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Durability of concretes produced with a mix of ornamental stone waste thermally treated and waste originating from glass stoning - A view to the corrosion resistance of the reinforcements

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ABSTRACT

In Construction Industry there is a constant search for optimization of materials aiming at greater sustainability in their processes, from the economic, environmental and social point of view. In this context, the incorporation of wastes into cement matrixes has been presented as an interesting alternative, since in addition to reducing the consumption of raw materials and the costs involved, it often contributes to a better performance of the materials. The ornamental stone waste thermally treated (OSWTT) and the waste originating from glass stoning are wastes generated in large quantities in the world, often presenting as environmental liabilities. However, several studies demonstrate the potential of these materials for incorporation in cementitious matrixes, since these, besides acting as a filler, have pozzolanic characteristics. In this way, this work has as objective to evaluate the performance of concretes produced with incorporation of OSWTT and waste from glass stoning mixture, in equal proportion (50% of each), against corrosion of the reinforcement. For this, concrete was produced using Brazilian Portland cement CP V-ARI, with cement replacement percentages of 0%, 10%, 15% and 20%, and water/cement ratio of 0.5. Corrosion assessment of concrete reinforcement was performed according to the procedure described by ASTM C876:2015, at age to 28 days, using accelerated corrosion test, in drying and immersion cycles of concrete specimens in a 5% NaCl solution. As results, statistically, there was no variation in the mean of the potential difference for 10% and 20% substitution values in relation to the reference test specimens, these results are shown to be positive since the substitution of cement by wastes that are unusable in the current market, thus, this procedure would represent an economy in the productive process, since it would replace the most expensive component of concrete, the cement, by the input of materials of low market value.

Keywords: Ornamental stone waste, Glass stoning waste, Concrete, Durability, Corrosion of reinforcement.

1 INTRODUCTION

Concrete is the most used building material in the world, with a consumption of 1.9 tons / hab.year, it is considered the most important structural and construction material of the present time and, in addition, there are estimates that its use is going to increase over the next years [1]. Data from ABCP (Brazilian Association of Portland Cement) and FIHP (Ibero-American Federation of Pre-mixed Concrete) show a 470% increase in the consumption of concrete in the world, between 2012 e 2015, whereas that in 2015 alone, world production of premixed concrete reached 2.4 billion m³ [2] [3].

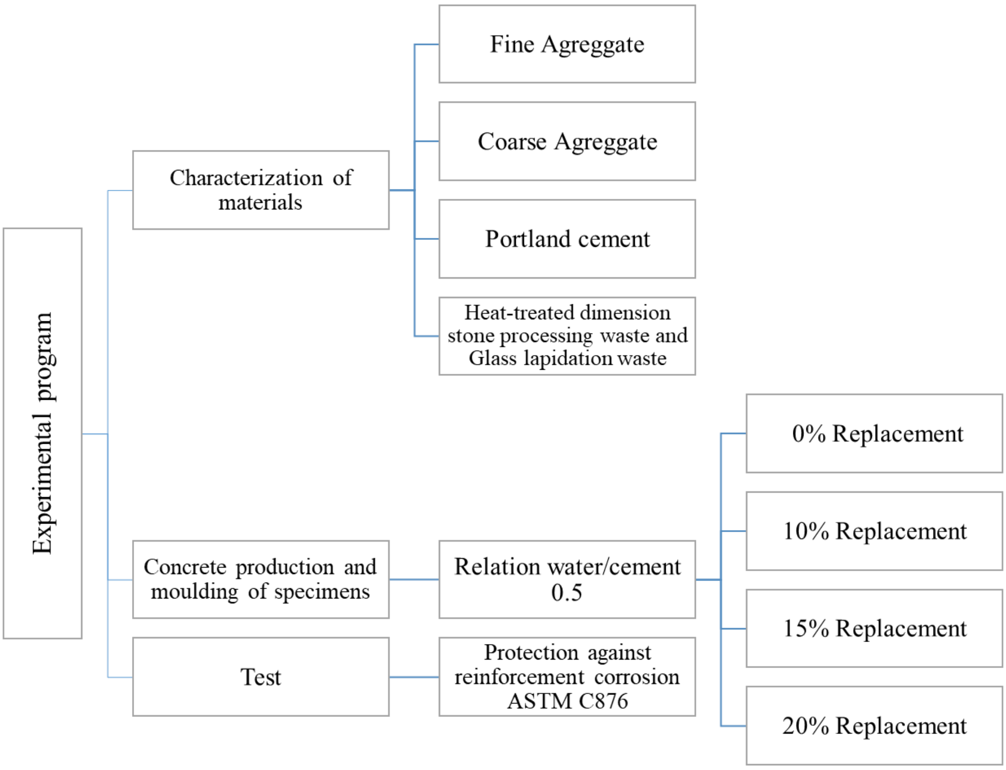
In the last years, several studies have been carried out on building pathologies and premature deterioration of structures, evidencing an importance of the duration of the concrete from the conception of the project, mainly due to the expenses with new constructions, and with the maintenance and repair of damaged structures [4]. However, only a few studies has been given importance to aspects of concrete durability, being only recently, in Brazil, inserted in NBR 15575 [5], as a performance requirement of the buildings. Among the aspects involved in the study of reinforcement concrete, the protection against reinforcement corrosion is one of the predominant items, since that it is essential component for buildings, and has more sensitivity to aggressive agents.

