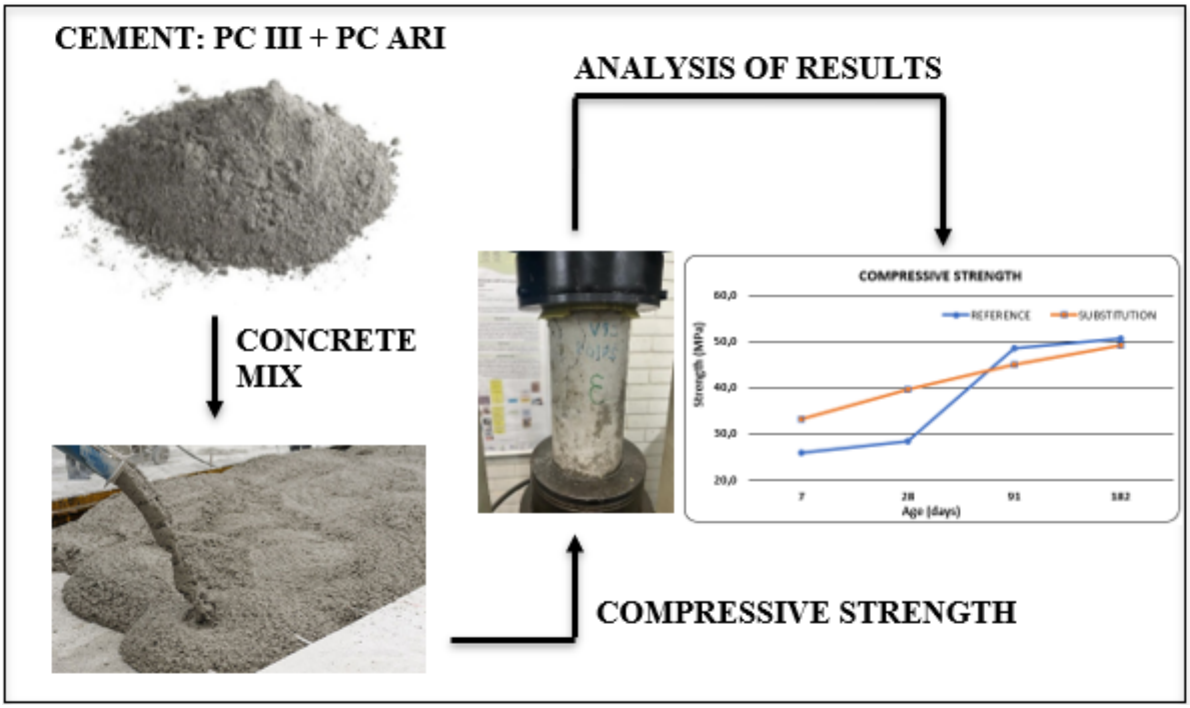
ISSN 2359-4799
Volume 11 / Number 1 / Year 2025 – p. 01-10
DOI: 10.36524/ric.v11i1.2822



ANALYSIS OF THE MECHANICAL AND PHYSICAL BEHAVIOR OF CONCRETE WITH PORTLAND CEMENT TYPE III AND PORTLAND CEMENT ARI

Filipe Martins Lima [1]*, Luiz Fernando Daniel da Silva [1], Alessandra Savazzini-Reis [1], and Georgia Serafim Araújo [1]

[1] Civil Engineering Coordination, Instituto Federal do Espírito Santo – IFES, Campus Vitória, 29040-780 Vitória – ES, Brazil.

*filipecursos.28@gmail.com

Article submitted in 11/06/2024, accepted in 05/05/2025 and published in 17/06/2025.

ORCID – Filipe Martins Lima: https://orcid.org/0009-0005-2959-1179
ORCID – Luiz Fernando Daniel da Silva: https://orcid.org/0000-0002-9262-7585
ORCID – Alessandra Savazzini-Reis: https://orcid.org/0000-0002-6978-2069
ORCID – Georgia Serafim Araújo: https://orcid.org/0000-0002-2029-6334

