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The effects of chemical admixture on the mechanical performance of Portland cement concrete for use in the Brazilian radioactive waste repository

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1. Introduction

Admixtures are essential components for contemporary concrete technology. The properties of fresh and hardened concrete can be modified or even improved by admixtures. ASTM C 125 defines admixture as a material other than water, aggregates, cement, and reinforcing fibers used in concrete as an ingredient and added to the mix immediately before or during mixing. ACI Committee 212 lists 20 essential purposes for use admixtures. For example, to increase the plasticity of concrete without increasing the water content, to reduce bleeding and segregation, to retard or accelerate the setting time, to accelerate the rates of strength development at early ages, to reduce the rate of heat evolution, and to increase the durability of concrete to specific exposure conditions. ASTM C 494, Standard Specification for Chemical Admixtures for Concrete, divides the water-reducing and set-controlling chemicals into the following seven types: Type A, water-reducing; Type B, retarding; Type C, accelerating; Type D, water-reducing, and retarding; Type E, water-reducing and accelerating; Type F, high range water-reducing; and Type G, high-range water-reducing and retarding [1]. Surface-active chemicals, also known as surfactants, cover admixtures generally used for air entrainment or reduction of water in concrete mixtures. Surface-active admixtures consist of long-chain organic molecules, one end of which is hydrophilic and the other hydrophobic. The hydrophilic end contains one or more polar groups, such as -COO-, $-SO_3$-, ou $-NH_3^+$. In concrete technology, mostly anionic admixtures are used either with a nonpolar chain or a chain containing polar groups. The former serves as air-entraining and the latter as water-reducing admixtures. Surfactants used as air-entraining admixtures generally consist of salts of wood resins, proteinaceous materials and petroleum acids, and some synthetic detergents. Surfactants used as plasticizing admixtures are salts, modifications, and derivatives of lignosulfonate acids, hydroxylated carboxylic acids, polysaccharides, or combinations of the previous three [2]. This study investigates the mechanical performance of two Portland cement concrete formulations. The authors consider that the present work as preliminary. It is part of an ongoing research project to provide technical requirements for constructing the Brazilian near-surface repository for radioactive wastes.

2. Methodology

2.1 Materials

For the study, the authors prepared two concrete mixtures according to the NBR-12655 Brazilian Standard Test Method [3], with characteristic compressive strength fck at 28 days of 35 MPa, containing river sand with fineness modulus of 2.29 as fine aggregate and 9.5 mm maximum-sized limestone and 19 mm maximum-sized gneiss as coarse aggregate. They used a Brazilian Portland cement CP III-40-RS equivalent to the ASTM Type IS blast furnace-slag cement as the binder. The authors used a modified polycarboxylate ether plasticizer GLENIUM 51 to reduce the water content. The mixture proportions of concretes were determined to achieve a slump flow of 100±20 mm. The casting of 100x200 mm test cylindrical specimens was according to the NBR-5738 Brazilian Standard Test Method [4]. Twenty-four hours after casting, the authors demolded the specimens and stored them in a humidity chamber for 28 days. Figure 1 shows the preparation of concrete and molding of specimens. Table I gives the mixture proportions of both concrete.

Table I: Concrete mixture compositions.

	M1	M2
Cement (kg/m^3)	446	446
River sand (kg/m^3)	697	697
Limestone coarse aggregate (kg/m^3)	317	317
Gneiss coarse aggregate (kg/m^3)	739	739
Tap water (kg/m^3)	205	123
Plasticizer (kg/m^3)	-	2.68
Water/cement ratio	0.47	0.28

2.2 Tests

The uniaxial compressive strength tests followed the NBR-5739 Brazilian Standard Test Method [5]. The authors used a compression testing machine PC200 from EMIC, with a machine capacity of 2000 kN with a sensitivity of 10 N.

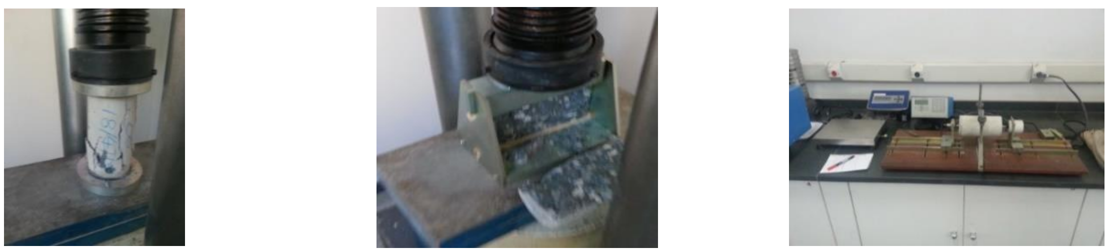
The tensile test performed using the same compression testing machine PC200 cited followed the NBR-7222 Brazilian Standard Test Method [6].

