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STEEL FIBER REINFORCED CONCRETE DURABILITY USING ELECTRICAL RESISTIVITY TEST

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ABSTRACT

Fiber reinforced concrete (FRC) is increasingly present in civil construction, and has often been used in floors and structures which are high mechanical strength and great capacity for energy absorption. Several studies approach FRC in terms of behavior, studies that consider one of possibilities of the scores are scarce. The electrical resistivity test, in turn, represents an alternative to the destructive tests to evaluate pathologies and longevity of concrete, considering that during its execution material under study is preserved. For this reason, cylindrical specimens of both FRC and reference concrete were molded, then evaluated by the electric resistivity and diametric compression. The ages of 7, 14, 21 and 28 days were studied to evaluate mechanical and electrical properties. Water absorption test was also performed to determine the porosity and specific mass of composites. From analysis and discussion of results it was observed that electrical resistivity for fiber reinforced specimens is much smaller when compared to conventional composite. That way, it is suggested that electrical resistivity test is not most adequate to evaluate durability of concrete reinforced with steel fibers, in view of which reinforcing material is conductive.

Keywords: fiber reinforced concrete (FRC); steel fibers; durability; electrical resistivity.

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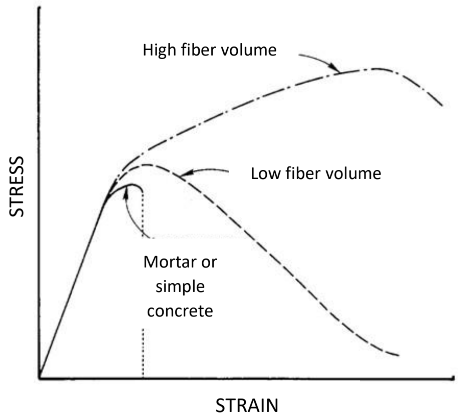
INTRODUCTION

Fiber-reinforced concrete (FRC) is a composite material in which short fibers are inserted during molding, randomly distributed in cementitious matrix, in order to improve some properties (BEZERRA, 2012). Besides technical advantages there are also economic benefits, with elimination of steps in the productive process (MONTE, 2015).

The reinforcing fibers can be of the most varied types of materials: steel, glass, polymer (polypropylene, polyester, nylon, polyethylene), carbon, synthetic, cellulose, asbestos, sisal and vegetal fibers, in various shapes and sizes (MEHTA, MONTEIRO, 2008).

According to Bentur & Mindess (2010), fibers when added to concrete alter fragile behavior of composite, improve mechanical behavior and deformation capacity before rupture. Figure 1 shows stress-strain behavior for conventional concrete, FRC with low fiber content and FRC with high fiber volume. The higher fiber content, more pronounced the deformation before rupture, which characterizes a ductile behavior and energy absorption during variations.

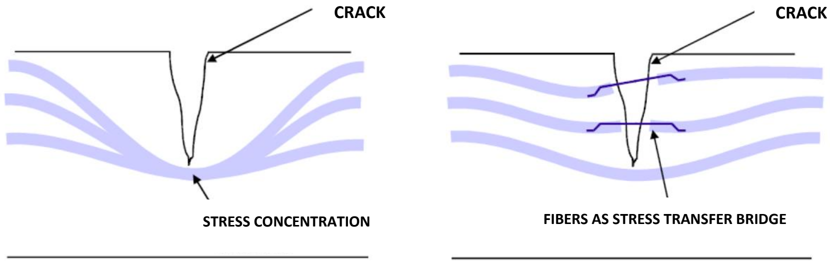
Figura 1: Stress-strain behavior of simple concretes, low fiber volume and high fiber content.



Source: Bentur & Mindess, 2010.

According to Nunes, Tanesi and Figueiredo (1997) and Bezerra (2012) FRC presents a distinct and peculiar performance when compared to conventional. The fibers act as a stress transmission bridge along cracks, making composite no longer brittle, as shown in Figure 2. Without presence of fibers, stresses acting on concrete are concentrated at the ends of cracks, which favors its propagation and consequent rupture.

Figure 2: Fibers as stress transfer bridge in a crack.



Source: Adapted of Nunes, Tanesi e Figueiredo (1997).

Specific resistance or resistivity is a characteristic of materials in general, it is related to resistance of passage of electric current and its value varies according to nature of material. According to pre-determined values of resistivity, materials are classified as conductors, semiconductors or insulators. Concrete saturated in water behaves as a semiconductor, while dry in a ventilated oven can be classified as insulating (LENCIONI, 2011).

