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Effect of Super Plasticizers on Fresh and Hardened State Properties of Short Carbon Fiber Reinforced Electrically Conductive Concrete

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Abstract: ***This study enlightens the influence of superplasticizers (SP) on the dispersion and distribution of carbon fibers in the carbon fiber reinforced concrete (CFRC) cast with a low w/c ratio. The effectiveness of Polycarboxylate ether (PCE) based SP in the enhancement of workability of concrete and deagglomeration of carbon fibers in CFRC has been studied extensively in this study. The effect of PCE based SP on the compressive strength properties and electrical properties of the CFRC were also studied. The microstructure of the CFRC specimens was also analyzed to study the impact of SP on the deagglomeration of carbon fibers in CFRC. It was observed that the inclusion of carbon fibers in the dry concrete mixes without SP showed a negative effect on the functional properties of concrete whereas the inclusion of SP in the CFRC mixes improved the mobility and viscosity of the CFRC mixes. The fresh and hardened state properties were effectively enhanced with the use of SP in the CFRC mixes. The magnitude of decrease in electrical resistance was better in SP based CFRC resulting in more electrical conductivity. The microstructure of the CFRC indicated improvement in the distribution of carbon fibers in SP based CFRC.***

Keywords: ***Superplasticizers, Carbon fiber reinforced concrete, Electrically conductive concrete.***

I. INTRODUCTION

The micro-cracks developing in the concrete impart detrimental effects on the strength of the concrete. These micro-cracks develop in the early stages of concreting as soon as placing the concrete and further develops with the application of load. The micro-cracks propagate more in the porous concrete due to the capillary movement in the porous concrete. The inherent micro-cracks eventually develop into macro cracks with the application of load and result in weakening the concrete structure [1]. Different fibers have been used to reinforce the concrete to prevent the propagation of microcracks at earlier stages. The principle basis of this prevention of propagation of microcracks is that the fibers act as the crack arrestors in the concrete matrix resulting in enhancing the overall strength thereby improving the structural properties of concrete[2 – 5].

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lass fibers [6], Steel fibers [7], cellulose fibers, polypropylene fiber [8], polyvinyl alcohol (PVA) fibers [9] are the most comprehensively used admixtures as reinforcement in concrete for improvement of the mechanical properties of concrete [10].

The recent studies have indicated the use of fibers in concrete that helped in enhancing the non- structural-functional properties of the concrete as well along with the structural-functional properties of concrete.

one such fiber being used is short Carbon fibers (SCF). The use of carbon fibers in the concrete is primarily done for improving the electrical conductivity of the concrete as the incorporation of the short carbon fibers in the concrete has lead to the successful development of electrically conductive concrete [11]. The electrically conductive carbon fiber reinforced concrete (CFRC) has the ability to sense its own internal damages. The signals about the damages are directly monitored by the lane or remote sensing systems. The signals on processing can be converted into stresses, strain, and detection of cracks in concrete members [11 - 13]. The carbon fibers also enhance the structural properties like compressive strength, tensile strength and drying shrinkage of the concrete. M.Yakhlaf states that as the carbon fiber content in the concrete increased, the splitting tensile strength, Modulus of rupture and toughness of Carbon fiber reinforced SCC (CFRSCC) mixtures also increased [14]. The attainment of such properties though depends on the proper distribution of carbon fibers in the concrete. The nature of the carbon fibers is to agglomerate and a proper viscous matrix is needed for the de-agglomeration of carbon fibers in concrete. The use of water to enhance the viscosity hampers the overall structural integrity of any concrete structure as the use of more water results in the reduction of mechanical strength and deterioration of structural members.

To overcome the viscosity limitations in concrete, super plasticizers (SP) are used. SP is used as high range water reducing additives that have improved the effective plasticizing effect on the wet concrete. Superplasticizers result in a substantial enhancement in workability at a given water-cement ratio. For constant workability, reduction of water content by up to 30% may be achieved by the use of superplasticizers. Superplasticizers can be used at higher dosages than conventional plasticizers in the range of 0.5% to 3% by weight of cement [15]. The advantage of the high plasticizing effect of SP on concrete can efficiently improve the carbon fiber cement matrix bond by helping in the deagglomeration of carbon fibers [16].

The use of superplasticizers thus eliminates the use of a high w/c ratio needed for providing a high viscous fluidic concrete mix for distribution of carbon fibers in CFRC.