Still, it is important to emphasize that in the current economic model there is a constant search for cost cutting, with consequent optimization of the use of materials and processes. Civil Construction industry is not only one of the most relevant in the world, but too also an industry responsible for major environmental impacts, with the consumption of 50% of the total natural resources in the world, production of waste and CO_2 emissions [6].
Besides that, it is the industry that has the greatest potential for recycling waste, in relation of some other industries. Since most of the building materials are inerts, it is possible to incorporate different residues into cement matrices, such as mortars and concretes, and in artifacts such as ceramic blocks, reducing the consumption of natural raw materials, energy and the emission of pollutants, as well as reducing waste disposal costs [7].
The incorporation of mineral additions into concretes, in addition to environmental benefits, improves the compaction of the structure, the execution of mechanical improvements and the durability. The additions act on the microstructure of the pores, allowing blockage and obstruction of the capillary voids by the action of the fineness of the grains, characterizing, thus, its physical effect and, by the chemical action, promoting the refinement of the pores and the grains, characterizing its effect pozolanic in a joint action these two effects provide an increase in compressive strength by the densification of the cement paste matrix and by the decrease of the transition zone [8].
Among the residues with potential for application in cement matrices, the Heat-treated dimension stone processing waste and Glass lapidation waste has shown a high viability, in view of the large volume generated in the state of Espirito Santo / Brazil and results of studies evidencing increase in the durability of concretes with the incorporation of these residues [9] [10] [11] [12].
Because of the characteristics of Waste Glass Sludge (WGS), it can improve the mechanical and durability properties of concrete, especially in late times. Regarding OSWTT, Vazzoler [12] suggests that it is a potential pozzolan when used in concretes. Still, the results of Mittri [11] suggest that 10% addition of waste, relative to a mass of cement, allows better results. Thus, it is inferred that a mixture between these wastes enhances the benefits presented.
In this way, this work had as objective to verify the resistance to the corrosion of reinforcements in concretes produced with OSWTT and WGS wastes, in different percentages of substitution in relation to cement mass.

2 EXPERIMENTAL PROGRAM

The experimental program of this research consists of the steps shown in the flowchart of Fig. (1). Fundamentally, the research is composed of three main steps. The first stage consists in the characterization of the materials necessary to produce the concretes (Ornamental stone waste thermally treated, Waste from glass stoning, fine and coarse aggregates, cement and water), the second step in the actual production of concretes, including the dosage for the determination of to be used. The third and last step is the evaluation of the corrosion potential of concrete using the methodology described in ASTM C876 [13] which involves immersion and drying cycles of prismatic specimens.

