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Incorporation of Carbon Fiber and Silica Fume in the Production of Conductive Concrete

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Abstract—Concrete is regarded as a composite material that has good mechanical and durability properties for construction. However normal concrete is poor in electrical conductivity. An endeavour has been made with concrete to have all these three properties. The addition of small amounts of short carbon fibers and a nanomaterial silica fume to the concrete mixture causes an increase in strength and durability properties as well as electrical conductivity. In this paper, experimental results of compressive strength and electrical resistivity are presented. This Concrete technology can be applied with low voltage current for de-icing on highways and airfields, during snowfall in the winter season. This technique will help to reduce the cost and environmental issues of roads in snow fall region.

Keywords: *Carbon fiber, compressive strength, concrete, de-icing, electrical conductivity, silica fume*

INTRODUCTION

The development of infrastructure necessitates the technological improvement in concrete. The current researches are therefore trying to improve or modify the property of the concrete to meet the needs of today's world. The conventional concrete has the desirable properties of strength and durability, according to the mix design and materials used. But it is very poor in electrical conduction property (Purushothaman M, *et. al.,* 2008). In addition to or replacement of the conventional materials used in the production of concrete by mineral and chemical admixtures, can change or improve the property of the concrete. Many experimental studies focussed on mechanical and durability properties but the studies on electrical properties of concrete are very limited.

The electric conductive property can be achieved by adding some conductive material to conventional concrete. This Conductive concrete can be widely used for melting snow of road, bridges, and airport (Xie P, *et. al.* 1995; Yehia S, *et. al.* 1999) and also used in radio frequency interference shielding, electromagnetic defense, protecting the building from lightning, radiation heating, corrosion protection, automated high way systems, etc (Xin Tian, 2012). America, Canada, and Northern European countries researched conductive concrete to solve the icy roads and bridge floors problem. China started the research of conductive concrete in the late 1980s (Xie Xin, *et. al,* 2015). But in India, a countable number of studies have been done.

A major portion of Kashmir in the western Himalayan region of India experiences heavy snowfall between November and April. Every year, traffic is closed for many days in the National Highway of 270-km, which is the single road linking Kashmir with the rest of the country, due to heavy snowfall (Mohammd Rafiq, 2018). It is a significant issue for the Indian government. In India, de-icing salts and mechanical equipment are used for snow clearance of roads. These methods are uneconomical and also affect the environment. In the Previous studies of conductive concrete in India, preliminary research has been made to study on electrically conductive concrete made with bottom ash (Purushothaman M, *et. al.,* 2008), Steel residue(Abid Ahmad Sofi, *et. al*, 2015), Waste coke powder, (Abid Ahmad Sofi, *et. al,* 2016).

The Conductive fiber material is a good conductive component than other types of materials for improving the conductive property of the conductive (Xin Tian, 2012-b). Recent studies on conductive concrete have also proved that carbon fiber can be added to conventional concrete to improve both mechanical and electrical behaviors (Mashudi, 2014; Xin Tian, 2012; Oscar Galao, 2016). Short length

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carbon fiber is simple to use and ease of dispersion in the mix (Ohama Y,1985). If the dispersion of carbon fiber in the concrete mix is not uniform, the resistivity will be different from the same carbon fiber. Therefore, the uniform dispersal of the carbon fiber is the prime importance in conductive concrete (Wu J, *et. al,* 2015). The addition of silica fume as an admixture in concrete will help for dispersion of the fibers in the mix and improving the bond between fiber and matrix, thus enhancing the properties of the concrete (Chung D.D.L, 2000; Wang Chuang, 2018). Well-dispersed carbon fibers in the cement matrix, can increase the compressive strength (Mashudi, 2014) and decrease the resistivity and becomes an electrically conductive cement composite (Oscar Galao, 2016; Wen S, *et. al.* 2003). Therefore, in this experimental study, the effect of carbon fiber for the production of conductive concrete in terms of resistivity property was studied.