Though the inclusion of SP in the CFRC can improve the fluidity of CFRC but at the very same time can influence the mechanical and electrical properties of CFRC. Also, it is imperative to investigate that whether the fluidity attained in the CFRC by the use of SP is better enough for the deagglomeration of carbon fibers in CFRC.

Therefore in this study, the effect of the superplasticizers on the fresh state and hardened state properties of CFRC has been investigated. The effectiveness of Polycarboxylate ether (PCE) based SP in the enhancement of the workability of concrete and deagglomeration of carbon fibers in CFRC has been studied extensively. The effect of SP on the compressive strength properties and electrical properties of the CFRC has also been presented in this study. The microstructure of the CFRC specimens has been investigated using scanning electron microscopy (SEM) analysis to access the distribution and dispersion of carbon fibers using PCE based superplasticizers.

II. EXPERIMENTAL PROCEDURE

1.1 Materials

Ordinary Portland cement 43 grade conforming to IS 8112:1989 [18] was used as a binder. Coarse aggregates of 10mm and fine aggregates of zone III conforming to IS383: 2016 [19] were used. Short carbon fibers (SCF) of 6mm length seen in figure 1 were used for attaining electrical properties in concrete. Modified polycarboxylic ether based Master polyheed 8101 was consumed as a Superplasticizer (SP). The properties of the SP and SCF are tabulated in table 1.

Figure 1. Pitch-Based Carbon fiber

Table 1. Properties of Superplasticizers and Carbon fibers

Masterpolyheed 8101		**Short Carbon Fibers (GC-700T-PU6)**	
Appearance and Form	Cream	Length of Fiber	6mm
Specific gravity	1.14 – 1.16	Elongation %	1.75
pH-value	4-6	Tensile Strength MPA	3500
Chloride ion content	<0.01%	Filament Diameter (µm)	6
Alkali content (Na2O equivalent %)	< 3%	Density (g/ltr)	350

1.2 Methodology

The methodology of the experimental study has been presented in the figure 2.

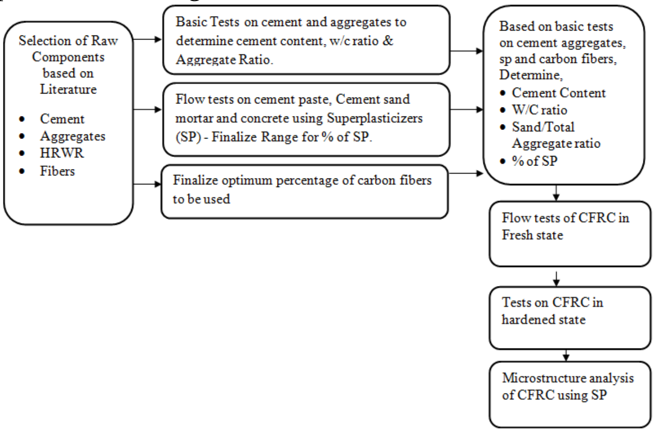

Figure 2. Methodology flow chart

1.3 Mixing Proportion

Nine mixes were prepared to investigate the effect of SP on the fresh state and hardened state properties of carbon fiber reinforced concrete. Nine mixes included three normal mixes without any added carbon fibers. These normal mixes were cast to investigate the impact of carbon fibers on the properties of concrete. W/C ratio and SP% were used as variables and CF% was kept constant. The composition of CFRC along with the water-cement ratio (W/C) is presented in table 2.

1.4 Mixing procedure

Hobart drum-based 100 ltr concrete mixer was used to prepare the CFRC. In the case of the normal concrete without SP and CF, the binder and aggregates were added to the mixer with the mixing water and were mixed thoroughly for 4 to 5 minutes. In the case of the concrete with CF and without SP, mixing water was added to the binder and aggregates in the mixer and the mixing was continued for 2 minutes. SCF fibers were then added to the semi mixed concrete mixture and the mixing was allowed to take place for further 3 minutes.

In the case of concrete with the SP and SCF, the mixing water was divided into two equal parts. The 1st half of water was added to the cement and aggregates in the mixer and the mixing took place for 90 seconds. The second half of water was blended with 1% SP (to the weight of cement) and was added to the semi mixed concrete. The mixing was continued for 90 seconds after which the carbon fibers were added to the mixture in the mixer. The mixing continued further for 2 minutes. The addition of SCFs took place at the later stage of mixing so that the fibers could get dispersed and distributed evenly in the concrete. The aptitude to disperse the carbon fibers within the matrix is elementary for obtaining the composite materials having enhanced properties and functionality.