Fig. 1: Scheme of the Experimental Research Program



2.1 Characterization of materials

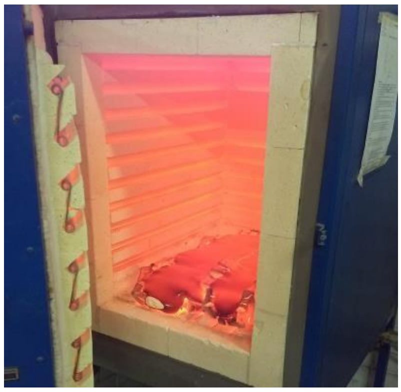
2.1.1 Ornamental stone waste thermally treated (OSWTT) and Waste from glass stoning (WGS)

Ornamental stone waste thermally treated (OSWTT) was collected from a company responsible for cutting of marble blocks and granite in sheets using both conventional looms and multi-loom looms. The company was in the city of Serra / ES / Brazil and generated two types of characteristic wastes, a waste with steel shot (OSW G) and another without steel shot (OSW D). In this research, only OSW D was used, being collected and sent to the LEMAC / UFES (Building Materials Tests Laboratory), for development of the experimental proceedings.

The heat treatment process was carried out in the Mufla brand Linn High Therm, model KK 170, at an approximate rate of 10 ° C / min until reaching the programmed temperature of 1200 °C, after reaching the desired temperature the temperature was maintained constant for 2 hours and then the natural cooling process was started up to room temperature, as proposed by Degen [9] - Fig. (2) and Fig. (3).

Fig. 2: OSWTT heat treatment process (before)

Fig. 3: OSWTT heat treatment process (after)



Waste from glass stoning (WGS) comes from a glassmaking company, located in Grande Vitória/ES/Brazil. The waste is generated in the stoning process of the soda-lime glasses, a mechanism that removes the ends using water and prevents the cutting of the plates. The final product is a greyish mud material containing a large amount of silica (SiO_2) and aluminum oxide (AL_2O_3). This material was collected and sent to the LEMAC where it was dried, discharged and ground.
The grinding process occurred in the ball mill and was carried out for both wastes (OSWTT and WGS). This procedure was necessary to improve the capacity of filling the pores of concrete and the pozzolanic activity of these materials as quoted by Dal Molin [14].

2.1.2 Cement

The cement adopted for the development of this research was the Brazilian Portland cement CPV ARI (which resembles rapid-hardening Portland cement - RHPC), for it is, in the Brazilian market, the one most similar in its chemical composition to ordinary Portland cement.

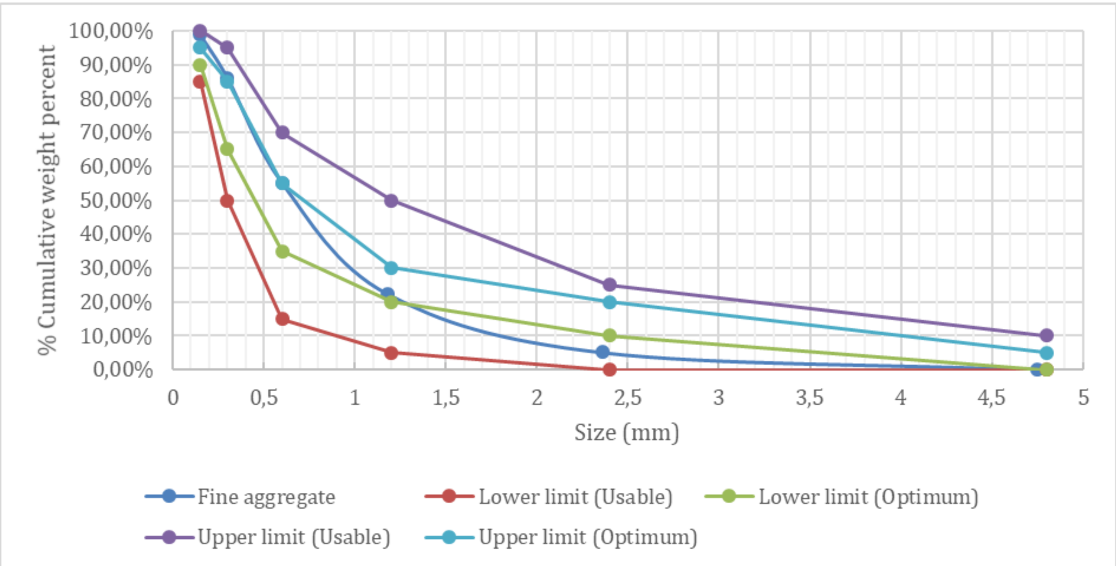
2.1.3 Fine and Coarse aggregates

The fine aggregate used was sand, removal from Doce river, an important river on North Espírito Santo region. For the concreting, the sand was sifted to remove impurities, such as leaves and sticks and dried in the air so that its moisture does not interfere with the concrete's mix proportion. Table (1) below shows some properties of the fine aggregate and Fig. (3) shows its granulometric distribution.