The electrical resistivity (ER) test can be used to evaluate durability of hardened concrete. According to Costa and Azzi (2017), in general, more porous in concrete, lower the resistivity and consequently lower durability. Thus, test indicates possibility of occurrence of corrosion phenomenon in structure.

Banthia, Djeridane and Pigeon (1991), Solgaard et al. (2014) and Fiala et al. (2016) studied behavior of electrical resistivity in concrete reinforced with steel fibers and evaluated that addition of conductive fibers decisively influences electrical properties. Banthia, Djeridane and Pigeon (1991) concluded that the inclusion of steel fibers in a cementitious matrix produces conductive composites. Solgaard et al. (2014) suggested that fibers conduct electricity during the tests, so electrical resistivity decreases considerably. Fiala et al. (2016) inferred that values of electrical resistivity are related to percentages of fibers used at the time of molding.

Fiber reinforced concrete (FRC) is a familiar construction material and is increasingly used for a wide variety of engineering purposes. The mechanical properties of FRC are well known and appreciated by wide experience in field. However, knowledge about other properties of material, including electrical resistivity, is scarce. In this sense, the present work aims to broaden understanding of electrical properties of steel FRC, especially electrical resistivity.

MATERIALS AND METHODS

The materials used were initial high strength Portland cement CP-V ARI as binder, natural sand washed as small aggregate, crushed stone as aggregate, reinforcing steel fibers, superplasticizer additive and water. Table 1 presents description and quantity of each of materials used.

As reinforcement of the matrix were used short steel fibers supplied by Maccaferri. The fibers have a length of 50mm, a diameter of 0.75mm, a shape factor (l / d) equal to 67, and extremity anchoed.

After defining proportions used, each of materials was separated, weighed and conditioned in a plastic container, as shown in Figure 3. The superplasticizer additive was previously mixed with water. The mixing of components was carried out in an electric mixer, in following order: water (with plasticizer), gravel, cement, sand, remaining water (with plasticizer) and finally fibers.

Table 1: Materials used in FRC proportion.

Materials	Description	Quantity (kg)
Binder	Portland Cement V – ARI	10,0
Fine aggregate	Natural sand	19,0
Aggregate	Crushed stone	24,9
Additive	Superplasticizer	0,2
Water	-	5,5
Fibers	Short steel fibers	2,8

Source: Author’s own.

Figure 3: Materials used in preparation of concrete.

Source: Author’s own.

For the present study, cylindrical specimens with 10x20cm dimensions were molded according to ABNT 5738/2008. Figure 4 shows specimens immediately after demolding. The fiberless specimens were referred to as the control group “C1”, while those reinforced with fibers were called "FF3".

The electrical resistivity tests were carried out in Laboratory of Characterization of Civil and Mechanical Construction Materials of Federal University of Minas Gerais (UFMG). To evaluate surface resistivity, equipment "Resipod", manufactured by company Proceq (figure 5) was used. However, volumetric resistivity test was performed in equipment developed by researchers of group of studies on electrical resistivity of UFMG (figure 6).

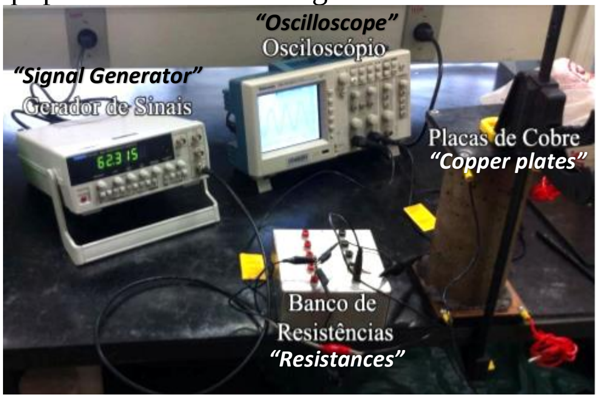
Figure 4: Concrete cylindrical specimens after demolding.

Source: Author’s own.

Figure 5 – Equipment used to test surface electrical resistivity.

Source: Costa *et al.*, 2017.

Figure 6: Equipment used for testing volumetric electrical resistivity.



Source: Adapted of Lage, 2018.

The mechanical behavior of FRC can be significantly assessed by its mechanical resistance to traction, flexure and compression. For this reason, diametrical compression test was chosen, with which one can evaluate traction behavior of the composite indirectly and consequently increment of resistance due to addition of fibers. Figure 7 identifies equipment used for diametrical compression test.