1.5 Casting & Curing

Cubical specimens of size 150 mm x 150mm x 150mm for 9 mixes with varying w/c ratio and SP percentages were cast and the variations in the fresh state and hardened state properties of concrete were noted

Table 2. Details of Mixture proportions per unit volume of concrete

Mix	Batch	Cement (kg/m^3)	CA (Kg/m^3)	FA (Kg/m^3)	W/C Ratio	SP%	CF%
CFRC1 (1 : 1.5 : 1.7)	M1	490	735	833	0.42	0%	0%
	M2	490	735	833	0.42	0%	1%
	M3	490	735	833	0.42	2%	1%
CFRC2 (1 : 1.2 : 1.6)	M4	520	624	832	0.40	0%	0%
	M5	520	624	832	0.40	0%	1%
	M6	520	624	832	0.40	1.5%	1%
CFRC3 (1 : 1 : 1.5)	M7	540	540	810	0.38	0%	0%
	M8	540	540	810	0.38	0%	1%
	M9	540	540	810	0.38	1.5%	1%

Notation: CA = Coarse Aggregates, FA = Fine Aggregate, W/C = Water Cement Ratio, SP = Super plasticizer, CF = Carbon Fiber

down. Specimen were cured in normal water of the laboratory curing tank and were tested at the stipulated times. The specimens were cast for the 14th day and 28th day of strength.

III. RESULTS

The influence of the SP on the fresh state properties of the concrete was analyzed using a slump flow test and V-Funnel test. In the hardened state, the concrete was investigated for its compressive strength and electrical properties. The electrical properties were observed using digital multimeter based on two probe method. The microstructure of the specimens was also analyzed to study the effect of SP on the carbon fiber distribution in the concrete. The properties of CFRC both in a freshly mixed state and hardened state are tabulated in table 3.

IV. DISCUSSIONS

The inclusion of SP proved to be a vital constituent as the improvement in the workability of the concrete with the addition of SP paved path for better distribution of carbon fibers in the concrete. The variation in the properties of concrete was observed in both the fresh and hardened state.

4.1 Influence of SP on CFRC in the fresh state

The inclusion of carbon fibers in the concrete resulted in the aggravation of the workability and compactibility of the CFRC without superplasticizers. This loss of workability is in concurrence to the prior studies [16,17]. The short carbon fiber filament threads tend to agglomerate in the rough mixes and need proper viscous homogenous paste for getting de agglomerated. The deagglomeration of carbon fibers does not affect the workability of the concrete mix to the extent that agglomerated fiber filaments does to any mix. The damage to the fresh state properties of the CFRC in this study was primarily done by the bunch formation of the carbon fiber threads that restricted the flow of the concrete.

The incorporation of superplasticizers was beneficial in overcoming this limitation as the mobility of the mix was enhanced which resulted in the more workable mix. The overall fresh state properties were improved which was due to the deagglomeration of carbon fibers to some extent by the mobility attained by the mix with the use of superplasticizers.

4.2 Influence of superplasticizers on compaction and workability properties

In this study, the influence of SP on the CFRC was investigated using a slump value test. The slump value test was done in accordance to the IS 456:2000 [20]. The control mixes in all the three variants i.e CFRC1, CFRC2 and CFRC3 showed a rough mix that needed compaction before casting. In the mix M1 and M4, the true slump was observed with lesser segregation as seen in figure 3. In the mix M7, more segregation of ingredients was observed due to lower w/c ratio and the slump observed was a shear slump. The pictorial illustration of the slump observed in the mix M7 is given in figure 4. Average Compaction was needed for all the three control mixes for casting the specimens.

