Electrical Resistivity for Assessing Durability of Fiber Reinforced Concrete

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Abstract

Electrical resistivity in concrete is a key parameter that can be correlated to its durability. The aim of this research is to correlate the relationship between electrical resistivity with the strength and durability characteristics of concrete. The influence of parameters such as grade of concrete, water to cement (w/c) ratio and fiber dosage, at constant degree of saturation and temperature was investigated. Four-probe method was used to measure the resistivity of M40, M30 and M20 grades of concrete with 0.5%, 0.75% and 1% fiber content. It was observed that for a given fiber content, higher grades concrete showed smaller percentage decrease in electrical resistivity as compared to its corresponding lower grade. A decrease in resistivity by 37.5%, 42.5% and 48.8% was observed with the addition of 1% of steel fiber for M20, M30 and M40 grades of concrete respectively. Similar trends were observed for resistivity in 0.5% and 0.75% fiber content mixes. It was observed that mixes with higher resistivity possessed greater strength and durability.

Keywords: *Electrical Resistivity in concrete, Durability Characteristics, Steel Fiber, Four-probe method*

1.0 Introduction

One of the key factors in serviceability of a structure is quality control. Concrete being a heterogeneous material, it is harder to assess its durability characteristics and use it as a quality control variable [1]. However, research suggests that the durability of concrete can be expressed as a function of its microstructure properties like porosity and electrical resistivity [2]. These microstructure properties are closely associated with interconnected channels within the hydrated composite and can be linked to porosity and electrical resistivity parameters. Strong inverse correlation exists between electrical resistivity and characteristics like corrosion, crack width, etc [3]. Attempts have been made to develop quantifiable non-destructive testing methods based on electrical resistivity measurements utilising the various quality control variables and their correlation with resistivity [4]. Presence of pore connections in concrete can be attributed to the porosity, which in turn can be used as a

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parameter to quantify its durability [5]. Electrical resistivity of concrete is defined as the ability of concrete to resist the flow of ions within the hydrated interconnections. Experimental studies suggest that concrete has a range of resistivity between 10-10^6 Ohm-m [6]. This suggests that electrical conductivity is caused due to the presence of interconnected channels in the concrete matrix. Thus, depending on the degree of saturation of these interconnected paths in the matrix, a range of corresponding resistive properties is exhibited.

Cement composition, its content, water cement ratio, temperature, admixtures, and additional cementitious materials in concrete are some factors that influence its electrical resistivity [7]. Electrical resistivity is also affected by the quality and composition of water used for mixing concrete and the age of the sample [8]. This measurement, in practice, is used as an indicator for degree of corrosion in the Reinforced Cement Concrete (RCC) structure. The greater the resistivity, lower the current passing between the cathodic and anodic areas of the reinforcing steel and thus lowering the extent of corrosion [9]. Of the two methods employed in measuring the resistivity in a concrete specimen; the use of two-probe technique in measurements is avoided in order to minimize the possibilities of error arising due to electrode polarization potentials [10]. Therefore, in the current study the Wenner probe method (Four-Probe Method) was used to measure the electrical resistivity of the specimens.

2.0 Methodology

2.1 Materials

Concrete samples of grade M20, M30, M40 were made using Ordinary Portland Cement (Grade 53) conforming to the specifications of IS 12269: 2013 as shown in Fig. 1. Coarse and fine aggregates conforming to IS 383: 2016 were used and were tested for water absorption and specific gravity. Hooked end steel fibers of length 35 mm, diameter 0.65 mm and an aspect ratio of 64 and a specific gravity of 7.75 were used as functional fillers. Ingredients for the concrete mix were proportioned as per the mix design as shown in Table 1 and subsequently cast into beams. The samples were tested for electrical response at 15 and 28 days.

Fig. 1. Beams left to dry after curing

Table 1. Concrete Mix Proportion Table

Sl. No.	Mix	Water (kg/m^3)	Cement (kg/m^3)	CA (10 mm) (kg/m^3)	CA (20 mm) (kg/m^3)	FA (kg/m^3)	Admixture (kg/m^3)
1	M20	200	333	437.52	291.68	1062.62	1.67
2	M30	200	400	423.78	282.52	1029.26	2
3	M40	200	500	403.18	268.79	1009.51	2.5

Note: Fiber dosage was taken as x% by weight of cementitious content. CA: Coarse Aggregate, FA: Fine Aggregate

2.2 Sample Geometry and Layout of Electrodes

Beams of dimensions 500 mm (length) X 100mm (width) X 100mm (depth) were used for experimentation in accordance with IS 10086-1982. The configuration of the electrodes has a significant effect on the electric field distribution in the concrete and on the electrical resistivity [11]. Electrodes were placed as shown in Fig. 2 (a:187.5mm, b: 10mm, 105mm, c:105mm). The location of electrodes is in the region of maximum bending moment and minimal shear force. Further, the electrodes are embedded deep into the concrete block for ensuring maximum integrity with the concrete.

