DOI: 10.53660/CLM-1693-23I08

Concretes prepared with recycled aggregate and metakaolin: aspects of mechanical resistance and electrical resistivity

Concretos preparados com agregado reciclado e matacualim: aspectos da resistencia mecânica e resistividade elétrica

Received: 2023-06-08 | Accepted: 2023-07-12 | Published: 2023-07-17

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ABSTRACT

Waste recycling is shown as an efficient alternative to minimize the impacts caused, such as the recovery of construction and demolition waste (CDW), but the properties should be studied and analyzed for their better use in concretes. In addition to environmental concern in the aggregate of concrete, another factor is the emission of CO2. Several studies are being done to replace part of the cement mass with other concrete components. Among these additions, it is possible to emphasize as the most used, in Brazil, the metakaolin. Studies show that concretes prepared with CDW generally tend to have a higher permeability, lower mechanical strength and difficulty in workability, and metakaolin as an additive that enhances the cementitious composite, compensating for the possible technical disadvantages of CDW as an aggregate. This work has as objective the macrostructural and microstructural analysis of concretes prepared with metakaolin and recycled aggregate CDW. A reference concrete, class 30, with consumption of 442 kg / m³, and families using CDW source aggregate with 25% and 50% substitution percentage and metakaolin in place of cement in 5 and 10% was prepared. The results show optimized behavior of the concretes prepared with metakaolin and CDW aggregate.

Keywords: Concrete; Metakaolin; Recycled aggregate.

RESUMO

A reciclagem de resíduos é mostrada como uma alternativa eficiente para minimizar os impactos causados, como a recuperação de resíduos de construção e demolição (RCD), mas as propriedades devem ser estudadas e analisadas para melhor aproveitamento dos concretos. Além da preocupação ambiental no agregado de concreto, outro fator é a emissão de CO_2. Vários estudos estão sendo feitos para substituir parte da massa de cimento por outros componentes do concreto. Dentre essas adições, é possível destacar como a mais utilizada, no Brasil, a metacaulim. Estudos mostram que os concretos preparados com RCD geralmente tendem a ter maior permeabilidade, menor resistência mecânica e dificuldade de trabalhabilidade e metacaulim como um aditivo que aprimora o compósito cimentício, compensando as possíveis desvantagens técnicas do WCD como agregado. Este trabalho tem como objetivo a análise macroestrutural e microestrutural de concretos preparados com metacaulim e agregado reciclado WCD. Foi preparado um concreto de referência, classe 30, com consumo de 442 kg / m³, e famílias que utilizavam agregado fonte WCD com porcentagem de substituição de 25% e 50% e metacaulim no lugar do cimento em 5 e 10%. Os resultados mostram comportamento otimizado dos concretos preparados com metacaulim e agregado WCD.

Palavras-chave: Concreto; Metacaulim; Agregado reciclado.

INTRODUCTION

A In Brazil, the construction industry is considered the main consumer of natural resources in cities and the main generator of solid waste. This industry is extremely important for the country, as it is responsible for approximately 40% of all productive economic activity (Zorzeto 2017). In the municipality of Salgueiro-PE, as well as in other municipalities in the Northeast region of Brazil, thousands of tons of CDW (construction and demolition waste) are collected by city governments.

Recycling waste is an efficient alternative to minimize the impacts caused. The processing of construction waste, more specifically ceramic material residues, mortar and concrete to transform them into aggregates is a good practice, but the properties of the resulting materials from this transformation must be studied and evaluated. ABRECON (Brazilian Association for C&D Waste Recycling) indicates that the lack of technical knowledge about recycled CDW products is responsible for their non-use.

ABRECON studies from 2017 also show that the processing of CDW in Brazil is only 21% of what was generated, while in developed countries such as the Netherlands, this rate reaches 90%.

Data from SNIC (National Cement Industry Union) 2016 shows that between 2004 and 2014 cement consumption more than doubled, going from 35 million tons to over 70 million, an increase in consumption present in all regions of Brazil. This strong increase and the prospect of continued growth led cement producers to invest heavily in the industrial park.

The use of CDW is environmentally beneficial, but Portland cement contributes significantly to the impact generated in the production of concrete. Using pozzolans to partially replace that binder is a good measure.

Metakaolin is a pozzolanic material available in the Northeast region of Brazil, which improves the properties of concrete.