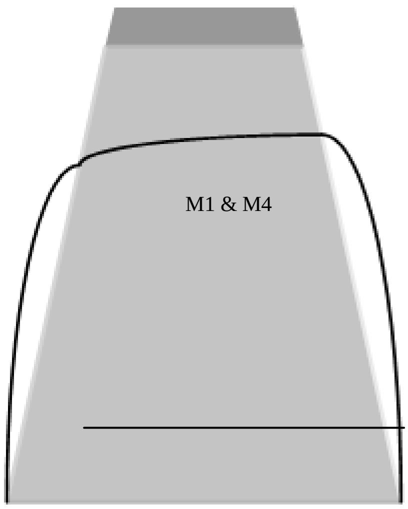

Figure 3. Pictorial representation of true slump of Control mix M1&M4

Table 3. Fresh Properties of different CFRSCC and control mixtures

Mix	W/C Ratio	SP%	CF %	Slump Value (mm)	V-Funnel	Compressive Strength 14th Day	Compressive Strength 28th Day	Electrical Resistance
M1	0.42	0%	0%	True Slump	33	13.6	20.9	365MΩ
M2	0.42	0%	1%	Shear Slump	46	10.5	16.9	5MΩ
M3	0.42	2%	1%	Collapse Slump - 396mm dia	21	13.8	19.6	286KΩ
M4	0.40	0%	0%	True Slump	31	15.9	22.7	256MΩ
M5	0.40	0%	1%	Shear Slump	38	14.2	20.8	89MΩ
M6	0.40	1.5%	1%	Collapse Slump - 404 mm dia	19	16.9	23.9	59KΩ
M7	0.38	0%	0%	Shear Slump	37	18.8	26.6	188MΩ
M8	0.38	0%	1%	Shear Slump	62	14.2	19.7	98MΩ
M9	0.38	1.5%	1%	Collapse Slump - 425 mm dia	18	19.2	27.6	0.8KΩ

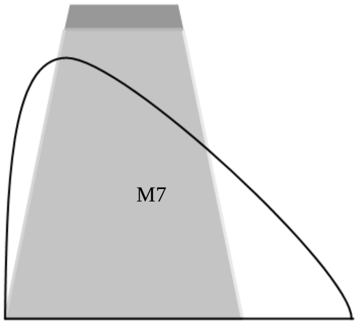

Figure 4. Pictorial representation of shear slump of Control mix M7

The inclusion of carbon fibers in the mixes M2, M5 & M8 worsened the workability of the CFRC mixes. The slump observed in all these three mixes was shear slump as seen in figure 5. Soaring segregation of the ingredients was observed in these mixes. The compaction level required for these mixes was very intense. Particularly in the mix M8, it was quite difficult to cast the specimens as the mix acquired was very rough and dry which could not get compacted with normal vibrating efforts. More lumps of aggregates and cement pastes were observed in these mixes.

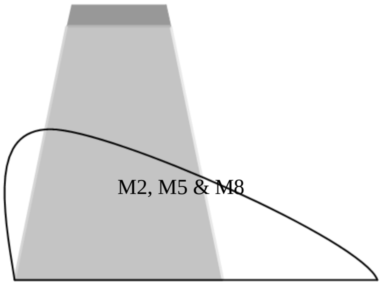

Figure 5. Pictorial representation of shear slump of CFRC mix without SP

The inclusion of superplasticizer in the CFRC mixes M3, M6 & M9, prevailed over all the limitations of compaction. More homogeneity was observed in all these mixes. The slump observed in all these mixes was a collapse slump as seen in Pictoral representation in figure 6. The mobility attained by the SP provided a path for the de-agglomeration of carbon fibers in the more wet mix. The distribution of fiber threads improved the interface between aggregates and binder and did not create any hurdles in the compaction of concrete. The compaction efforts needed for casting these mixes were very low and mechanical compaction was not required.

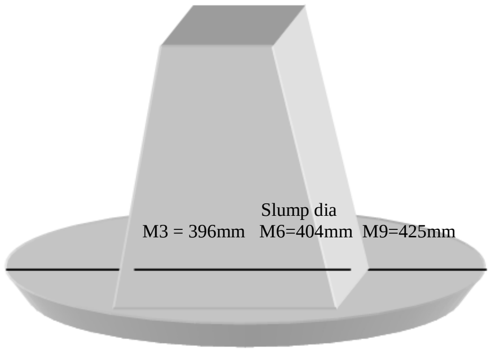

Figure 6. Pictorial representation of collapse slump of CFRC mix with SP

4.3 Influence of SP on Filling ability of CFRC

The inclusion of carbon fibers in the concrete tends to decrease the workability of the concrete and thus makes the concrete less viscous. The decrease in viscosity of the concrete hampers the filling ability of concrete which has to be overcome with addition of extra mixing water or more mechanical vibrations for compaction, thus increasing the compaction efforts.