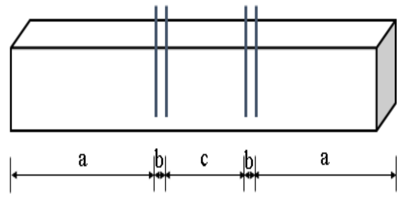

Fig. 2. Layout of electrodes used in experimentation (All dimensions are in mm a: 187.5mm, b: 10mm, c:105mm)

Fig. 3. Experimental set-up for measurement of electrical resistivity

2.3 Experimental Set-up

The Wenner probe method (Four-Probe Method) was used for the current setup to minimize the contact resistivity and concrete and polarization potentials between the electrodes as shown in Fig. 3. [12]. When DC current is applied during the measurement of voltage, the movement and concentration of the ions in the concrete matrix results in polarization [13], which causes fluctuations in the measured voltage values. The measurements reported in this paper were carried out at constant temperature and stable testing conditions. Various dosages of steel fibers (0.5%, 0.75%, 1%) were used within the mix design to establish a relation between functional filler dosage and electrical resistivity. The voltage readings were taken at the dry condition of the concrete specimen to mitigate the effect of water content within the sample during 15 and 28 days testing. In order to mitigate the effects of temperature variation in the concrete matrix [14], the experiment was performed in a uniform temperature environment.

3.0 Preliminary Results and Discussion

3.1 Voltage-Current (V-I) Characteristics of Samples

As the initial current is passed through the concrete specimen, the ensuing polarization mechanism causes fluctuations in the voltage measurements due to its sensitivity to temperature and degree of saturation. In order to maintain near equal levels of hydration and uniform temperature, all the samples were tested exactly after 28 days of curing under similar conditions. The V-I characteristics thus obtained for various grades of concrete with varying fiber dosages are shown below. It can be seen from Fig. 4 - 7 that the slope of the V-I curve increases with grade of the concrete. This can be attributed to the reduction in water to cement ratio of the concrete mix, which narrows the interfacial transition zone of the matrix and thus reducing the porosity.

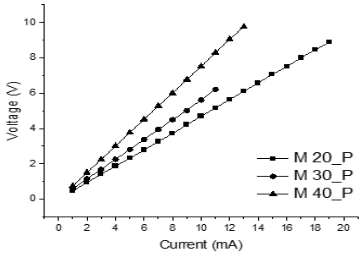

Fig. 4. V-I Characteristics for Control Mix i.e., M20, M30 and M40 grades of concrete

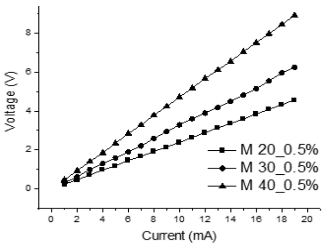

Fig. 5. V-I Characteristics for M20, M30 and M40 grades of concrete with 0.5% fiber dosage

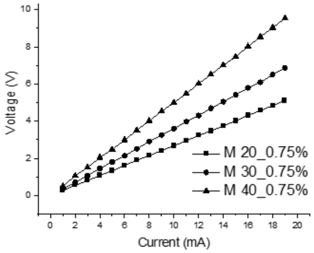

Fig. 6. V-I Characteristics for M20, M30 and M40 grades of concrete with 0.75% fiber dosage

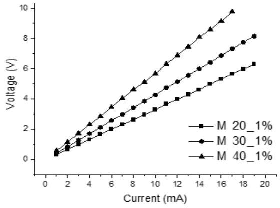

Fig. 7. V-I Characteristics for M20, M30 and M40 grades of concrete with 1% fiber dosage

3.2 Resistivity vs Fiber content

The V-I characteristic of concrete generally follows an Ohmic trend. By addition of 0.5% of steel fiber, a decrease of 37.5%, 42.5% and 48.8% in electrical resistivity was observed for M20, M30 and M40 grades of concrete respectively. A similar trend is followed by the specimens with 0.75% and 1% fiber dosage, as shown in Table 2. The variations obtained in the resistivity values with respect to the varying grades of concrete and fiber contents is due to the dispersion and orientation of fiber in the matrix. In order to observe the effect of water to cement ratio on electrical resistivity, various grades of concrete were tested with water to cement ratio 0.6, 0.5 and 0.4. It was observed that as the water to cement ratio increases, the resistivity decreases as shown in Table 2. Fig. 8 shows the direct relationship between the electrical resistivity of concrete and its characteristic compressive strength. From Fig. 9, it can be seen that the change in electrical resistivity directly varies with the grade of concrete. This direct relationship between electrical resistivity, characteristic compressive strength is due to the reduction in the water to cement ratio of the concrete mix, which further narrows the interfacial transition zones of the matrix; thereby reducing its porosity leading to increase in strength.

