**Effect of varying high and low-speed churners on the dispersion of carbon fibers in self-compacting concrete for flow and electro mechanical properties**

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**Abstract :**

In this study, the influence of two varying speed RPM mechanical churners on the de-agglomeration of short pitch-based carbon fibers for proper dispersion and distribution in SCC were investigated. The degree of dispersion was assessed by investigating the change in rheological and electrical properties of carbon fiber based self-compacting concrete. The tests were done on fresh state properties, compressive strength properties and electrical properties of SCC incorporating carbon fiber. The fresh concrete properties of carbon fiber based concrete varied with varying techniques. A decrease in the electrical resistance properties was observed in both the methods employed with variations in the magnitude of the decrease as per the method engaged.

Key words : Mechanical Dispersion, High-Speed Churner, Low-Speed Churner, Carbon fiber, Self Compacting Concrete, Electrically conductive concrete

1. **Introduction:**

Short fibers are used as admixtures in cement-based materials for the purpose of decreasing the drying shrinkage, increasing the flexural toughness, and, in some cases, increasing the flexural strength as well (1-6). In the case that the fibers are electrically conductive, the fibers may also provide nonstructural functions, such as self-sensing for sensing the strain, damage, or temperature, self-heating for deicing, and electromagnetic reflection for electromagnetic interference shielding, i.e., EMI shielding. *(1, 7)*

Carbon fiber cement-matrix composites are structural materials that are gaining in importance quite rapidly due to the decrease in carbon fiber cost (8) and the increasing demand of superior structural and functional properties(9). Carbon fiber incorporated concrete (CFIC) have been extensively used as smart civil engineering materials for health monitoring, non-metal heating elements for buildings against electromagnetic wave shielding (10-13) structural monitors, intelligent buildings and deicing or snow-melting pavements (14-20*).* The resistive, piezoresistive, thermoelectric, and electromagnetic behavior of cement-matrix composites are greatly modified by the use of short carbon fibers. Short carbon fibers are efficient in enhancing the piezoresistive behavior and enhancing the effect of damage on the resistive behavior. Submicron diametercarbon filaments are effective for enhancing the electromagnetic reflection behavior.*(21*)

The effectiveness of a fiber admixture for improving the structural or functional properties of cement-based materials is greatly affected by the degree of fiber dispersion. The attainment of a high degree of fiber dispersion is particularly critical when the fiber volume fraction is low. A low fiber volume fraction is usually preferred, because the material cost increases, the workability decreases, the air void content increases, and the compressive strength decreases as the fiber content increases (22). In cases where the fiber volume fraction is below the percolation threshold (the fiber volume fraction above which the fibers touch to form a continuous electrical conduction path), the greater the degree of fiber dispersion, the higher is the conductivity of the composite.

The desirable distribution of carbon fiber in cement-based composites is the foundation to the functional properties of Carbon fiber based cement composites (23). It is difficult to achieve structural and electrical function roles of carbon fibers when they are poorly dispersed (24-26)*.* The dispersion of the micro carbon fibers in a cementitious matrix is rather delicate because the micro threads of the carbon fibers tend to agglomerate in the water due to the presence of attractive forces (Van der Waals). Infiltration of agglomerates with matrices is very difficult, and their presence is, therefore, the source of potential defects in micro composites. The process of de-agglomeration and subsequent distribution of short micro carbon fibers is achievable with the proper dispersion of fibers. The dispersion can take place either due to abrupt splitting up of agglomerates into small fragments under high stress (rupture) or due to continuous detachment of small fragments at a comparatively lower stress (erosion). The dispersion behavior of Carbon micro fibers depends on a few critical factors such as length of micro materials, their entanglement density, volume fraction, matrix viscosity, and attractive forces (27). Wang et al. (28, 29)in their study illustrated that the reinforcing ability of CFs depended on how the fibers were dispersed throughout the composites. Poorly dispersed fibers provided little or no reinforcement in some regions, which then acted as flaws in the composites. Therefore, the uniform dispersion of CFs is important for improvement in the functionality of the composites. (29)

In order to make carbon fibers uniformly dispersed in the cement matrix, appropriate techniques have been suggested in the previous studies. Many researchers have suggested that suitable dispersants, and additives (30,31) should be added in the preparation of CFRC composites (13). Cao and Chung (32)explain that cement mortar reinforced by short carbon fibers was improved by using acrylic dispersion as an admixture in the amount of 15% by mass of cement. The improvement of the tensile properties (particularly strength and ductility) was more than those attained by using methylcellulose, styrene acrylic, or latex as admixtures (29).