In this study the investigation on the filling ability of CFRC with addition of SP was done to analyze the effect of SP on the filling ability of CFRC. The filling property was analyzed using V-Funnel test in accordance with EFNARC 2005[15]. The v-funnel investigations illustrated in figure 7 revealed that the addition of SP to the CFRC can certainly enhance the filling ability of concrete. In the mix M2, M5 & M8, the time taken by the control mix concrete to leave the v-funnel apparatus aggravated with the inclusion of carbon fibers. This was primarily due to the roughness and dryness of the mix as the flow of concrete was restricted by the bunch formation of the carbon fiber concrete matrix.

With the addition of SP in the mix M3, M6 & M9, the filling ability of concrete got enhanced positively as the time taken by the CFRC to leave the V-Funnel apparatus decreased from a maximum of 62 seconds in mix M8 to a minimum of 18seconds in M9 as seen in figure 7.

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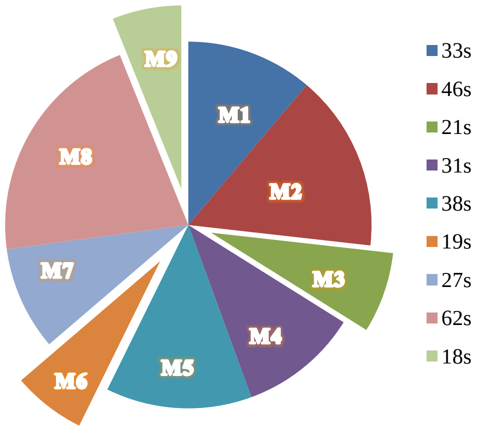

Figure 7. Filling ability (V-Funnel) observations of CFRC

4.4 Compressive Strength Properties of CFRSCC

The graphical representation of the variations in the strength properties is represented in figure 8 and figure 9.

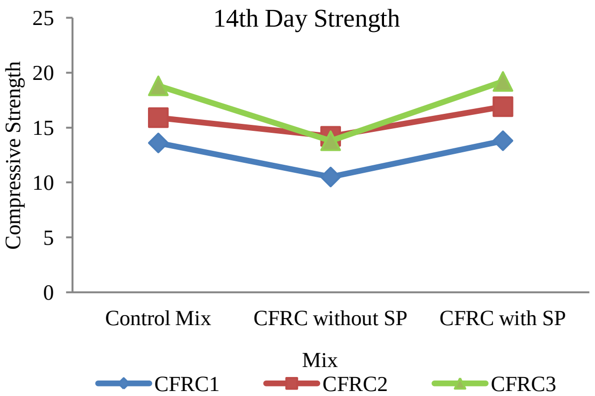

Figure 8. 14th Day compressive strength

An improvement in the compressive strength properties of CFRC was observed with the inclusion of SP compared to the control mix and CFRC without SP both at 14th day and 28th day as seen in figures 8 and 9. The inclusion of carbon fibers in the mix M2, M5 and M8 without SP illustrated a decrease of strength as the fibers were seen getting tangled with each other and were unable to disperse in the harsh and rough mixes. The tangled fibers resulted in the more porous mix which lead to the elevated capillary movement. The propagation of cracks were enhanced by the porous inner structure with elevated capillary action. M2, M5 and M8 illustrated a decrease of 19.1%, 8.4% and 25.9% in the 28th day compressive strength when compared to their normal control mix M1, M3 and M7 respectively. The maximum decrease of strength was observed in the M8 with 0.38W/C ratio. This maximum decrease in the mix M8 was due to the non-dispersion of carbon fibers in the rough mix. The fibers instead agglomerated further which could be observed by bare eyes.