Table 1: Characteristics of Fine aggregate

Characteristic	Method	Result
Maximum characteristic dimension (mm)	ABNT NBR NM 248 [15]	2,36
Fineness modulus	ABNT NBR NM 248 [15]	2,67
Specific mass (g/cm³)	ABNT NBR NM 52 [16]	2,40
Unitary mass (g/cm³)	ABNT NBR NM 45 [18]	1,53

Fig. 3: Granulometric distribution of Fine aggregate

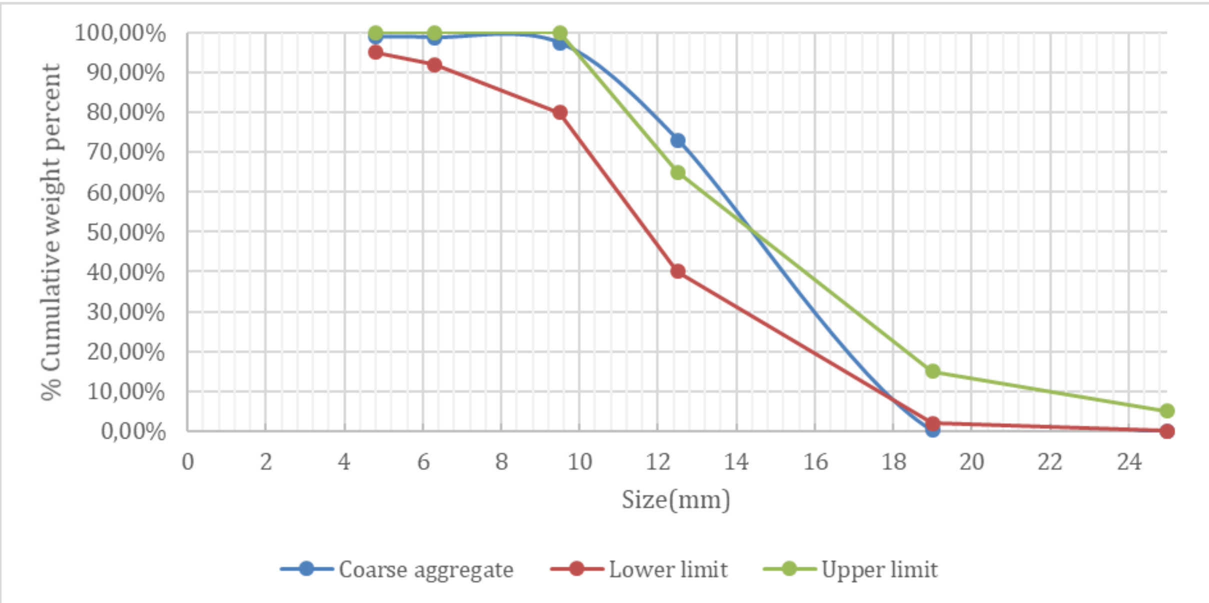


Coarse aggregate was obtained in Vila Velha / ES/ Brazil. To perform the concreting, coarse aggregate was washed for removal of powdery materials and air dried. Table 2 below shows some properties of the coarse aggregate and Fig. (4) its granulometric distribution.