 Different chemical methods have also been tried till date to achieve a homogeneous dispersion of carbon materials in water and various polymers such as using solvents, surfactants, functionalization with acids, amines, fluorines, plasma, microwave and matrix moieties, noncovalent functionalization, using block polymers, wrapping conjugated polymers, and other techniques. On the other hand, the basic physical technique used for carbon material dispersion is the ultrasonication, which is often used in combination with the other methods mentioned above (27)*.* Surface treatment of carbon fiber (e.g. by heating or by using ozone, silane , SiO2 particles or hot NaOH solution ) has also proven to be useful for improving the bond between ®ber and matrix, thereby improving the properties of the composite (9).

Nowadays researchers have been focusing more on various mechanical mixing methods for dispersion techniques of carbon fibers in concrete and their influence on the fresh state properties, mechanical properties and electrical behavior of concrete in comparison to chemical additive methods that cause interference in the properties of cement matrix. Mixing methods of carbon fibers can manifestly influence their dispersion in the cement matrix.The mixing of the mixture, the agitation method, and the vibrating molding process all have a great influence on the dispersion of carbon fibers in the cement matrix and the density of the CFRC composites (20,33). Yan Huang et al (34),state that when being mixed in a solution, filler aggregates are subjected to shear stresses imparted from the medium (e.g., solvent or polymer melt). Therefore, the flow of the medium in response to an external force (e.g., through the rotation of a mixer blade, or cavitation in ultrasonication) generates the local shear stresses that are ultimately responsible for dispersion. Thus a mixing process can be interpreted as the delivery of mechanical energy into the solution to separate the aggregates. The opposing factor against separation is the binding energy which holds the aggregates together. Considering the above two factors, one can establish the mixing criteria for effective aggregate separation as the supplied energy from the chosen mixing technique to be greater than the binding energy of the carbon fiber aggregates. On the other hand, to retain the morphology of individual Carbon fiber thread, the supplied energy should also be lower than the amount required to fracture a thread. Hence, an ideal aggregate separation technique should supply an energy density between the binding energy of the aggregates, and the fracture resistances of individual carbon fiber thread (34).

The separation of the cluster carbon fibers in the concrete influence directly on the rheological and electrical behavior of concrete and the deviations in the properties of concrete are often used to obtain the degree of dispersion achieved using a particular method. Yang, et al. (35) and Woo, et al. (36) reported that the fiber dispersion in the conductive cement concretes, such as CFRC and steel fiber reinforced concrete, can be characterized by the deviation in the electrical resistivities of multiple specimens (23). Woo et al. (37) compared the conductivity of different specimens to determine the uniformity of steel fiber dispersion (20).

 Good dispersion of carbon fibers thus is the main factor for transmitting the smart functional properties of carbon fibers into the cement matrix. Though Different chemical and mechanical techniques have been investigated, the influence of the combination of dispersants and molding processes on the dispersion degree of carbon fibers either in the aqueous solution or in the cement matrix is rarely investigated (33).

In summary, the dispersion degree of the CFs in the composites plays a significant role on physical mechanics and durability. However, it is not easy to evaluate the dispersion degree quantitatively. Therefore, it becomes imperative to study the influence of carbon fiber dispersion in concrete using varying dispersion techniques and to recommend suitable mixing methods for preparing the carbon-fiber-reinforced cement-based composites.

This research studied the effect of short carbon fibers on the fresh state properties, compressive strength properties and electrical properties of concrete with varying methods of mechanical dispersion of carbon fibers in concrete. Two mechanical churners with varying RPM are used in two different ways of mixing procedure to disperse the carbon fibers in concrete and their effects on the properties of concrete, both in the fresh and hardened state are presented in this study.