Abstract: The concrete used in prestressed slabs in Greater Vitória, Espírito Santo, Brazil, usually contains PC type III (blast furnace slag Portland cement) (ABNT, 2018) and PC type V High Early Strength (Portland cement V ARI) (ABNT, 2018), facilitating faster execution of protension. The aim of this study is to analyze the behavior of concretes with PC III and PC ARI in their composition with up to 182 days of age. In order to do so, two types of concrete were manufactured: the reference one - containing only PC III - and the other one in which 30% of PC III was substituted by PC ARI. By analyzing the concretes' strength to axial compression at the 7th day, we observed that the concrete with substitution displayed a resistance to axial compression that is 28.2% higher than the reference concrete. Meanwhile, at 91 days of age, the reference concrete displayed an axial compression that was 7.6% higher than the concrete with substitution. Therefore, we notice a significant change in the behavior of concrete composed of cement with high early strength (PC ARI).

Keywords: Portland Cement III; Portland Cement High Early Strength; Prestressed Concrete; Axial Compression Strength.

1 INTRODUCTION

The first applications of protension in Brazil were applied in infrastructure sites, highways, bridges and viaducts, allowing constructors to overcome large spans and securing the viability of said works. In addition, protension technology has been applied in conventional works for the past few decades. This way, this constructive technique has been increasingly more popular in the Brazilian construction industry, now being implemented in residential and commercial works, buildings, houses, warehouses and industries, both as pre-made pieces and in elements made on-site. This is due to the fast evolution of the project by increasing production, reducing the overall work cost, as well as a diversity of ground plan options for architectural projects.

Prestressed Concrete consists of executing concrete with a Post-Tensioning Systems, in addition to conventional reinforcement. For elements molded on-site, the reinforcement is submitted to pre-elongation after the concrete hardens (post-stress) and with constituent support from the structural element itself.

The ABNT (Associação Brasileira de Normas Técnicas) NBR 16697:2018 prescribes the composition of Brazilian commercial Portland cements (ABNT, 2018). In the PC type III has a composition of 25% to 65% clinker + calcium sulphates, 35% to 75% blast-furnace slag and up to 10% calcium carbonate, while PC type V ARI has 90% to 100% clinker + calcium sulphates and up to 10% Calcium carbonate.

Unlike reinforced concrete structures in which Portland cement (PC) types II and III are applied, we observed that for prestressed concrete the common practice is to substitute part of these cements by PC V High Early Strength (ARI), in order to create tension on the wire ropes at the earliest stage possible. This stage is when concrete reaches f_{ckj} (characteristic compressive strength of concrete at j days), the resistance necessary to withstand the tension of protension, as estimated by the structural project. In Greater Vitória, the strength for structural projects is usually set as 70% of f_{ck} (characteristic compressive strength) and, in general, occurs between the 3rd and 5th day after concreting the structural element.

In Brazil, the use of prestressed concrete with greased and plastic-coated wire ropes began in 1998, in infrastructure works, due to the fact that its technology made it possible to overcome large spans (VERÍSSIMO, CÉSAR JR., 1998).

In the state of Espírito Santo, the first construction performed with this technique was in a residential building named Siena, located at Dante Michelini Avenue, at Camburi Beach, Vitória-ES (PTE, 2020).

Espírito Santo, among Brazilian states, is one of the pioneers in using protension technology in concretes for construction works. For construction works, the analysis of concrete strength to compression strength is limited to 28 days of age. The present article displays the results of mechanic performance of sample concrete pieces made with a mixture of PC III and PC ARI at ages 7, 28, 91 and older, with a 182 days (6 months) old part.

2 THEORETICAL REFERENCE

Oliveira and Pereira (2021) points out that PC III, Blast Furnace Portland Cement, has as its main characteristics low heat of hydration, high durability and impermeability, good resistance to temperature variations (expansion and contraction), as well as resistance to sulfate-based materials. It can have up to 70% slag content in its composition, while PC V ARI, High Initial Strength Portland Cement is a type of cement similar to the common one, as it does not have additives in its formula. However, its manufacturing method doses the clay and limestone differently, with fine grinding. Due to its physical composition, it acquires strength more quickly.

The process of clinkerization forms components such as alite (C_3S), the clinker's main constitutional element with around 40% to 70% of mass, and belite (C_2S), which represents only around 10% to 20%, as well as C_3A (tricalcium aluminate) and C_4AF (tetracalcium aluminoferrite). Alite is responsible for the hardening process and for mechanical strength from 1 to 28 days of curing, meanwhile belite is responsible for the same processes after the first 28 days. As for C_3A, it promotes concrete setting, and C_4AF acts on the cement's chemical resistance, especially against sulfates (KIHARA; CENTURIONE, 2005). Most studies have been researching cement mechanical resistance until its first 28 days, often relating it to the present compounds.