MATERIALS AND METHODS

Ordinary Portland cement of 43 grade Portland according to IS: 8112-1989; potable tap water; locally available river sand; crushed hard blue granite stone of size 20mm and below; Silica fume (SF) obtained from Elkem. India private Ltd., Mumbai, India; Polyacrylonitrile (PAN)-based short carbon fibers (CF), of length 5mm to 7mm, purchased from SRJ composites, Hyderabad, India, was used to prepare the concrete specimens. The properties of fine and coarse aggregate were determined as per IS:2386-3,1963 and the properties of cement, silica fume and carbon fiber were collected from the supplier. Table 1. and Table 2 shows the properties of CF and SF.

Three groups of concrete namely conventional concrete (CC), concrete with silica fume (CSF) and electrically conductive concrete (ECC) were considered in this study.

Table 1: Properties of Carbon Fiber

Property	Value
Diameter	7μm
Length	5mm to 7mm
Carbon content	93%
Tensile strength	2800 MPa
Resistivity	1.43×10^{-3} Ω-cm

The proportions of the ingredients for CC of grade M30 was arrived by following IS:10262-2009. To know the optimum dosage of silica fume, the volume of the cement of the CC mix was replaced by 0% to 20% of Silica fume and the volume of other ingredients kept constant. The 28 days compressive strength test results for 150 mm cube specimens prepared from each mix and the corresponding dosages of silica fume was plotted as shown in Fig.1. from the experimental results, 10% in volume of cement is the optimum for the concrete mix. Beyond this level of replacement, the reduction in strength of concrete was observed. Strength and resistivity are the two important parameters considering in the production of ECC.

As strength is concerned, the experimental results of various researchers (Andrey Nevsky, *et. al.,* 2015, Manivel, *et. al,.* 2019, Navya H.A, 2018) showed 1% of carbon fiber is the optimum. Considering the percolation threshold, the optimum dosage of carbon fiber for heating performance is 1% by Volume (Alireza Sassani, 2018). Therefore, in this experiment, the electrical resistivity of ECC made with 1% of carbon fiber was studied. As the absolute volume method is adopted to prepare the ECC mixture, 1% of carbon fiber in the volume of concrete was added by adjusting the fine aggregate content. The other ingredients were adopted as same as the CSF mixture. Mix proportions of these three mixes are shown in Table 3. The high range water reducing agent (HRWR) and fiber dispersive agent (FDA) were also used in the mix. Methylcellulose of 0.4% by weight of binder was used as FDA in all the three mixes for consistency.

The ECC mix was prepared as per the procedure followed by HOU zuofu (HOU zuofu, *et. al.* 2007). Methylcellulose in powder form was first added into part of the designed water and stirred well to dissolve completely, carbon fibers were then added and stirred gently again. The SF and cement were mixed well in a dry state; HRWR has added with the rest of the mixing water stir well for uniformity. HRWR mixed water was added into the rotary mixer first, then the binder mix was added and allowed to rotate for 3 min. Finally, the CF mix was poured into the mixer and allowed to rotate for 1 min, then the FA aggregate followed by CA was added and allowed to run for 3 min each. The admixtures methylcellulose and silica fume will help to fiber dispersion and increase the fiber–matrix bond strength (Jingyao Cao, D.D.L. Chung 2001; Yunsheng Xu and DDL Chung, 2001).

Six numbers of 150 mm × 150 mm × 150 mm cube specimens were cast from each mix. Three specimens used for compressive strength test (IS: 516,1959), and the remaining three was used for resistivity test. Water curing for 28 days was adopted for all the specimens.

Table 2: Properties of Cement and Silica Fume

Property	Specific Gravity	SiO_2	Al_2O_3	MgO	CaO	Fe_2O_3
Cement	3.1	21.94	5.04	2.08	63.61	3.16
Silica fume	2.2	93.2	0.48	0.4	0.1	0.36

Table 3: Mix Proportions-kg/m^3

Materials / Mix	Cement	SF (10%)	FA	CA	CF (1%)	w/b
CC	394	---	776	1082	---	0.5
CSF	394	28	776	1082	---	0.47
ECC	394	28	749	1082	18	0.47

RESULTS AND DISCUSSIONS

Compressive Strength

Compressive strength test results from the mean value of three cubes for CC, CSF, and ECC mixes are given in Table.4. From the test results, it is known that the strength of ECC mixes is greater than other mixes. This may be due to the incorporation of carbon fiber and silica fume in the concrete mixture. Incorporation of a pozzolanic material, Silica fume to concrete will help for dispersion of the fibers in the mix thus enhancing the properties of the concrete; improved durability; and the mechanical properties of concrete (Shetty. M.S, 2007; Chung D.D.L, 2000; Mashudi, 2014).