As concretes prepared with CDW aggregate generally tend to have higher permeability and lower mechanical strength, metakaolin can improve the performance of this type of concrete. In fact, cementitious composite, compensating for the possible technical disadvantages of C&D as aggregate. Mehta & Monteiro 2014 explain that the size and distribution of concrete pores are determinants in controlling durability and electrical resistivity, for example, and pozzolanic additions confer an improvement to the cementitious paste.

Recent studies by Ghoddousi & Saadabadi 2017 confirm the efficiency of adding metakaolin to cementitious matrices in increasing the electrical resistivity of the composite. The authors also report that the electrical resistivity of concrete is an important parameter in the study of the hydration process.

Regarding the influence on capillary absorption of concretes prepared with metakaolin, Dinakar et al. 2013 indicated in their studies that concretes with metakaolin reduced water permeability, absorption and chloride permeability, they claim that this may be due to the filling effect of metakaolin particles that substantially reduced permeability or porosity of concrete.

Therefore, this work aims to analyze the macrostructural and durability properties, in terms of mechanical strength, electrical resistivity and capillary absorption of concretes prepared with metakaolin and recycled CDW aggregate from the municipality of Salgueiro, Brazil.

METHODOLOGY

To carry out this work, the Construction Materials Laboratories of the IF Sertão PE and the LABEME (Materials and Structures Testing Laboratory) of the UFPB were used.

Materials

The recycled coarse aggregate originating from the crushing process of CDW used in this work comes from the city of Salgueiro-PE, located in the Northeast of Brazil. It was used in place of conventional coarse aggregate, of granite origin. For the processing of CDW, the same crusher used for the granite origin aggregate was used in the city of Petrolina. The appearance of the two aggregates is seen in Figure 1.

Figure 1 – Coarse aggregates CDW (a) and granite rock with a maximum diameter of 19 mm (b).

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The conventional binder was Portland Cement CPV ARI (high initial strength), with a specific mass of 3.06 g/cm³, Blaine fineness of 4,695.70 cm²/g, loss on flame of 4.31% and compressive strength at 7 days of 38.21 MPa, all parameters compatible with ABNT NBR 5735/1991.

The Metakaolin used in this research, in partial replacement of cement at 5 and 10%, with a specific mass of 2.56 g/cm³, Blaine fineness of 15,000 cm²/g, loss on flame of 2% and pozzolanicity index with cement of I=112%, according to ABNT NBR 5752.

For the determination of chemical composition, the analytical technique of X-ray fluorescence spectrometry (XRF) was used. Table 1 presents the chemical components of CPV cement and metakaolin.

Table 1 – Chemical composition of cement and metakaolin

Chemical composition			
Cement CP V		Metakaolin	
CaO	43.9443 %	SiO2	52.2462 %
SiO2	35.4620 %	Al2O3	36.2322 %
Al2O3	5.8501 %	Fe2O3	7.4016 %
MgO	4.5052 %	TiO2	1.4167 %
Fe2O3	4.4511 %	MgO	0.9465 %
SO3	3.9981 %	K2O	0.4360 %

$Na2O$	0.7868 %	CaO	0.2754 %

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Table 2 presents the physicochemical characterization of the water used in the work, provided by the water supply concessionaire, COMPESA - Pernambuco Sanitation Company.

Table 2 – Physicochemical analysis of the water used in the concretes

pH	CE	K^+	Na^+	Ca^{+2}	Mg^{+2}	SO_4^{2-}	CO_3^{2-}	HCO_3^-	Cl^-	CSR	NaCl	$CaCO_3$	RAS	Class
	$dS\ m^{-1}$	---------------------------- $mmol_c\ L$ ----------------------------------									------$mg\ L^{-1}$------		$(mmol_c\ L)^{0,5}$	
7,8	0,08	0,04	0,15	0,4	0,2	0,02	0,00	0,96	0,6	0,36	33,9	33,5	0,27	**C1S1**[1]

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From a physicochemical aspect, according to CONAMA Resolution No. 20 of June 1986, the above samples meet the potability criteria for total dissolved solids (TDS) content, as they contain 800.00 and 51.2mg/L, respectively, since according to MS Ordinance 2914/2011 the maximum value allowed is 1000 mg. L-1.

Methods

The concretes were prepared according to Table 3, totaling 07 families, varying the substitution of metakaolin and coarse CDW aggregate.

