivity was 4x10-5, which surged to 200 times in specimens with 0.5% fibers. This led to an overall increase of 0.007 (in the third cycle) for FCR relative to specimens without fibers. The multiplication factor for FCR increases by 1.36 from 0.5 to 1%, 2.2 from 1 to 1.5%, and 1.52 from 1.5 to 2%.

4. CONCLUSION

In the current study, self-consolidating concrete cubes with varying carbon fiber dosages were evaluated for stress sensing and damage detection tests. The study led to the following conclusions:

Electrical Resistivity and Percolation Levels: The study revealed a decrease in electrical resistivity as the dosage of carbon fibers increased, with percolation levels observed at a dose of 1.5 percent of carbon fiber in the cement weight.

Compressive Strength: It was noted that the maximum compressive strength decreased with higher carbon fiber dosages. This decline was attributed to the formation of fiber agglomerates, leading to voids and a reduction in strength.

Correlation between Properties: The presence of carbon fibers at 1.5% and 2% by weight of cement demonstrated a strong correlation between concrete properties (strain/stress) and electrical resistivity (FCR). From an economic standpoint, 1.5% carbon fiber was identified as the optimal dosage for this correlation.

Implications for Structural Health Monitoring (SHM): The results of the stress and damage sensing tests offer a novel approach to Structural Health Monitoring (SHM). This non-destructive testing (NDT) method proves effective in detecting changes in load, stress, and strain acting on structures or structural elements by measuring electrical resistance.

These findings represent a significant step forward in the field of SHM, providing valuable insights into non-destructive methods for monitoring and understanding the structural behavior of concrete elements under varying conditions.

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