Figure 7: Diametral compression test for conventional and fiber reinforced concrete.

Source: Author's own.

The specimens were tested at 7, 14, 21 and 28 days for both electrical resistivity and diametrical compression. The specimens were kept in a humid chamber until time of tests in order to guarantee maximum saturation and to carry out tests in condition of greater humidity.

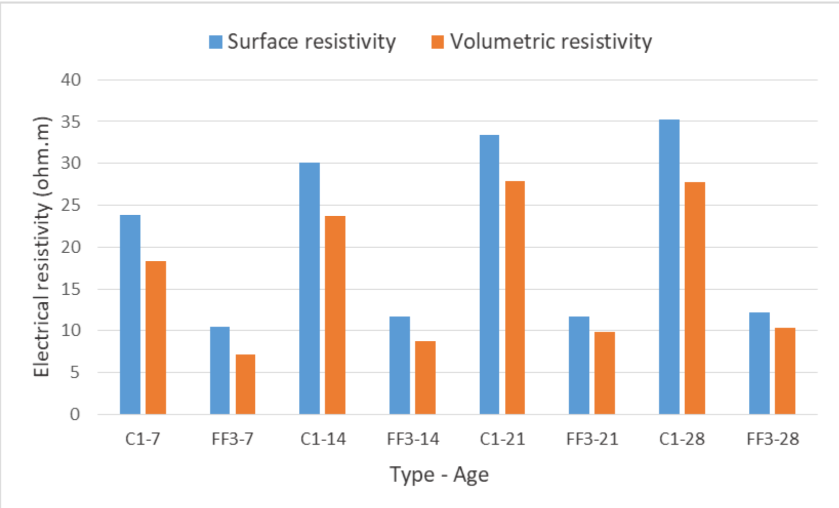
RESULTS AND DISCUSSION

The values obtained for surface and volumetric electrical resistivities are shown in figure 8, both for control group (C1) and for steel FRC (FF3).

It is noticed that both surface and volumetric electrical resistivity tend to increase over time. However, it is remarkable that values obtained for FRC are much smaller when compared to conventional concrete.

It is suggested that such behavior is due to addition of steel fibers as reinforcement, conductive material. During test, when an electric current is applied to the specimen, electricity flows both through water present in pores of cementitious matrix and through steel fibers. Thus, electrical resistivity decreases accordingly.

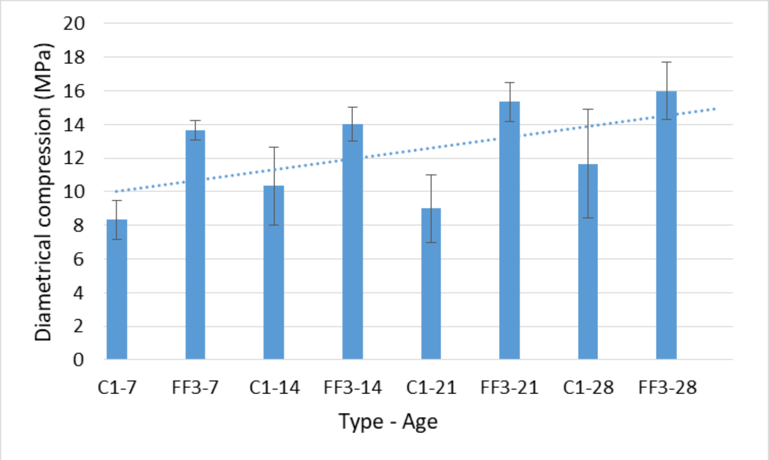
Figure 4: Surface and volumetric electrical resistivity values.



Source: Author’s own.

The values obtained for mechanical resistance to diametrical compression are shown in figure 9. It can be observed that values obtained for FRC are much larger than for conventional concrete. Also, there is a tendency for increased resistance over cure time to 28 days. This gain of residual resistance with addition of fibers can be explained by action of fibers as a bridge of transfer of tension between cracks during application of loads.

Figure 5 - Diametric compression resistance.



Source: Author's own.

Table 2 presents results for water absorption, void index and specific mass of reference concrete, while in Table 3 are values for FRC. The porosity of material is represented by void index. FRC presented lower water absorption and consequently lower void index when compared to conventional concrete. The specific mass of FRC was higher, a fact already expected due to presence of steel fibers.

Although FRC has a lower porosity, which results in a favorable framework for durability of material, presence of fibers is determinant for electrical resistivity values.