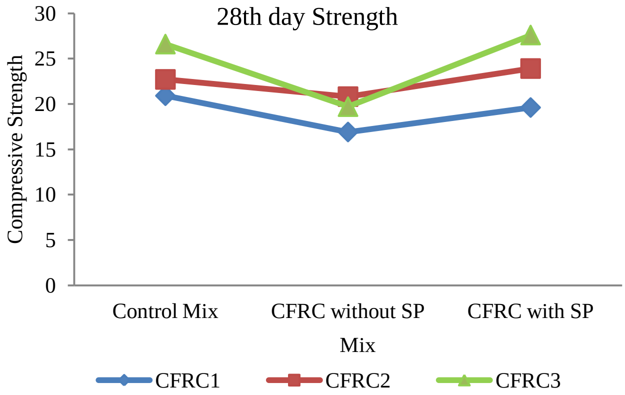

Figure 9. 28th Day compressive strength

While as in the mix M3, M6, M9 with SCF and SP, an increase in the compressive strength properties was observed both at 14th day and 28th day. At 28th days of curing, an increase of 13.8%, 12.9%, 28.6% were observed in M3, M6 and M9 when compared to the mix M2, M5 and M8. The inclusion of SP and SCF in M6 and M9 also illustrated an increase in the compressive strength when compared to control mix M4 and M7. An increase of 5.0%, 3.6% in the 28th day compressive strength was observed in mix M6 and M9 when compared to normal control mix M4 and M7

The increase in the strength is evidently attributed to the addition of SP which paved the path for proper distribution of carbon fibers in the concrete and thus resulting in the less porous mix. The previous studies on the CFRC revealed that the SCF can enhance the structural performance of concrete depending on the magnitude of dispersion attained. The same was evident in this study as the inclusion of SP enhanced the workability of concrete resulting in more flowable concrete giving a medium for dispersion and distribution of fibers. These distributed fibers acted as bridges for the early micro-cracks developing in the concrete and thus prevented the propagation of these micro-cracks, thus enhancing and improving the compressive strength. The increase in the compressive strength was observed

4.5 Influence of superplasticizer on electrical properties of CFRC

The electrical measurements observed in the normal control mix depicted a very high resistance to the electrical current flow. The elevated electrical resistance is evident in the fact that concrete is a bad conductor of electricity. The electrical measurements were observed using a highly precise digital multimeter working on the principle of two probe method. The observed electrical resistance variations in the CFRC are illustrated in figure 10.

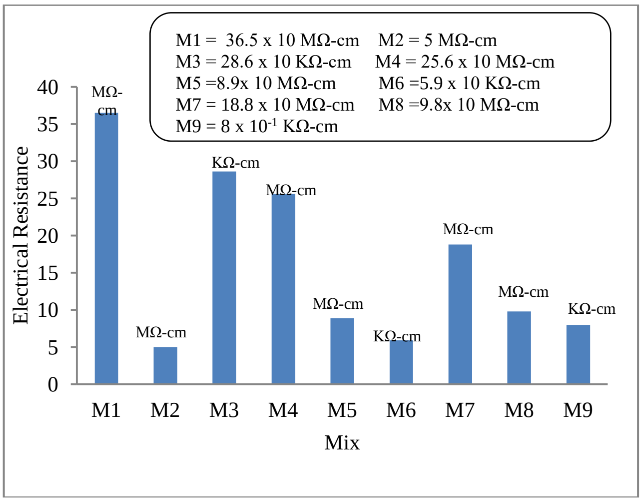

Figure 10. Change in Electrical resistance

An overall decrease in the electrical resistance was observed in the CFRC mix M2, M5 and M8 specimens cast without any SP and CFRC mix M3, M6 and M9 specimens cast with SCF and SP. The decrease in the electrical resistance was due to the inclusion of carbon fibers. The carbon fibers are electrically conductive and the previous studies reveal that the inclusion of carbon fibers in the concrete enhances the electrical conductivity of the concrete making the concrete to conduct electricity. The magnitude of conductivity though depends on the dispersion and distribution of fibers in the viscous medium of concrete.

In this study, it was observed that the magnitude of decrease in the electrical resistance was more in the mix M3, M6, and M9 as compared to all other mixes. The inclusion of carbon fibers in mix M2, M5 and M8 decreased the electrical resistance but the magnitude of decrease was very less as compared to the mixes cast with SCF and SP. This is because of the rough and less viscous medium of concrete which did not allow the carbon fibers to distribute evenly.

The magnitude of decrease in the mixes M3, M6 and M9 with carbon fibers and superplasticizers observed was from megaohms to kilo-ohms. The workable concrete in these mixes provided a more viscous medium for the distribution of carbon fibers which resulted in de agglomeration of carbon fibers. The even distribution of de agglomerated carbon fibers imparted the property of electrical conductance more effectively in these mixes when compared to other mixes without SP. This is in concurrence to the previous studies which reveal that the effectiveness of the transmitting the smart behavior of electrical conductance of carbon fibers in the concrete composites depends on the dispersion and distribution of carbon fibers in the concrete medium[16,17].