* 1. **Materials**

Materials used in preparation of Carbon fiber based self-compacting concrete (CFBSCC) mixtures included

Portland Cement 43 grade conforming to IS 12269 – 1987, Coarse aggregates of maximum size 10mm and fine aggregates of Zone II conforming to IS383 – 1970 and high range water reducer (HRWR). The fiber used to reinforce the cementitious composite to attain the electrical properties was Pitch based short (micro) Carbon fiber as seen in figure 1 of length 6mm. and dia 8(µm). HRWR based on modified polycarboxylic ether - Master polyheed 8101 was finalized to attain the target workability in the concrete. The selection of HRWR was done on the basis of trail mixes. The properties of the ingredients used are tabulated in table 1 and the properties of carbon fiber are summarized in table 2.

|  |  |  |  |
| --- | --- | --- | --- |
| Cement | Fine Aggregate | Coarse Aggregates | HRWR |
| Specific Gravity | 3.11 | Specific Gravity | 2.72 | Specific Gravity | 2.6 | Appearance and Form | Cream |
| Specific gravity @ 25°C | 1.14 – 1.16 |
| Consistency | 30% | Water Absorption  | 2.57 | Water Absorption | 0.56 | pH-value @ 25°C | 4-6 |
| Initial Setting Time | 144min | Gradation | Zone II | Fineness Modulus | 7.4 | Chloride ion content ≤ | <0.01% |
| Final Setting Time | 350min | Fineness Modulus | 2.7 | Alkali content (Na2OEquivalent %) | < 3% |
| Table 1 Properties of Cement and Aggregates |

|  |  |
| --- | --- |
| Carbon Fiber Chopped | GC-700T-PU6 |
| Length of Fiber | 6mm |
| Carbon Content | 95% |
| Elongation % | 1.75 |
| Tensile Strength MPA | 3500 |
| Tensile Modulus Gpa | 230 |
| Filament Diameter (µm) | 8 |
| Density (g/ltr) | 350 |
| Table 2 Properties of Carbon Fibers |



Figure 1 Pitch Based short carbon fibers

Mechanical churners of varying RPM were employed for the distribution and dispersion of carbon fibers. Dispersing agent Sodium Dodecyl benzene sulfonic acid salt (surfactant) was also used. The surfactant paved the way for dispersion of chopped short carbon fibers in the water by reducing the surface tension of water. The methods of dispersion of carbon fibers were based on the mechanical churners rather than chemical admixtures.

* 1. **Mixing Proportion**

Several mixing methods were used to achieve the desired properties of self-compacting concrete and proper distribution of electrically conductive short carbon fibers in self-compacting concrete (SCC). During the preparation of mixtures, w/c ratio, Aggregate to cement ratio and HRWR ratio were kept constant. The percentage of HRWR was set after observing the influence of varying dosages on the flow properties of reference concrete. 2 percentages of 0.5% and 2% of carbon fibre were added in the SCC mixtures based on the available literature. The mixture was finalized after a set of trail mixes. The trials were aimed to obtain a mix with proper self-compacting properties conforming to EFNARC 2005 guidelines for self-compacting concrete. The composition of CFRSCC is presented in table 3.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Mix | Cement (kg/m3) | CA (Kg) | FA (Kg) | W/C | CF % | HRWR |
| M1 | 490  | 735 | 833 | 0.42 | 0% | 2% |
| M2 | 490  | 735 | 833 | 0.42 | 0.5% | 2% |
| M3 | 490  | 735 | 833 | 0.42 | 1.5% | 2% |
| Table 3 Details of Mixture proportions per unit volume of concrete |

* 1. **Mixing Procedure**

The CFBSCC was prepared in a laboratory mixer of 100 ltr maximum capacity. Coarse & fine aggregates were mixed together by adding the 1/4th of mixing water for 60s. The binder was then added followed by the second quarter of water and mixed for 90s. The 3rd quarter of mixing water was then blended with HRWR and was added to the mixture in the mixer and the concrete mixture was mixed further for 60s. The final quarter of water was used for dispersion of CF. As the cement and aggregates were mixed in the mixer, the process of dispersion of carbon fibers in the final quarter of water took place simultaneously and was then added after completing the process of dispersion of carbon fibers.

* 1. **Dispersion of Carbon Fibers**

The dispersion of the micro carbon fibers in a cementitious matrix is rather delicate because the micro threads of the carbon fibers tend to agglomerate in the water due to the presence of attractive forces (Van der Waals), The process of de-agglomeration and subsequent distribution of micro materials within matrices or solvents is called dispersion. The dispersion can take place either due to abrupt splitting up of agglomerates into small fragments under high stress (rupture) or due to continuous detachment of small fragments at comparatively lower stress (erosion) (27).