Table 2: Characteristics of Coarse aggregate

Characteristic	Method	Result
Maximum characteristic dimension (mm)	ABNT NBR NM 248 [15]	12,5
Fineness modulus	ABNT NBR NM 248 [15]	1,97
Specific mass (g/cm³)	ABNT NBR NM 53 [17]	2,96
Unitary mass in loose state (g/cm³)	ABNT NBR NM 45 [18]	1,44

Fig. 4: Granulometric distribution of Coarse aggregate

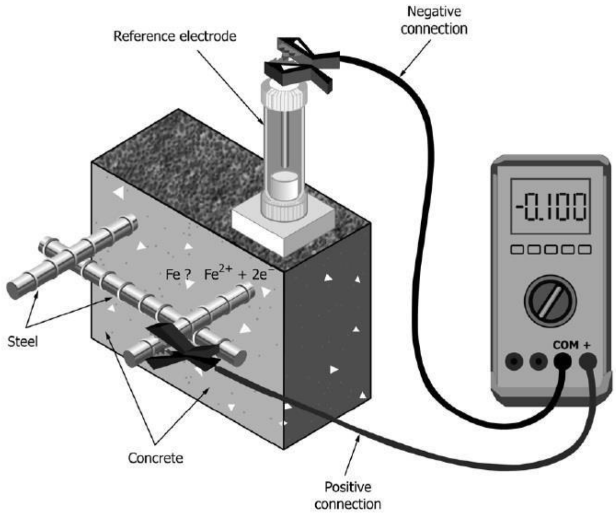


2.2 Corrosion Potential Test

The corrosion potential test is a non-destructive and qualitative procedure to obtain corrosion potentials in concrete reinforcement, providing the likelihood of depassivation and corrosion of the reinforcement. This assay is standardized by ASTM C876: 2015 [13].

The test consists of verifying the potential difference between the steel bar in the concrete and the reference electrode using a high impedance multimeter. The positive pole wire coming out of the multimeter connects to the steel bar, and the negative pole that is connected to the reference electrode is placed in contact with the concrete using a well impregnated with a solution of water and detergent at 5 % for easy connection [9]. Fig. (5) shows an embodiment of the corrosion potential test.

Fig. 5: Demonstration of corrosion potential test



Reference: Adapted of ATMN C876 [13].

For the molding of the prismatic specimens, two plywood shapes were used (with dimensions of 15 cm x 17 cm x 7 cm), containing 2 bars of CA - 50 steel of 6.3 mm diameter in each. Wood pieces were used to guarantee the thickness of cover of 2 cm as shown in Fig. (6). The 2 cm cover is the minimum nominal cover permitted in ABNT NBR 6118 [19].

Fig. 6: Demonstration of specimens molding steps

In order to accelerate the process of deposition of the reinforcement, alternating cycles of immersion and drying of the test specimens were carried out in an aggressive solution of 5% NaCl, simulating a marine environment containing enough salts contents that could de-pass the steel bars of the concrete, shown in Fig. (7). These cycles accelerate the corrosion process, because when saturated the test pieces accumulate chlorides, when the drying process begins, there is oxygen inlet and diffusion, which is responsible for evaporating the water from the concrete pores, leaving only the free chlorides that reach the armature and destroy its passive layer, provoking the phenomenon of corrosion [22].

Fig. 7: Immersion in 5% NaCl solution and oven drying

The corrosion potential readings were performed using the copper electrode / copper sulphate electrode and occurred with the concretes in a saturated situation, after immersion in NaCl solution. All specimens were submitted to 77 days of test, however, there was not enough time for all the bars to present a probability of more than 90% depassivation, which according to ASTM C-876 [13], showed in Table 3, this occurs when the measure of potential difference is more negative than -350mV for the copper electrode / copper sulphate (Cu / CuSO4), which was used in the test.

Table 3: Probability of occurring despassivation in the armature

Electrode	Electrochemical Corrosion: Probability		
	<10%	10% - 90%	>90%
ENH	> 0,118V	(-0,118V) - (-0,032V)	< -0,032V
Cu/CuSO4, Cu2+ (ASTM C 876)	> -0,200V	(-0,200V) - (-0,350V)	< -0,350V
Hg, Hg2 Cl2/KCl (saturated)	> -0,124V	(-0,124V) - (-0,274V)	< -0,274V
Ag, AgCl/KCl (1M)	> -0,104V	(-0,124V) - (-0,254V)	< -0,254V

Reference: Adapted of Degen [9].