4.6 Micro Structure of CFRSCC and Fiber distribution

The microstructure of the inner surface of the specimens was observed using scanning electron microscopy (SEM) analysis. The microstructure of the CFRC specimens without SP seen in figure 11 depicted a tangled agglomerated bunch formation of carbon fiber threads that were formed due to rough surface of the concrete mix in M2, M5 and M8. The decline of the compressive strength in these mixes was evident due to the tangled nature of the fibers observed in the microstructure. The microstructure of the mixes with CFRC with added superplasticizers depicted a less agglomerated nature of fibers as seen in figure 12. The threads of carbon fibers observed in the M3, M6 and M9 mixes portrayed an evener distribution throughout the concrete inner surface. The even distribution of fibers in these mixes lead to the bridging of microcracks which provided the path for proper electrical conductivity and thus reducing the electrical resistivity. The bridging of microcracks leads to the prevention of propagation of microcracks and thus enhancing the overall strength of these mixes.

Figure 11. The microstructure of CFRC Specimen without SP

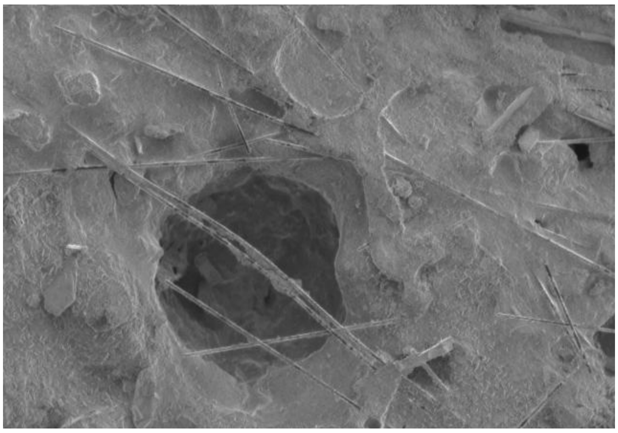

Figure 12. The microstructure of CFRC Specimen with SP

V. CONCLUSION

In this study, the influence of SP on the fresh state and hardened state properties of CFRC was investigated. The variations in the properties of CFRC were also compared to the control mixes. Following conclusions were drawn from this study:

- It was observed in this study that the incorporation of carbon fibers in the dry concrete with low w/c ratio impart a negative approach on the properties of concrete both in fresh and hardened state and the carbon fibers could not get distributed evenly in the dry concrete mixture.
- It can be thus concluded that the presence of high mobility and viscosity is an important factor for the de-agglomeration of carbon fibers so as to attain functional properties of carbon fibers into the concrete.

- It was observed that the inclusion of superplasticizers successfully enhanced the workability and mobility of the CFRC which resulted in the improvement of functional structural and non-structural properties of CFRC.
- The magnitude of decrease in the electrical resistance was observed more in the SP added CFRC mixes.
- The microstructure of the CFRC samples including SP depicted the better distribution of fibers as compared to the CFRC mix without SP.
- It could be concluded from this study that the incorporation of SP in the CFRC mix can progressively improve the mobility and viscosity of the CFRC mix but proper dispersion techniques and methods are required for obtaining optimum functional benefits of carbon fibers in the carbon fiber reinforced concrete.

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Conflict Of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