Table 3 – Prepared concretes

Families Prepared						
Concretes	Binder (kg/m^3)		Fine aggregate (kg/m^3)	Coarse aggregates (kg/m^3)		Water (l/m^3)
Families	cement	metakaolin[2]	stone powder	conventional	CDW[3]	
F1 (reference)	441,27	–	617,78	1059,05	–	211,81
F2 (25CDW)	441,27	–	617,78	794,29	264,76	211,81
F3 (50CDW)	441,27	–	617,78	529,52	529,52	211,81

[1] **C1S1:** Water without risk of soil salinization.

[2] In replacement of cement

[3] Recycled coarse aggregate in replacement of conventional.

F4 (25CDW 5MK)	419,21	22,06	617,78	794,29	264,76	211,81
F5 (25CDW 10MK)	397,14	44,13	617,78	794,29	264,76	211,81
F6 (50CDW 5MK)	419,21	22,06	617,78	529,52	529,52	211,81
F7 (50 CDW 10MK)	397,14	44,13	617,78	529,52	529,52	211,81

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Table 4 shows the macrostructural properties studied in this work in concretes prepared with CDW and metakaolin with the appropriate substitution proportions. The test specimens used were cylindrical with a diameter of 10 cm and a height of 20 cm.

Table 4 – Test Specimens

Families	Ratio	Axial compressive strength (28 days)	Capillary absorption (28 days)	Electrical resistivity (28 days)
F1 (reference)	1:2,4:4,2:0,48	9	3	3
F2 (25CDW)		9	3	3
F3 (50CDW)		9	3	3
F4 (25CDW 5MK)		9	3	3
F5 (25CDW 10MK)		9	3	3
F6 (50CDW 5MK)		9	3	3
F7 (50CDW 10MK)		9	3	3

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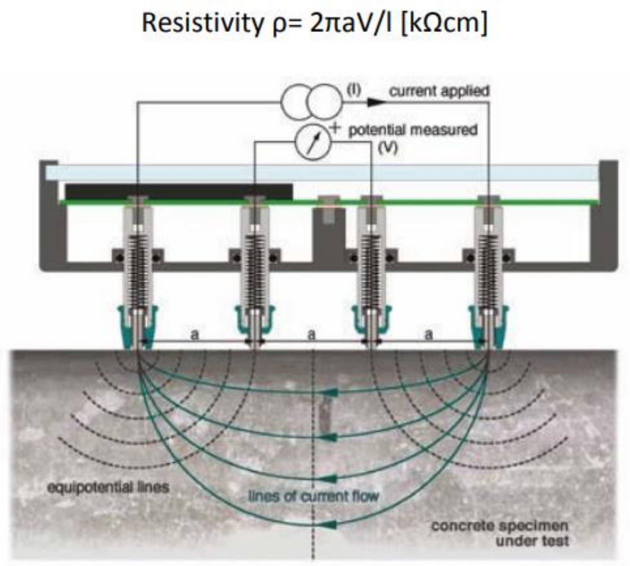
The concretes were prepared in the laboratory according to NBR 5738/03 recommendations - Procedure for molding and curing concrete test specimens, with 15 test specimens for each family. They were stored for 28 days in an environment with a temperature of 22 ºC (+/- 2ºC) and relative humidity of 98% (+/- 2%).

The concretes were subjected to axial compression strength tests according to NBR 7215/96: Portland cement - determination of compressive strength, capillary absorption test according to NBR 9779/95: hardened mortar and concrete - determination of water absorption by capillarity and surface electrical resistivity test, according to standards adopted by AASHTO TP

95-14, using the RESIPOD- Resistivity Meter 38 mm measurement device. Operating on the Wenner probe principle, the ResiPod is designed to measure the electrical resistivity of concrete or rock. A current is applied to the two outer probes and the potential difference is measured between the two inner probes, as shown in Figure 2.

Figure 2 – Diagram of the measurement of electrical resistivity in concrete



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The 38 mm model was specifically designed to meet the AASHTO standard for ‘Surface Indication of Concrete’s Resistivity to Chloride Ion Penetration Resistance’. Figure 3 shows the measurement of surface electrical resistivity on a concrete test specimen.