Mechanical churning methods were employed for better and proper distribution of carbon fibers in this study. The addition of carbon fiber was facilitated by dispersing the carbon fiber in water along with the Sodium Dodecyl benzene sulfonic acid salt (surfactant). Mechanical churners with varying RPM were then used for splitting up of agglomerates into small fragments. The influence of the dispersed fibers thus on SCC properties for every method was observed in both fresh and hardened state. The variations in the electrical properties of concrete with varying methods of dispersion were also observed. The methods employed for the dispersion of carbon fibers in concrete are explained under as:

* + 1. *Method of dispersion of carbon fibers using High RPM Mechanical Churner – Method 1*

Meanwhile, the mixing of cement and aggregates took place in the mixer, the surfactant was added to the final quarter of the mixing water and the water was churned for around 15seconds to acquire the foam. The carbon fibers were then gradually added to the foam generated and the foamed water was churned using the high-speed RPM router (Figure 2). The properties of the mechanical high-speed RPM router is summarized in table 4. The carbon fibers were added to the foamed water in three equal divisions and the churning continued till all the fibers were added. The churning was continued for 120seconds after which it was added to the concrete in the mixer gradually and the mixing was allowed to take place for further 90s. The mixture was then poured and tested for slump flow properties and the specimens were then casted.



Figure 2 High-speed RPM Churner

|  |  |
| --- | --- |
| Brand Name  | Brand Name  |
| Model | Model |
| Power Watt | Power Watt |
| Frequency Hz | Frequency Hz |
| Input Voltage Ac | Input Voltage Ac |
| Speed RPM | Speed RPM |
| Churner Diameter mm | Churner Diameter mm |
| Table 4 High-speed RPM properties |

*2.4.2 Method of dispersion of carbon fibers using low RPM Mechanical Churner – Method 2*

The low-speed RPM mechanical churner as seen in figure 3 was used so as to compare the effect of the mechanical churning at varying RPM’s. The properties of the churner as illustrated in table 5. The carbon fibers were added to the foamed water as described in method 1 and the churning of the foamed water followed at low speed. The churning started at 300 RPM and continued till 60seconds. The speed was increased to 1440 RPM gradually till all the fibers were added in the water. The churning continued for more 120seconds.

The water containing carbon fibers was then added to the mixer and the mixing lasted for more 90seconds. The properties of concrete were then noted down and the specimens were casted.



Figure 3 Low RPM Churner

|  |  |
| --- | --- |
| Brand Name  | Brand Name  |
| Power Watt | Power Watt |
| Input Voltage Ac | Input Voltage Ac |
| Speed RPM | Speed RPM |
| Churner Diameter mm | Churner Diameter mm |
| Table 5 Low-speed RPM properties |

* 1. **Specimen Casting**

Cube specimen of size 150mm x 150mm x 150mm were casted for evaluating the effect of each mixing methods on the compressive strength properties of hardened concrete. The concrete poured just after mixing was tested for flow properties in the plastic state. For assessing the flow properties, slump test, L-box test, and segregation tests were done. The concrete then was casted in the cube moulds and was unmolded after 24hours and kept for curing.

* 1. **Electrical Measurement**

The influence of the carbon fibers on the electrical properties of concrete was observed. The change in electrical resistance with a change in mixing methods depicted the amount of dispersion of fibers in the concrete. Two probe method was employed for assessing the electrical measurements. The electrical contacts on the concrete cube specimens were made by two copper wires wound along the surface of the specimen in two layers as seen in figure 4. The cubes were color coated with conductive paint for ensuring minimum leakage in the circuit. A highly precise digital multimeter was connected to the copper wires to record resistance measurements digitally. The properties of the digital multimeter used are illustrated in table 6. Resistance measurements were all made at a DC current in the range of 500µA to 10A.



Figure 4 Electrical connections on cube specimen

|  |  |
| --- | --- |
| Model  | Model  |
| Counts | Counts |
| Bandwidth | Bandwidth |
| Voltage AC/DC | Voltage AC/DC |
| Current AC/DC | Current AC/DC |
| Frequency | Frequency |
| Table 6 Properties of digital Multimeter |

* 1. **Results & Discussions**

The main aim of this study was to evaluate the variations in the properties of SCC both in fresh state (Flow Properties) and hardened state (compressive strength and electrical properties) using two varying speed RPM mechanical churners for dispersion of carbon fibers in concrete. The properties that were examined during the fresh state of concrete were flow properties and the segregation properties. In the hardened state, the SCC was examined for its compressive strength and electrical properties.

