Análise da Migração de Cloretos e Seu Impacto em Concretos de Ultra Alto Desempenho Reforçados por Fibra (UHPFRC)

Chloride Migration Analysis and its Effect on Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC)

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RESUMO

A degradação das armaduras de aço em estruturas de concreto armado, causada pela presença de cloretos em áreas costeiras, pode comprometer sua capacidade de suporte. Os testes de migração de cloretos são amplamente empregados para avaliar a reação do concreto a esse agente agressivo. Este estudo apresenta o desenvolvimento de uma célula de energia de baixo custo, com o objetivo de simplificar a investigação desse fenômeno em concretos de ultra alto desempenho reforçados com fibras (UHPFRC). Além disso, foram realizadas inspeções visuais para acompanhar a expansão das fibras metálicas no UHPFRC. Os resultados revelaram que, apesar da baixa porosidade do UHPC (Concreto de Ultra Alto Desempenho), a inclusão das fibras metálicas acelerou a penetração dos cloretos, possivelmente devido à maior condutividade elétrica dessas fibras.

PALAVRAS-CHAVE: Cloretos, degradação, célula de energia, concretos UHPC e UHPFRC, testes de migração de cloretos.

ABSTRACT

The degradation of steel reinforcement in reinforced concrete structures, caused by the presence of chlorides in coastal areas, can jeopardize their load-bearing capacity. Chloride migration tests are widely employed to assess concrete's response to this aggressive agent. This study introduces the development of a low-cost energy cell aimed at simplifying the investigation of this phenomenon in ultra-high-performance fiber-reinforced concrete (UHPFRC). Additionally, visual inspections were conducted to monitor the expansion of metallic fibers in UHPFRC. The results disclosed that, despite the low porosity of UHPC (Ultra-High-Performance Concrete), the inclusion of metallic fibers expedited chloride penetration, potentially owing to the higher electrical conductivity of these fibers.

Keywords: Chlorides, degradation, energy cell, UHPC and UHPFRC concretes, chloride migration tests.

INTRODUCTION

Ultra-High Performance Concrete (UHPC) is a remarkable material known for its extraordinary compressive strength, exceeding 100 MPa, achieved through a minimal water-cement ratio of about 0.2 (YAN et al., 2018). However, UHPC is inherently brittle (GIDRÃO; KRAHL; CARRAZEDO, 2020). To enhance its performance, metal fibers are commonly integrated, creating Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) (RESPLENCINO; JACQUES, 2013). UHPC is also recognized for its durability and low diffusivity coefficients (WANG; WEI, 2014). This study investigates UHPFRC's response to chloride ion exposure, an area where consensus on fiber additions is lacking (Abbas et al., 2015).

Chloride exposure is a significant concern in coastal regions due to salt-induced corrosion. This study delves into chloride transport mechanisms, including ionic diffusion, capillary sorption, permeation, and migration (Table 1) (Zhang et al., 2022). Accelerated corrosion tests often involve applying an electric current or additives like CaCl2 (OTIENO et al., 2014; LIU et al., 2016). Chloride migration testing uses an electric field (ASTM C1202) (RIBEIRO et al., 2012; RIBEIRO et al., 2021).

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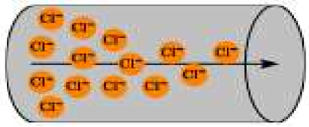
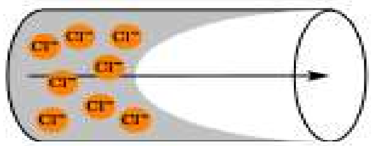
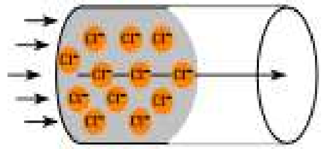
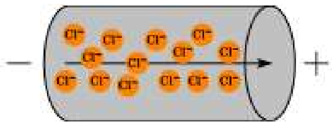
Table - 1 Chloride transport mechanisms