Figure 3 – Measurement of surface electrical resistivity

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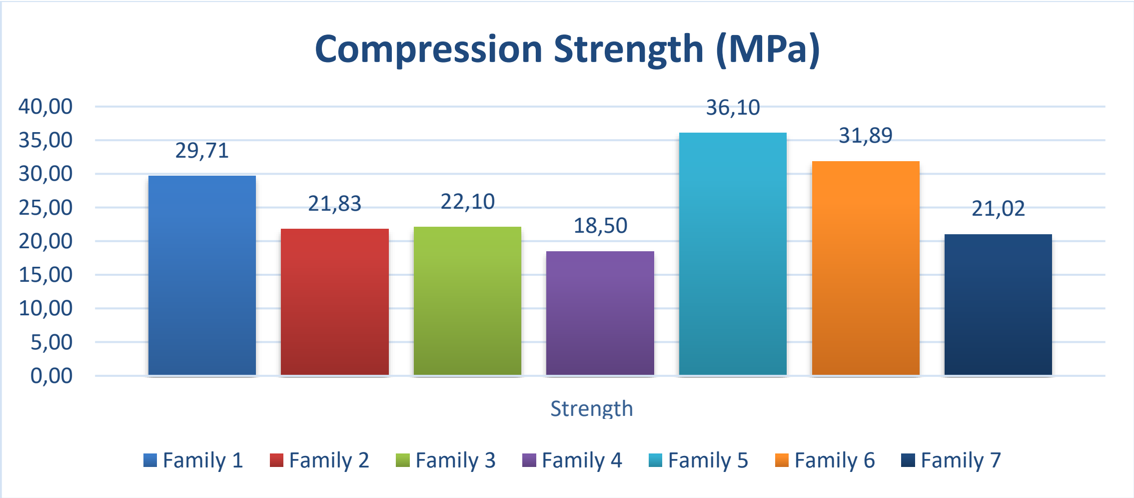
Results and discussion

At 28 days of age, the concretes were subjected to axial compression strength testing, and the results are shown in Figure 4.

Figure 4 – Axial compression strength



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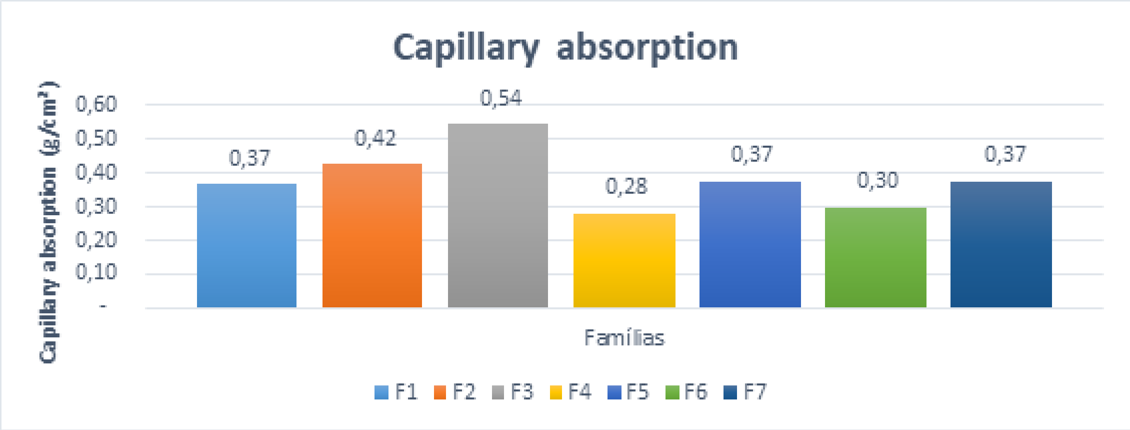
The reference concrete (F1), theoretical class 30 MPa, corresponds approximately to the expected strength. There is a loss of strength in concretes prepared with only CDW in substitution of 25% and 50% respectively (F2 and F3).

On the other hand, concretes prepared with CDW and metakaolin behaved differently. F4 (25% CDW and 5% metakaolin) had a 37% drop in mechanical strength, unlike F5 (25% C&D and 10% metakaolin) where strength increased by 21.55%.

In general, concretes with 50% CDW aggregate performed better mechanically than those with 25% substitution, especially those containing metakaolin (F6 and F7).

Regarding capillary absorption tests, the results are shown in Figure 5.