Table 2: Water absorption, void index and specific mass of reference concrete.

Reference				
Calculations			Especific mass	
Sample	**Absorption**	**Void index**	**Dry**	**Saturated**
1	12,56	24,99	1,99	2,24
2	12,57	24,97	1,99	2,24
3	11,68	23,63	2,02	2,26
Average	12,27	24,53	2,00	2,24

Source: Author's own.

Table 3: Water absorption, void index and specific mass of concrete with FF3 fibers.

Fibers FF3				
Calculations			**Especific mass**	
Sample	**Absorption**	**Void index**	**Dry**	**Saturated**
1	8,96	19,49	2,18	2,37
2	9,31	20,03	2,15	2,35
3	9,93	21,20	2,13	2,35
Average	9,40	20,24	2,15	2,36

Source: Author's own.

CONCLUSIONS

(1) Values obtained for electrical resistivity increase with curing time for both conventional and FRC concrete.

(2) Electrical resistivity for fiber reinforced specimens is much lower when compared to conventional composite.

(3) Volumetric electrical resistivity is smaller than superficial resistivity. This behavior is independent of ages.

(4) The tensile strength in diametrical compression is higher for FRC compared to conventional concrete;

(5) There is a tendency to increase tensile strength in diametrical compression over time.

(6) The void index for FRC was lower, which suggests lower porosity and more cohesive pore structure.

(7) Electrical resistivity test is not most suitable to evaluate durability of steel FRC, considering that reinforcing material is conductive.

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REFERENCES

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). NBR 5738: Concrete - Procedure for molding and curing samples. Rio de Janeiro, 2008. (in portuguese).

AZZI, Sarah Silva; COSTA, Josiane Moraes. **Comparison of surface electrical and volumetric resistivity of concrete in Portland cement IV.** Construindo, v. 9, n. 01, 2017. (in portuguese).

BENTUR, A., MINDESS, S. Fiber reinforced cementitious composites. Elsevier Science Publishers, 1st Ed. London, England, 1990.

BEZERRA, Augusto Cesar da Silva. **Concrete with short steel fibers subjected to high temperature.** Doctoral thesis. Advisor: PhD. Paulo Roberto Cetlin. Belo Horizonte, 2012. (in portuguese).

BANTHIA, N.; DJERIDANE, S.; PIGEON, M. Electrical resistivity of carbon and steel micro-fiber reinforced cements. **Cement and Concrete research**, v. 22, n. 5, p. 804-814, 1992.

BRANDT, Andrzej M. **Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering**. Composite structures, v. 86, n. 1-3, p. 3-9, 2008.

COSTA, Josiane Moraes *et al*. **Pathological analysis through the non destructive test using surface electrical resistivity of the concrete.** Construindo, v. 9, n. 3, p. 25-35, 2017. (in portuguese).

FIALA, Lukáš et al. Experimental study on electrical properties of steel-fibre reinforced concrete. **Procedia Engineering**, v. 151, p. 241-248, 2016.

LENCIONI, J. W. **Studies on surface electrical resistivity in concrete: analysis and quantification of intervening parameters in the tests.** Thesis (PhD in Aeronautical Infrastructure Engineering) - Instituto Tecnológico de Aeronáutica, ITA, Brasil, 2011. (in portuguese).

MEHTA, P. Kumar; MONTEIRO, Paulo. Concreto: microestrutura, propriedades e materiais. Ibracon, 2008. (in portuguese).

MONTE, Renata. **Characterization and control of the mechanical behavior of reinforced concrete with tubes.** Doctoral thesis. Advisor: PhD. Antônio Domingues de Figueiredo**.** São Paulo, 2015. (in portuguese).

SALVADOR, Renan Pícolo, Antonio Domingues de FIGUEIREDO. **" Comparative analysis of mechanical behavior of reinforced concrete with polymeric macrofiber and with steel fiber. "***Matéria* 18.2 (2013): 1273-1285. (in portuguese).

SARZALEJO, A. G.; ROSSI, B.; PERRI, G.; WINTERBERG, R.; ARISTEGUIETA, R. E. P. Fibers as structural element for concrete reinforcement. (Technical manual). **Maccaferri do Brasil Ltda.,** 2009. (in portuguese).

SOLGAARD, Anders Ole Stubbe et al. Observations on the electrical resistivity of steel fibre reinforced concrete. **Materials and structures**, v. 47, n. 1-2, p. 335-350, 2014.