* 1. **Dispersion of fibers in mixing water**

High-speed RPM churners used in method 1 was not fruitful in dispersing the fibers. It further escalated the agglomeration of fibers by damaging the individual threads of micro fibers which in turn got accumulated rather than dispersing it. The fibers accumulated in mass groups and got inter twisted with each other by the high speed action of churners leaving no space for dispersion of the carbon fibers.

While as the low-speed RPM churner evenly distributed the fibers in the water by providing the right amount of churning energy that was feasible in even distribution of fibers. The fibers did not bound further with each other but started getting apart and individual threads getting apart could be visualized clearly.

* 1. **Properties of SCC in fresh state**

Table 7 summarizes the flow properties of SCC incorporating carbon fibers using two varying speed RPM churners. The results are compared to the reference mix without carbon fibers. The filling ability and passing ability tests were done in accordance with EFNARC 2005 and the segregation test was done in accordance with the guidelines prescribed by Ministry of Transportation, Ontario in there Laboratory Testing Manual, LS 438. Visual segregation test index is tabulated in table 8.

* + 1. *Method 1*

 The flow properties summarized in Table 7,reveal that there is a variation in the properties of CFBSCC with varying methods of mixing. In method 1, the slump flow (Filling ability) tests observed show a decreasing trend in the flow properties. The slump flow shows a decrease of 6.2% and 37% when 0.5% CF and 1.5% CF is being added to the SCC. This decrease illustrates the non dispersed condition of carbon fibers which hindrances the flowability properties with an increase in the carbon fiber percentage. The agglomerated fibers do not allow the concrete to move freely thus restrict its action of flow. The addition of carbon fibers beyond 0.5% with this method made the flow to lose its self compacting property as the diameter of flow obtained does not lie in the range of 550mm to 850mm as prescribed by EFNARC 2005.

 The passing ability in this method is too adversely affected by the increasing percentage of carbon fibers. With the increase of 0.5% CF and 1.5% CF , the ratio of L-box reduces from 0.89 to 0.69 which is well below the specified range of 0.8 to 1 for self-compacting concrete. (EFNARC 2005)

 The visual segregation tests in this method also indicate no improvement. The segregation index shows no changes with the increasing percentage of carbon fibers thus this method doesn’t improve the segregation resistance in the SCC.

* + 1. *Method 2*

During this method, an increase in the flowability properties was observed up to a certain level of incorporation of carbon fibers after which a decrease in the flow properties was observed as tabulated in Table 7. The slump flow increased with the addition of 0.5% CF and decreased at 1.5% CF. The flow depicted an increase of 2.3% at 0.5% CF and a decrease of 8.5% at 1.5% CF. The initial increase in the flow is attributed to the minimum hindrance by dispersed fibers in the concrete and also to the addition of surfactant in the mixing water which further made the concrete to flow. The decrease in the flow property is due to the generation of friction properties with the incorporation of carbon fibers that restrict the concrete to flow freely. The decrease though did not make the concrete to lose its self compacting property as the flow even after the decrease was well above 550mm which is within the prescribed range of 550mm to 850mm.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Method | Batch | CF % | W/C | SP % | Slump (Filling Ability) | L Box Ratio(Passing Ability) | Segregation Visual Stability Index |
| Reference Mix | M1 | 0% | 0.42 | 2% | 645mm | 0.82 | 02 |
| Method 1 | M2 | 0.5% | 0.42 | 2% | 605 mm | 0.79 | 02 |
| M3 | 1.5% | 0.42 | 2% | 405 mm | 0.69 | 03 |
| Method 2 | M2 | 0.5% | 0.42 | 2% | 660 mm | 0.89 | 00 |
| M3 | 1.5% | 0.42 | 2% | 590 mm | 0.76 | 01 |
| Table 7. Fresh Properties of CFRSCC and control mixture |

The passing ability also depicted an initial increase with the addition of 0.5% CF and a decrease in the property with the addition of 1.5% CF. L-box ratio increased from 0.82 to 0.89 with 0.5%CF addition and decreased to 0.76 with addition of 1.5% CF. SCC lost its flow passing property beyond 0.5 %CF.