Figure 5 – Capillary absorption



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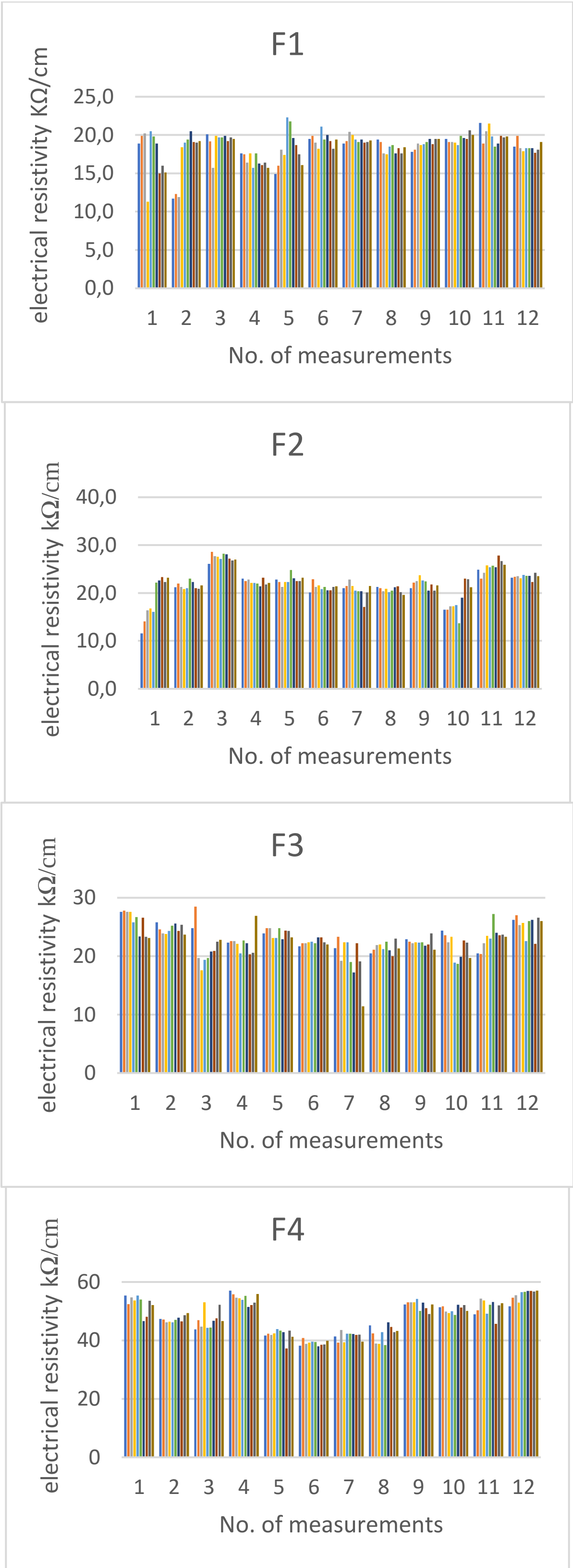
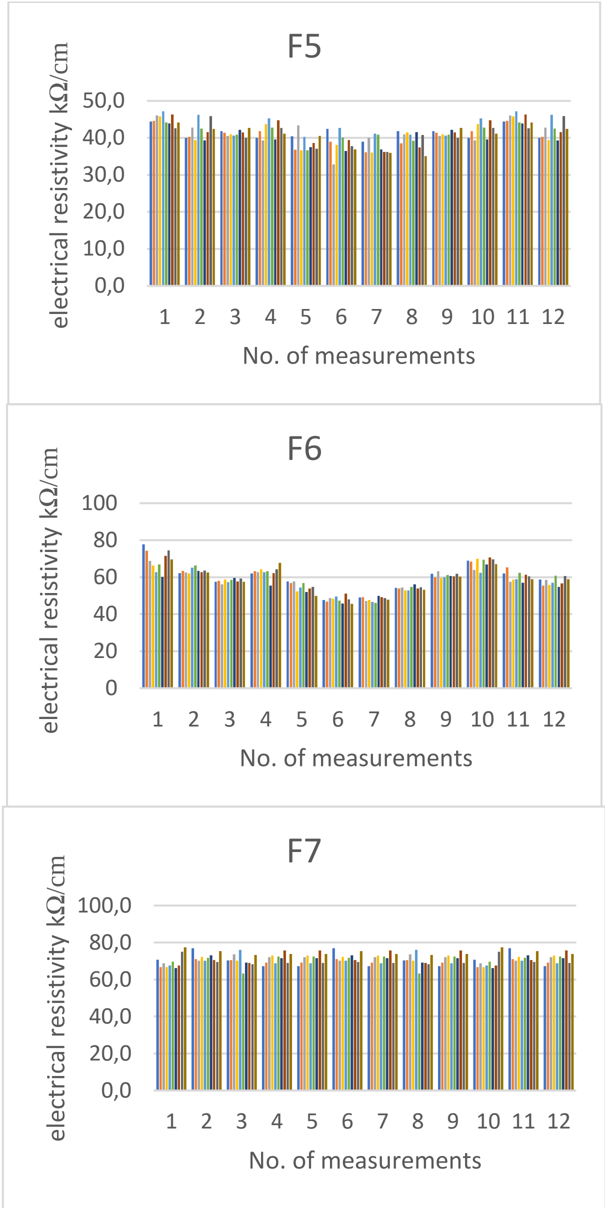
Concretes prepared with metakaolin have better results in terms of capillary absorption, especially families with 5% substitution (F4 and F6), presenting values of 0.28 and 0.30 g/cm² respectively.