Electrical Resistivity

The value of resistivity depends on the properties of the conductive material. Resistivity and conductivity are inversely proportional. On reducing the resistivity of the concrete, the conductivity will be more. The electrical resistivity of the concrete mixes was determined using the Two-probe method. In this test, a thin copper plate is pasted on the side surfaces of the cube specimen as an electrode. It should be checked for no gap between the plate and the concrete surface. Then only a uniform current will pass through the side surfaces. The (Direct current) DC source of 50v applied to the electrode. A voltage difference between the electrodes (V) and current (I) was measured using a multimeter. The following expression is used to calculate the resistivity.

$$\text{Resistivity, } \rho = \frac{AV}{IL} \qquad (1)$$

Where,

V = Voltage drop across the specimen; A = Area of cross section, cm^2

I = Direct current taken by the conductive specimen (amps)

L = Length of the specimen between the two electrodes, cm.

The resistivity of the conventional concrete under dry condition varies from 6.54×10^3 Ω – m to 11.40×10^3 Ω-m, hence it acts as a pure resistor (Whittington *et. al.,* 1981) When the resistivity is reduced, the electrical conductivity will be more. The use of conductive materials in concrete reduced the resistivity considerably. The resistivity of carbon fiber used in this study is less than the resistivity value (< 5 Ω-m) of standard resistance reducing agent as per Chinese national standard (Xin Tian, 2012; Mashudi, *et. al.,* 2018).

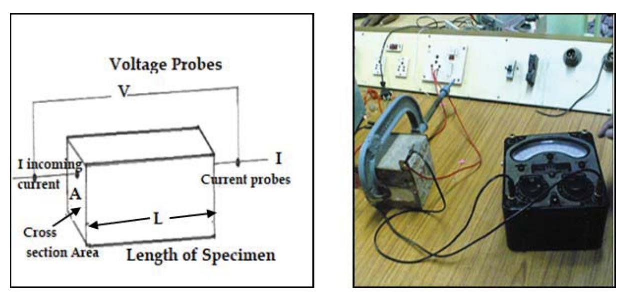

Fig. 2: Schematic Diagram and Test Setup for Electric Resistivity

The average resistivity of the cube specimens of each mix is tabulated in Table 4. The high electrical resistivity was observed with CSF cube, comparing with CC cubes, whereas the reduced resistivity was observed with ECC mixture when compared to CC and CSF mixtures. Generally, if the compressive strength of concrete and the resistivity are directly proportional. But, the test results of ECC mixture made with carbon fiber show high compressive strength and low resistivity value than 10 Ω-m which is required for de-icing (Hou, *et. al.;* Oscar G, 2016; Tang, *et. al.* 2005). From this, it could be understood that the addition of carbon fiber is well dispersed in the concrete system and can be used to produce conductive concrete. Anyhow, further experimental study with slab specimens of different size, test for surface heating is to be done.

Table 4: Test results of Concrete Cube Specimen

Property	CC	CSF	ECC
Comp. strength, MPa	31.2	34.9	38.7
Electrical resistivity, Ω-cm	9.2×10^6	1.12×10^7	801

CONCLUSION

1. The addition of copper fiber in the conventional concrete reduces the resistance and improves the strength of concrete. So copper fiber can be considered as a good ingredient for making conductive concrete.
2. The resistivity of Electrically conductive concrete made from copper fiber is lower than that resistivity required for de-icing.
3. The electrical resistivity of concrete with silica fume is higher when compared to the conventional concrete. It is due to the pozzolanic effect of silicafume.
4. Nowadays the whole world is facing a major problem of environmental pollution. Utilization of an industrial waste silica fume as cement replacement material in concrete for construction, will help to protect our environment.
5. This study may helpful for future experiments on electrically conductive concrete and could be an eco-friendly solution to the de-icing problems of snow fall regions of India.

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