2.3 Data analysis

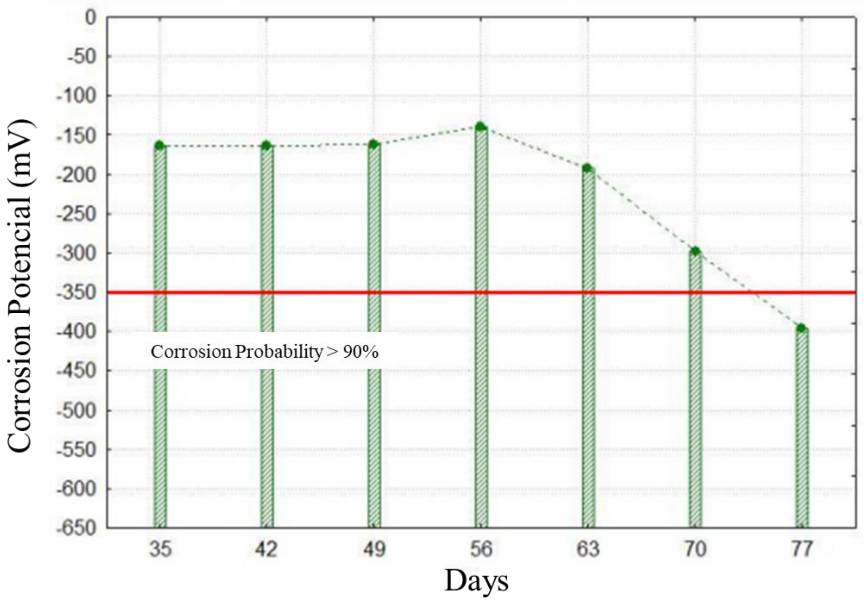
For the data analysis, the Statistica version 7 program was used with the method of analysis of variance at a significance level of 5%.

3 RESULTS AND DISCUSSION

The corrosion potential test only provides the probability of the steel reinforcement present within the concrete to be passive or in the active state as a function of the potential difference measured in accordance with ASTM C876: 2015 [13]. This test started when concrete presented 28 days of age and was interrupted at 77 days of age, totaling 7 cycles of immersion and drying, at that age 10 of the 16 test specimens already had a probability of more than 90% of the disassembling of the reinforcement. The corrosion potential data were submitted to analysis of variance (ANOVA). The only significant variable was age, in isolation. No significant results were obtained in relation to the replacement of cement by residues alone or with interaction with age.

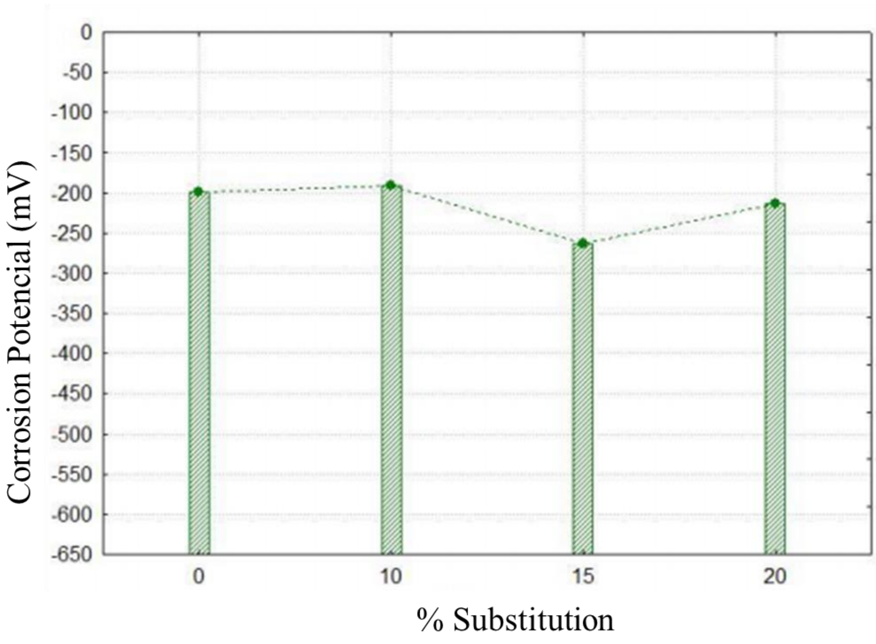
It can be seen from the graph of the corrosion potential in relation to age - Fig. (8) - that there is an increase in the potential difference between the armature and the reference electrode over time, this behavior is expected due to the increase of free chlorides in the as mentioned in item 2.3.