TRANSPORT MECHANISM	DRIVING FORCE	SCHEMATIC REPRESENTATION
a) IONIC DIFFUSION	Concentration gradient	
b) CAPILLARY SORPTION	Surface tension	
c) PERMEATION	Absolute pressure	
d) MIGRATION	Electric field	

Adapted from Zhang et al, 2022

Chloride ions can lead to reinforcement corrosion by initiating depassivation and reacting with iron to produce ferrous oxide, causing fiber expansion (MEHTA; MONTEIRO, 2014). Understanding the electrical resistances of UHPC and UHPFRC is crucial. UHPFRC has lower electrical resistance due to steel's high conductivity (CAVILL; REBENTROST; PERRY, 2006). UHPC's low porosity mitigates this effect.

In conclusion, this study explores UHPFRC's behavior under chloride ion exposure, focusing on transport mechanisms, electrical resistance, and the impact of fibers on corrosion resistance.

MATERIALS AND METHODS

In this section, we provide an overview of the production process for Ultra High-Performance Fiber-Reinforced Concrete (UHPFRC) and describe the subsequent evaluation, including resistivity and chloride penetration analyses. The production of UHPFRC demands meticulous control over materials and the integration of high-quality cement, fine aggregates, and fibers. These investigations yield valuable insights into optimizing UHPFRC production, enhancing its strength properties, and ensuring its long-term durability in diverse applications.

PRODUCTION OF UHPC AND UHPFRC

For this study, test specimens were prepared using molds measuring 10 cm in height and 5 cm in diameter. After the preparation of the fresh concrete, the test specimens were molded with the aid of a vibrating table to achieve compaction. Subsequently, the specimens underwent a 24-hour waiting period before demolding, followed by a 7-day curing process. The test specimens were then cut to dimensions of 44 mm, as specified by ASTM C 1202 (2022), to facilitate the testing process.

The composition of the test specimens in this study adheres to the base mix outlined in Table 2. Notably, the concrete underwent thermal curing at a temperature of 90 ºC, and the mix properties employed align with those previously utilized by Gidrão (2020).

Table 2: Composition of UHPFRC and UHPC Mixtures

Material	Cement* (kg/m³)	Sand (kg/m³)	Silica Fume (kg/m³)	Metallic Fibers (%)**	Quartz Powder (kg/m³)	Water (kg/m³)	Superplasticizer (kg/m³)
UHPFRC	768	844	192	2	384	154	69
UHPC	768	844	192	0	384	154	69

(GIDRÃO 2020)

Note:

- **The cement used was CPV - ARI.**
- **Metallic fibers are represented as a percentage of the total volume of UHPFRC.**

ANALYSIS OF RESISTIVITY

In this study, an energy cell operates by subjecting a test specimen, representing electrical resistance, to an input voltage of 4.9 V. One face of the test specimen is exposed to an aqueous solution containing NaCl, while the other is in contact with distilled water.

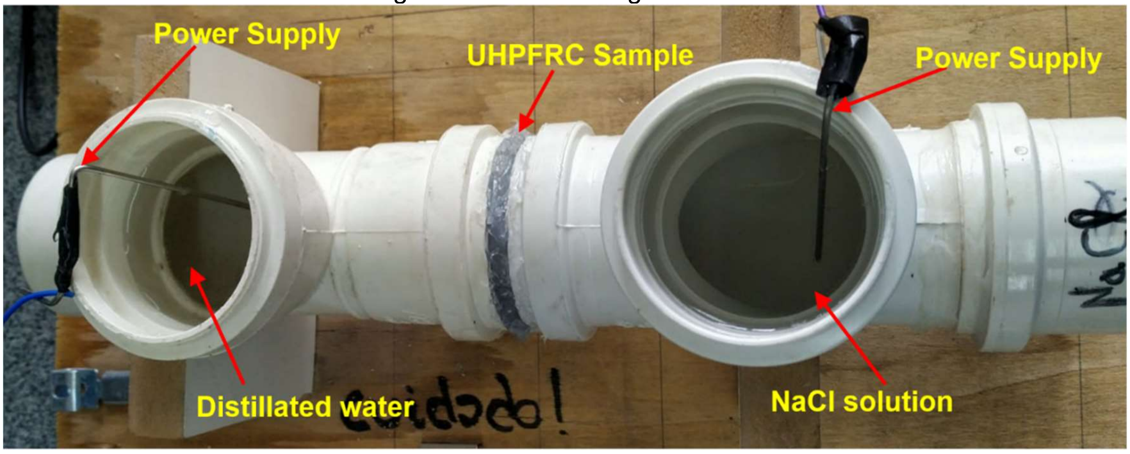
Chloride ions migrate from one face to the other, increasing the current, as observed by a multimeter. By measuring current and voltage, the material's resistivity can be determined using Ohm's law equation 1:

$$\frac{U}{I} = \frac{\rho.L}{A} \tag{1}$$

The apparatus used consists of two components: a power source cell and a multimeter. The chloride migration test includes a test specimen reservoir made from PVC pipes, a 10-volt power source, and equipment for measuring voltage and current (Minipa brand model ET-3200B) with an accuracy of 0.001 volts.

The reservoir comprises two "T"-shaped tubes, each 50mm in length, with a 90-degree angle and sealed caps. The test specimen is inserted into the tubes, creating two compartments for liquids (NaCl and distilled water). One side is exposed to a 1-mole sodium chloride solution, and the other is in contact with distilled water. The electrolytic phenomenon is depicted in Figure 1.

Figure 1 - Chloride migration test



Authors (2023)

This electrolytic phenomenon results in the migration of Cl- ions, leading to pH variations and fiber-matrix degradation in concrete.

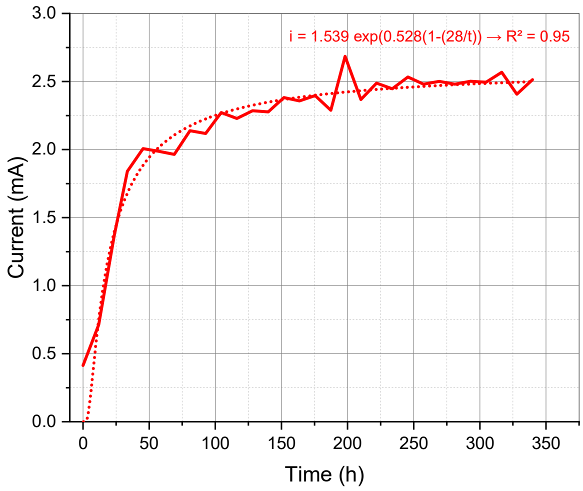
Voltage and current are measured hourly and recorded in Excel for 21 days, representing the current stabilization.

RESULTS

Data collection of current and voltage over time was performed. The multimeter results were processed with MATLAB to reduce data and eliminate signal noise. Figure 2 illustrates voltage increase during a 3-week UHPFRC test. The Y-axis represents electrical current, and the X-axis shows time in hours. The graph displays an initial current rise followed by an asymptotic value of XX. Figure 2 displays an initial current increase in the first hours, followed by a slower rise. Later in the test, current tends to stabilize.

Resistivity loss over time is calculated using Equation 1 and presented in Figure 3. Initially, UHPC exhibits higher resistivity compared to UHPFRC samples, which persists throughout tests. UHPC has notable signal noise, but the overall trend of nearly constant resistivity is evident.

Figure 2 - UHPRFC voltage variations over time



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The differences between UHPC and UHPFRC behavior can be attributed to UHPC's higher resistivity, approximately 10 times greater (CAVILL et al., 2006). The observed resistivity loss isn't substantial enough to damage the concrete, as indicated in (SPRAGG et al., 2012) and shown in Table 3. UHPFRC's significant resistivity degradation is explained by the introduction of steel fibers, enhancing concrete conductivity.