The segregation properties of SCC got improved with this method of mixing. The fibers dispersed evenly in the concrete and did not accumulate in groups that resulted in lowering the segregation index and thus increasing the segregation resistance as tabulated in table 7. The segregation index for both 0.5%CF and 1.5% CF was well within the index prescribed in table 8.

|  |  |
| --- | --- |
| **Rating** | **Criteria** |
| 0  | No evidence of segregation in the slump flow patty or in the mixer drum or wheelbarrow. |
| 1 | No halo or aggregate pile in the slump flow patty but some slight bleeding or air bubbles on the surface of the concrete in the mixer drum or wheelbarrow. |
| 2 | A slight halo (<10 mm) at the perimeter of the slump flow patty and/or aggregate pile in the slump flow patty and highly noticeable bleeding in the mixer drum and wheelbarrow. |
| 3 | Clearly segregating by evidence of a large halo (>10mm) at the perimeter of the slump flow patty and/or large aggregate pile in the centre of the concrete patty and a thick layer of paste on the surface of the resting concrete in the mixer drum or wheelbarrow. |
| Table 8. Segregation Index Criteria, Laboratory Testing Manual, LS 438. |

* 1. **Compressive strength Properties**

Table 9 illustrates the compressive strength test results of specimens incorporating electrically conductive carbon fibers and reference mix at 28days and 56days of curing for the 2 methods employed. Results are the average from triplicate test specimens. The compressive strength test results are further illustrated in figure 5.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Method | Batch | CF % | 28th Day Mpa  | 56th Day Mpa |
| Reference Mix | M1 | 0% | 22.6 | 25.9 |
| Method 1 | M2 | 0.5% | 21.8 | 24.9 |
| M3 | 1.5% | 19.2 | 21.5 |
| Method 2 | M2 | 0.5% | 23.9 | 26.5 |
| M3 | 1.5% | 24.7 | 27.6 |
| Table 9. Compressive strength properties |

As seen in figure 5, in the first method of mixing and dispersion, the compressive strength specifies a decrease with increasing carbon fiber percentage when compared to the reference mix. At 28th day, specimen with 0.5% CF and 1.5% CF showed a decrease of 3.67% and 17.7% in the compressive strength respectively. At 56th day, a decrease of 4% and 20% was observed at 0.5% CF and 1.5% CF respectively.

In the 2nd method, the compressive strength results demonstrated an increase with the increasing percentage of carbon fibers. At 28th day, the specimens with 0.5%CF and 1.5% CF depicted an increase of 5.6% and 9% respectively. At 56th day, an increase of 2.3% and 6.5% were observed for 0.5%CF and 1.5% CF.

The decrease in the strength properties with respect to the first method was observed due to non distribution of fibers in the cementitious matrix. The method employed using high-speed RPM churner made the fibers to accumulate further in masses and did not serve in splitting up of agglomerates into small fragments. It adversely affected the distribution of fibers by grouping of fibers as masses which resulted in further agglomerates. The agglomerates in the matrix paved way for generation of more and more pores and enhanced capillary movement of water resulting in early micro cracks which resulted in weakening the strength.

 Figure 5 Compressive strength comparison

The increase in strength in the second method is attributed to the de agglomeration of the carbon fibers which resulted in the better dispersion and distribution of carbon fibers in the cementitious matrix. The dispersed fibers acted as crack healers by arresting the early cracks developed in the concrete and did not allow micro cracks to propagate with the increasing age of concrete thereby making concrete to achieve surplus strength. The lower speed RPM churners disturbed the grouping of the carbon fibers in such a way that the supplied energy for disruption of agglomerates was higher than the binding energy and the energy supplied at the very same time did not harm the morphology of carbon fibers.

The supplied energy (or, to be more precise, the local energy density) from the chosen mixing technique should be greater than the binding energy of the Carbon fibers (to be more precise, the energy per local volume of the contact). On the other hand, to retain the morphology of carbon fibers, the supplied energy should also be lower than the amount required to damage the physical properties of micro carbon fiber. Hence, an ideal fiber separation technique should supply an energy density between the binding energy of the fibers, and the fracture resistance of individual micro carbon fiber(27). In this study, it was found that the method 2nd fruitfully dispersed the fibers in the concrete without making physical damages to the fibers. The abundant result in the second method was due to lower speed RPM churner that maintained the right amount of energy density for prolific dispersion of fibers.