According to the ASTM C215–19 [7], the obtained dynamic modulus of elasticity of the concrete is a crucial mechanical parameter reflecting the ability of the concrete to deform elastically.

An ultrasonic test evaluates the discontinuities in the specimens produced in the laboratory and verifies the quality of their compactness. The ultrasonic pulse produced by applying a rapid change of potential from a transmitter-driver to a piezoelectric transformation element, makes it vibrate at its fundamental frequency. The transducer is placed in physical contact with the material surface to transfer the vibrations to the material. A receiver unit receives the vibrations after traveling through the material. The time of travel of an ultrasonic pulse wave from a transmitter to a receiver is the chosen parameter to achieve it. The authors executed the ultrasonic tests following the NBR 8802 Brazilian Standard Test Method [8]. They selected a direct method of reading, which is performed in the diagonal direction with 100mm of wave travel, using transducers of 50mm diameter with gel coupled with a specific contact. Figure 2 shows the mechanical testing of the cylindrical concrete specimens.

(a) (b)

Figure 1: (a) Concrete preparation, (b) molding of cylindrical concrete specimens.



(a) (b) (c)

Figure 2 : The mechanical testing of the cylindrical concrete specimens: (a) compression testing machine, (b) tension testing machine, (c) dynamic elasticity modulus testing machine.

3. Results and Discussion

Statistical analysis of the results for α=0.05 (significance level) of compressive strength (fc), tension strength (ft), and dynamic modulus of elasticity (Ed) are in Table II. The n-1 degrees of freedom employed to obtain the confidence interval of the population mean (μ) was 14. The results showed an improvement of all the mechanical properties for the M2 mixture. The compressive strength results of the M2 mix increased 33.5% compared to the M1 mix. The tension strength results of the M2 mix increased 18.8% compared to the M1 mix. The dynamic modulus of elasticity results of the M2 mix increased 8.7% compared to the M1 mix. Adding a plasticizer when mixing the constituents during the production of concrete and mortar is to establish a system with good dispersion of the cement particles, thus improving the ease and homogeneity constituents can be mixed [1, 2]. In a particulate composite, which has both a particle phase and a matrix phase, the dispersed particles, because of their greater rigidity than the matrix, tend to restrict the movement of the matrix phase. The matrix then transfers part of the charge acting in the system to the dispersed phase, and the degree of reinforcement will depend on the bond that occurs at the interface between particles and the matrix [9]. Concrete is a particulate composite, with fine and coarse aggregate particles dispersed in the hardened cement paste matrix. More efficient mixing of the constituents in the fresh state will ensure that all sand particles will be surrounded by a cement paste when in the hardened condition, enabling the perfect mechanical reinforcement, making the M2 mix mechanical performance superior to the M1 mix.

Table II: Compressive strength, tension strength, and dynamic modulus of elasticity results.

Mixture	f_c (MPa)	f_t (MPa)	E_d (GPa)
M1	$37.7 < \mu < 38.1$	$3.1 < \mu < 3.3$	$38.8 < \mu < 39.2$
M2	$49.3 < \mu < 51.9$	$3.7 < \mu < 3.9$	$42.3 < \mu < 42.5$

Statistical analysis of the results for α=0.05 (significance level) of the ultrasonic pulse propagation time (UPV) is presented in Table III. The n-1 degrees of freedom employed to obtain the confidence interval of the population mean (μ) was 14. The results showed the ultrasonic propagation time results of the M2 mixture decreased 5.5% compared to the M1 mix. The velocity of the ultrasonic pulse through concrete is the outcome of the time taken by the pulse to travel through the hardened cement paste and the aggregate [9]. Material attenuation is one of the primary mechanisms by which an ultrasonic wave attenuates, and, in its turn, scattering is one source of material attenuation. Scattering losses are overly complex and depend upon the intrinsic length scale of the scatter. The volume and distribution of spreads and the acoustic properties of these scatter concerning the matrix material [10]. The ultrasonic pulse velocity in concrete is strongly affected by its microstructure discontinuities. The lesser water/cement ratio of the M2 concrete mixture produced a denser microstructure than the M1 mixture, and it explains the obtained results.

Table III: Ultrasonic pulse propagation time results.

Mixture	UPV (μs)
M1	$28.9 < \mu < 29.5$
M2	$27.4 < \mu < 27.8$

4. Conclusions

The results showed an improvement in mechanical properties. The values of compressive strength, tension strength, and dynamic modulus of elasticity of the M2 mixture increased by 33.5%, 18.8%, and 8.7%, respectively, compared to the M1 mixture. In addition, the ultrasonic propagation time results decreased 5.5% for the M2 mixture compared to the M1 mixture. It is an outstanding result because the only difference between M1 and M2 mixtures is the plasticizer admixture and the lesser water content in the M2 composition.

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