Families that used only CDW aggregate as replacement elements (F2 and F3), as expected, showed higher capillary absorption rates compared to the reference concrete.

The surface electrical resistivity values of the concretes were obtained from 120 measurements for each representative family, with 40 measurements with the portable device for each of the 3 test specimens. The results are presented in the following graphs.

Figure 6 – Surface electrical resistivity of concrete at 28 days





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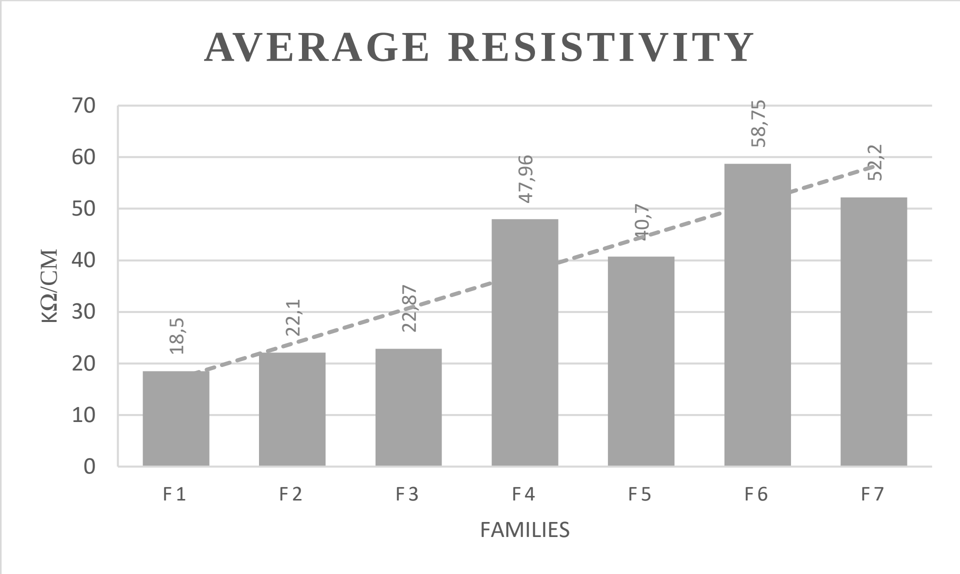
Families F1, F2 and F3 had similar behaviors, around 20.00 kΩ/cm, without significant changes in electrical resistivity results. Therefore, families with metakaolin addition had altered results with greater effect.

Families with 5% metakaolin (F4 and F6) performed the best results compared to the reference concrete (F1), F4 and F6 had results of 47.96 kΩ/cm and 58.75 kΩ/cm respectively, and families with 10% metakaolin (F5 and F7) had results of 40.70 kΩ/cm and 52.20 kΩ/cm respectively.

The average values of surface electrical resistivity are described in Figure 7.

Figure 7 – Average values of surface electrical resistivity of concretes



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CONCLUSIONS

Concretes with CDW aggregate replacing conventional aggregate led to less favorable mechanical strength and capillary absorption.

Concretes prepared with metakaolin, in partial replacement of cement, improved the macrostructural properties of concretes in relation to the reference, even using recycled CDW aggregates.

The addition of metakaolin to concretes prepared with CDW aggregate obtained mixtures with much superior performance in terms of electrical resistivity compared to the reference concrete. This improvement is more evident in concretes with 5% metakaolin in partial replacement of Portland cement, that is, the recycled aggregate was not a determining obstacle in this durability property of concrete.

The use of aggregates of CDW origin is contested for use in structural concretes. However, with the use of metakaolin in partial replacement of cement, the properties were optimized (axial compressive strength, capillary absorption and electrical resistivity), which is a prime indication for the viability of this more sustainable type of concrete.

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