* 1. **Change in Electrical Resistance**

Figure 6 illustrates the measured electrical resistance of the cementitious matrix containing electrically conductive fibers. The resistivity measurements observed in the specimen with no carbon fibers portrayed very high resistance values. The higher resistance is generally due to the micro-cracks in the concrete that make concrete non conducting material. While as the resistivity measurements observed in specimens incorporating carbon fibers demonstrated a considerable decrease in electrical resistance. The decrease in the resistivity of the concrete is due to filling up of gaps and micro cracks by short micro carbon fibers that act as a medium that became a path for propagating the electrical circuit.

 Figure 6 Electrical Measurements for varying percentages of CF

In case of the reference concrete with no carbon fibers (0% CF), incredibly high resistivity was observed and it continued to increase with growing time. The resistivity observed in concrete sample without carbon fibers was 490 x 106 MΩ-cm.

As seen in Figure 6, It is being observed the that there is a decrease in the electrical resistance with the increasing percentage of carbon fibers in electrical resistivity measurement of the specimen’s casted by method 1. The electrical measurements observed at 0.5% CF and 1.5% CF are 388 x 103 KΩ-cm and 166 x 103 KΩ-cm respectively. The resistivity in the specimens thus got decreased from MΩ-cm to KΩ-cm.

Figure 6 further summarizes the electrical resistivity measurement of the specimen’s casted using method 2. It is being observed that there is a soaring decrease in electrical resistance with the increasing percentage of carbon fibers. The electrical measurements observed at 0.5% CF and 1.5% CF are 190 x 103 KΩ-cm and 155 Ω-cm. The resistivity in the specimens thus got decreased from MΩ-cm to Ω-cm.

The magnitude of the decrease is better in CFBSCC casted by method 2nd. It is clearly due to the proper and uniform distribution of carbon fibers by this method that lead to the increased conductive paths of electric circuits which eventually decreased the resistivity in the concrete.

**Conclusion**

In this study, the influence of two varying speed RPM mechanical churners on the de-agglomeration of carbon fibers for proper dispersion and distribution in SCC were investigated. The tests were done on fresh state properties, compressive strength properties and electrical properties of SCC incorporating carbon fiber. Based on the experimental investigations, the following conclusions can be drawn:

* The mixing method 2 is dominating in the properties of all the investigations.
* Method 2 is proven to be a feasible method for dispersing the carbon fibers in concrete as the fibers get de agglomerated by the action of low-speed churners while as the high-speed churners damage the fibers and also make them to inter twist with each other resulting in further agglomeration.
* The addition of carbon fibers with method 1 reduced the workability properties and also was not helpful in reducing the segregation in the SCC while as the addition of carbon fibers, with method 2 incurred better results of workability for lower percentage of CF and also reduces segregation. The addition of CF at higher percentages reduced the fluidity. The decrease in fluidity in method 2 at higher percentages is due to the addition of more carbon fibers that restrict the flow by creating friction in SCC particle to particle flow.
* From the fresh concrete properties it was concluded that the dispersion of fibers was more effective in method 2nd as the influence of dispersion positively improved the self-compacting property and at the very same time did not make the concrete to lose its self-compacting property. The mixing method 1 affected the concrete adversely in a negative manner.
* In compressive strength, the results worked out using method 1 show a decreasing trend with increase in the CF while as in method 2, there is an increase in the compressive strength with increasing carbon fibers. The decrease in the strength in method 1 specimens is due to the accumulation of agglomerated fibers in the concrete mass that generate more and more pores that eventually lead to more development of micro cracks which weaken the concrete. The increase in the strength in method 2 is attributed to even distribution of fibers in concrete that lead to filling up of micro cracks by the fiber filaments and arrest the cracks at the very initial state from further propagation.
* In both methods, there is a decrease in the electrical resistivity. The electrical resistivity measurements in method 2 illustrate an advanced decline in the resistivity properties than in method 2.
* The current study investigated two different speed churners in the area of mechanical dispersion of carbon fibers and it was concluded that the low-speed mechanical churners can very well be used for dispersing the fibers in the concrete thereby replacing the need of costly and complex chemical additives.

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