Table 2. Change in electrical resistivity with varying fiber dosage for various grades of concrete

Fiber Dosage	Change in Electrical Resistivity for different grades of concrete		
	M20	M30	M40
0.5	23.70	23.90	29.30
0.75	33.22	36.06	42.80
1	37.50	42.50	48.80

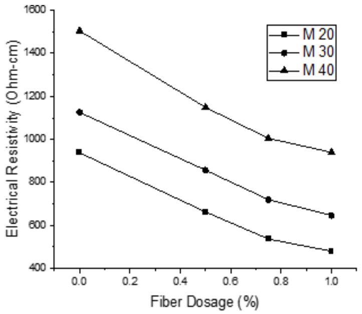

Fig. 8. Resistivity v/s fiber dosage for various grades of concrete

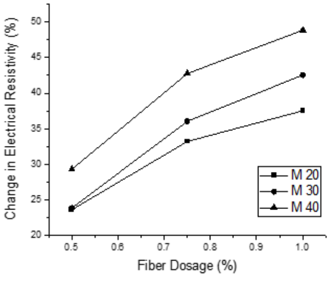

Fig. 9. Change in electrical resistivity v/s fiber dosage for various grades of concrete

3.3 Effect of Age of Concrete on Electrical Properties

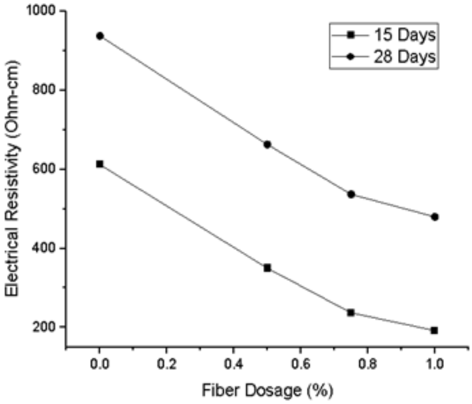

Fig. 10. Resistivity vs. fiber dosage of M20 grade of concrete after 15 and 28 days of curing respectively

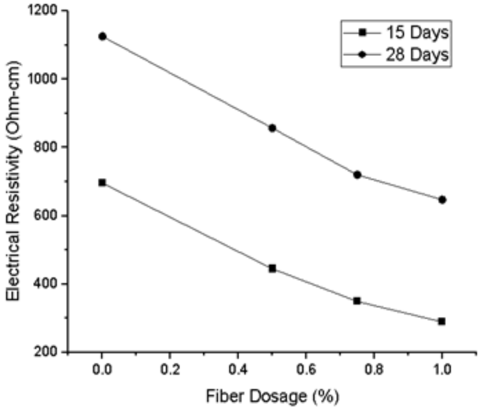

Fig. 11. Resistivity vs. fiber dosage of M30 grade of concrete after 15 and 28 days of curing respectively

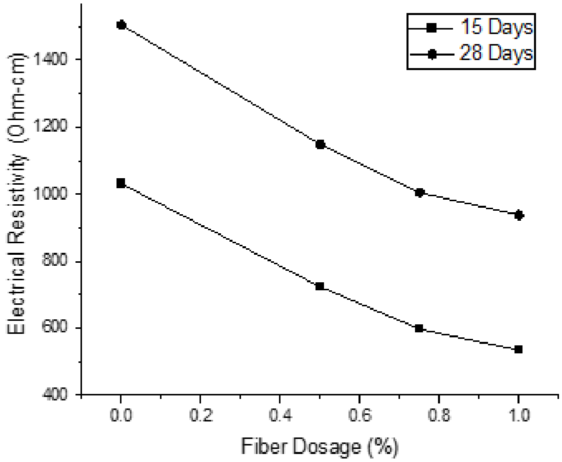

Fig. 12. Resistivity vs. fiber dosage of M40 grade of concrete after 15 and 28 days of curing respectively

Another interesting observation is the increase in electrical resistivity with the age of the concrete sample as shown in Fig. 10-12. An average increase of 52.59%, 48.28% and 38.63% was observed in the electrical resistivity for M20, M30, and M40 grade respectively at 28 days as compared to measurements at 15 days. This variation is because of the increase in the gel space ratio with the age of concrete; the volume occupied by the hydration product also increases. This increase in volume restricts the flow of electrons or ions through interconnections in the composite and inhibits electrical conductivity. After 28 days of curing, 99% hydration reaction is achieved and no further significant increase in electrical resistivity is observed.

4.0 Conclusions

The increase in the volume of functional fillers causes a drop in the electrical resistivity values in the concrete matrix. By addition of 0.5%, 0.75% and 1% of steel fiber, a decrease of 23.7%, 33.22% and 37.5% in electrical resistivity was observed for M20, 23.9%. 36.06%, 42.5% for M30 and 29.3%, 42.8%, 48.8% for M40 grades of concrete respectively. Owing to the direct correlation between the presence of hydration products with the age of the concrete, it was also observed that there is an increase in the electrical resistivity with respect to the age of the specimen. At 28 days, an average increase of 52.59%, 48.28% and 38.63% was observed in the electrical resistivity for M20, M30, and M40 grade respectively, at different fiber dosage, compared to 15 days measurements. The trends observed in this paper indicate the presence of hydration products in the concrete specimen leading to larger gel space ratios, which ultimately increases electrical resistivity.

Future work would involve a flexure test on the specimen during conduction of electricity in a load-controlled environment to establish electrical resistivity as a viable structural health monitoring parameter. Attempts will be made to correlate electrical resistivity measurements with strain developed in the specimen.

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