Fig 8. Graphic isolated effect of age variation on the average corrosion potential results



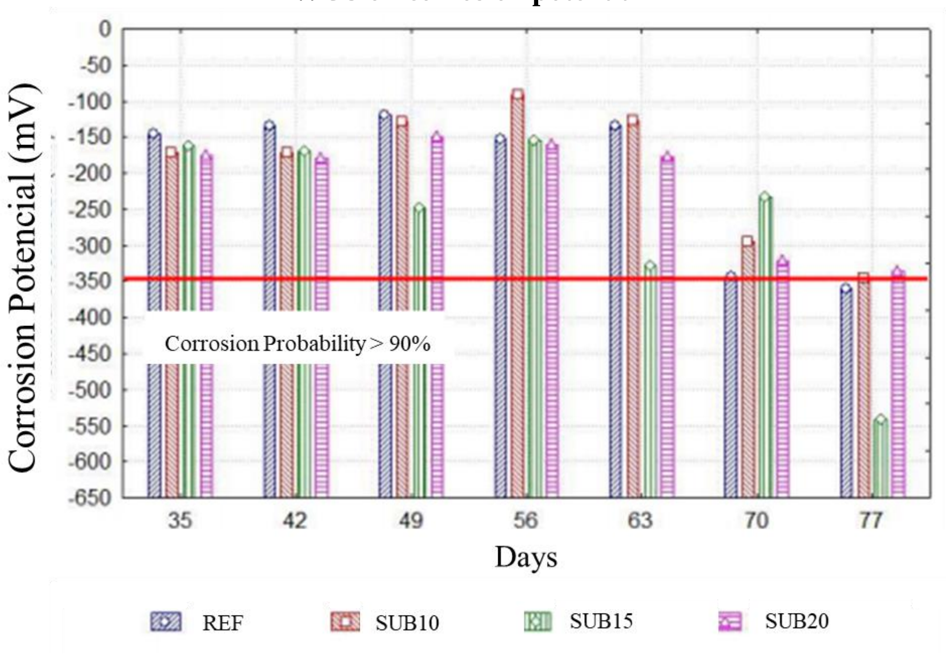
According to Degen [9], when OSWTT content is increased, the corrosion potential decreases, a result explained by the fact that the concrete produced with the residue has lower capillary absorption, which hinders the entry of aggressive agents inside the concrete. However, when evaluating the figure, it can be seen that there is a discrete variation in the potential difference for 10% and 20% of substitution in relation to the reference, however, the increase in corrosion potential for the 15% substitution percentage the result without significance, since it does not follow a pattern of results. In Fig. (9) it is possible to observe the variation of the potential of corrosion in relation to the variation of the percentage of substitution of OSWTT and residue of stonework of the glass in relation to the cement.

Fig 9 - Graphic isolated effect of varying the percentage of OSWTT and WGS on the average corrosion potential results



The graph of Fig. (10) shows the effect of the interaction between age and percentage of waste. It is observed that the concretes with contents of 10 and 20% presented better performance than the reference after the 6th immersion and drying cycle, in addition, the content of 10% was the one that presented better performance and the content of 20% was the one that stood out the most against the reduction of corrosion potential over time. In the reference concrete, S10 and S20 the dispassivation occurred in two of the four specimens with 6 cycles, the reference and the S15 already presented a bar with dispassivation to the 3rd cycle and to the 7th cycle all the bars presented a 90% chance of presenting corrosion.

Fig 10. Graph of the effect of the interaction between the age and the percentage of OSWTT and WGS on corrosion potential



4 CONCLUSION

From the results presented, it can be verified that, statistically, with the advance of the concrete age, the cement substitution by the OSWTT and WGS mixture, in the percentages of 10% and 20%, did not present difference for the corrosion potential in relation to the concrete reference. These results prove to be positive since it was used instead of cement for residues that are unusable in the current market, thus, this would represent an economy in the productive process, since it would replace the more expensive concrete input by materials low market value.

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