The results indicate that adding these conductive fibers significantly increases concrete's overall electrical conductivity, primarily due to iron and copper's conductive nature.

Using UHPFRC test specimen 2 as a basis, a time-based function was approximated, as shown in Figure 4. This function follows a logarithmic pattern, suggesting ongoing degradation with asymptotic behavior over time

Table 3 Maximum Resistivities (SPRAGG, et al., 2012)

Chloride Penetration	Electrical Resistivity (ohm.m)
High	Less than 50
Moderate	Between 50 and 100
Low	Between 100 and 200
Very Low	Between 200 and 2000
Irrelevant	Above 2000

Figure 3 – Resistivity loss a function of time

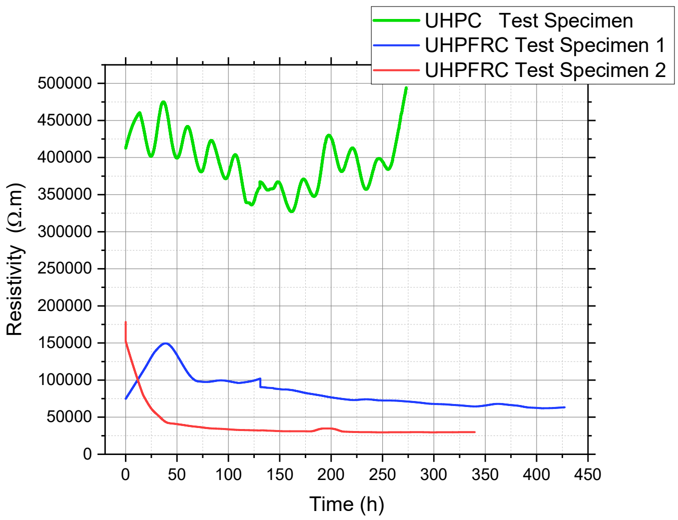

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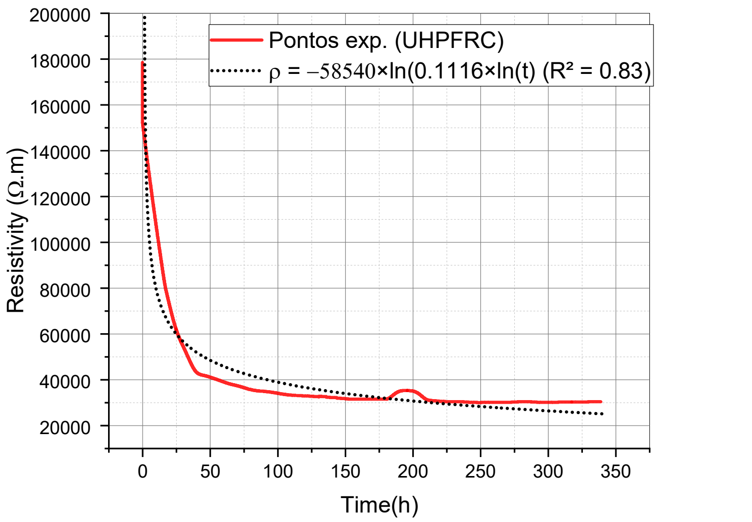
Figure 4 – Approximation of function for Test specimen 2



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Conclusion

In summary, this study investigates the behavior of Ultra-High Performance Fiber-Reinforced Concrete (UHPFRC) when exposed to chloride ions. The research emphasizes the significant reduction in electrical resistivity in UHPFRC, attributed to the presence of conductive fibers. While UHPFRC's resistivity decreases gradually over time, it remains within acceptable limits, highlighting its potential for use in chloride-prone environments without substantial damage. These findings enhance our understanding of UHPFRC's suitability for practical applications requiring high durability and corrosion resistance.

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Conflito de interesse

A patent for the energy cell is of interest.

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