REFERENCES

1. Md. Safiuddin, A. B. M. Amrul Kaish, Chin-Ong Woon and Sudharshan N. Raman (2018). Early-Age Cracking in Concrete: Causes, Consequences, Remedial Measures, and Recommendations. *Appl. Sci.* ;8 (2018); 1730; DOI:10.3390/app8101730
2. A. Sivakumar, Manu Santhanam (2007), "Mechanical properties of high strength concrete reinforced with metallic and non-metallic fiber". *cement and concrete composite;* 29 (2007), 603-608.
3. Amit Rai, Dr. Y.P Joshi (2014), Applications and Properties of Fibre Reinforced Concrete. *International Journal of Engineering Research and Applications*; 4 (5)(1) (2014); pp.123-131.
4. S.Ragavendra, I.Praveen Reddy, Dr.Archanaa Dongre (2017), Fibre Reinforced Concrete- A Case Study, Architectural Engineering Aspect for sustainable building envelopes" *ArchEn-BuildEn-2017*, Institution of Engineers India
5. Richa Agarwal, Archana Tiwari (2017), Fortifying of Concrete by Fibre Reinforcement. *International Journal of Engineering Science and Computing*; 7 (2) (2017); 4658 – 4661.
6. Ahmad S, Umar A, Masood A (2017), Properties of Normal Concrete, Self-compacting Concrete and Glass Fibre-reinforced Self-compacting Concrete: An Experimental Study. *Procedia Engineering*; 173 (2017): 807-813.
7. Akcay B, Tasdemir MA (2012), Mechanical behavior and fiber dispersion of hybrid steel fiber reinforced self-compacting concrete, *Construction, and Building Materials*; 28(1) (2012): 287-93.
8. Aslani F, Samali B (2014), Flexural toughness characteristics of self-compacting concrete incorporating steel and polypropylene fibers. *Australian Journal of Structural Engineering*; 15(3) (2014): 269- 86.
9. Umar, A. Masood, A., Ahmad, S (2016). "A comparative study of the performance of self-compacting concrete using glass and polyvinyl alcohol fibers". International Conference on Hybrid And Composite Materials, Chemical Processing (HCMCP), *St. Peter's Engineering College*, Hyderabad, Telangana, India, 25th-27th October, pp. 27-33.
10. Subhan Ahmad and Arshad Umar (2018), Fibre-reinforced Self-Compacting Concrete: A Review, International Conference on Mechanical, Materials and Renewable Energy, *Materials Science and Engineering*, 377 (012117). DOI:10.1088/1757-899X/377/1/012117.
11. Park JM, Kwon DJ, Wang ZJ, et al. (2015) Review of self-sensing of damage and interfacial evaluation using electrical resistance measurements in nano/micro carbon materials-reinforced composites. *Advance Compos Materials*, 24 (2015): 197–219.
12. Sohel Rana, Subramani P, Raul Fangueiro, and Antonio Gomes Correia (2016), A review on smart self-sensing composite materials for civil engineering Applications, *AIMS Materials Science*, 3(2) (2016): 357-379, DOI: 10.3934/matersci.2016.2.357
13. Rita Salvado, Catarina Lopes, Leszek Szojda, Pedro Araujo, Marcin Gorski, Fernando Jose Velez, Joao Castro-Gomes and Rafal Krzywon (2015), Carbon fiber epoxy composites for both strengthening and health monitoring of structures. *Sensors* 15 (2015): 10753–10770. DOI : 10.3390/s150510753
14. M. Yakhlaf, K.A. Soudki (2015), Carbon fiber reinforced self-consolidating concrete - Fresh and mechanical properties. *International Concrete Abstracts Portal*; 299 (2015), 1-16
15. EFNARC F (2005), Specification and guidelines for self-compacting concrete. European 29 Federation of National Associations Representing producers and applicators of specialist 30 building products for Concrete (EFNARC), 32:31. http://www.efnarc.org/pdf/SCCGuidelinesMay2005.pdf
16. Md. Safiuddin, M. Yakhlaf, K.A. Soudki (2018), Key mechanical properties and microstructure of carbon fiber reinforced self-consolidating concrete, *Construction, and Building Materials*; 164 (2018); 477–488, https:// doi.org/10.1016/j.conbuildmat.2017.12.172.
17. Biswajit Jena, Asha Patel (2016), Study on the mechanical properties and microstructure of chopped carbon fiber reinforced self-compacting concrete, *International Journal of Civil Engineering and Technology (IJCIET)*, 7(3) (2016),223–232, http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=7&IType=3
18. IS 8112-2013, Indian Standard ordinary portland cement, 43 grade - specification, Bureau of Indian Standards, http://www.iitk.ac.in/ce/test/IS-codes/is.8112.2013.pdf
19. IS 383 – 2016, Coarse and Fine Aggregate for Concrete – Specification, Bureau of Indian Standards, https://archive.org/details/gov.in.is.383.2016
20. IS 456 - 2000, Indian standard plain and reinforced concrete - code of practice (fourth revision), Bureau of Indian Standards, http://www.iitk.ac.in/ce/test/IS-codes/is.456.2000.pdf

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