Lima (2024) study aims to analyze the physical-mechanical performance of concrete containing PC III and PC ARI cements at usual ages 7, 28 days and at advanced ages of up to 1 year. For this, two types of concrete were made: a Reference one - only with PC III - and another with the Substitution of PC III by 30% of PC ARI by mass. When analyzing the axial compressive strength of the concretes, the Substitution concrete obtained an increase of 21.6% in strength in relation to the Reference concrete on the 7th day. While at 28 days, it obtained a 1.7% increase. According to literature reports, this is due to the fact that PC ARI has a higher content of C_3S and C_3A in its composition, which influences the increase of strength in the first ages of concrete, and PC III has a greater presence of C_2S that contributes to the increase of resistance at more advanced ages.

Li, Bizzozero and Hesse (2022) tested the behavior of the formation of hydrated calcium silicate (C-S-H) and the strength of concretes containing cement and blast furnace slag and in the Reference concrete (without blast furnace slag). In this research, when performing XRD, these authors observed, at early ages, greater formation of C_3A and C_3S in the Reference concrete, and in the sample with the addition of blast furnace slag, greater formation of C_2S was observed. Additionally, the final strength (at older stages) of cement rich in C_2S is higher than that of other cements with lower levels of this same mineral element.

Campos et al. (2023) investigated the influence of additives in cement pastes with CP IV and CP V ARI cements. These authors, when analyzing the influence of the same additive in different types of cement, the behavior of the cement paste compositions was divergent, finding that the type of cement used directly influences the behavior of each additive, coexisting with different cement-additive reactions.

Therefore, we can observe that the majority of the mentioned studies reported results for up to 28 days, demonstrating that PC V ARI displays more strength in early ages. However, they usually do not exhibit the behavior of concrete with PC III and PC ARI at more advanced stages, at 182 days for example, not taking into consideration the influence and behavior of the type of Portland cement used in concrete throughout a long period of time.

3 METHODOLOGY

3.1 Materials and characterization

To create the mixture used, cements PC III 40 RS (Sulphate Resistant cement) and PC ARI (High Early Strength Cement) (ABNT, 2018), sand from the Rio Doce, Espírito Santo, and granitic gravel were mixed. All of these materials were bought from business in the Greater Vitória region. Aside from water, which was also added and was provided by the local dealership.

In order to characterize the fine mesh aggregate, we carried out an granulometric analysis according to NBR 17054 standard (ABNT, 2022).

3.2 Concrete mix

The concrete mix adopted as Reference was composed of 1:1.13:2.10 of, respectively, PC III : medium sand : gravel, using a water/cement ratio of 0.45. For the concrete substitution, 30% for PC III was substituted by PC ARI, the same substitution pattern applied to prestressed slabs in Grande Vitória-ES.

3.3 Preparation, consistency and molding of concrete samples

The concrete was mixed through 3 steps: the first step was to add gravel and 1/3 of water into the concrete mixer, then adding cement and the second 1/3 of water, and, lastly, adding sand and the last 1/3 of water. At each step the combination was mixed for 1 minute and, at the end, for other 5 minutes, thus mixing for a total of 7 minutes and resulting in a homogeneous material.

A slump test was performed according to the NBR 16889 standard (ABNT, 2020) after the mixture of materials was finished.

In order to analyze the hardened cement, samples were molded into cylindrical test specimen with 10x20 cm dimensions according to the NBR 5738 standard (ABNT, 2016).

3.4 Compressive strength

The compressive strength was obtained through the test method described by the NBR 5739 standard (ABNT, 2018). For each stage (7, 28, 91 and 182 days) 2 cylindrical test specimens of each mix were tested, that is, 8 specimens for the reference mix (PC III) and another 8 more specimens for the substitution mix (PC III + PC ARI). Before each rupture, the specimens were removed from immersion curing, dried with damp cloths, measured and clad in Sulphur.

3.5 Tensile strength by diametrical compression

The tensile strength by diametrical compression test was conducted according to the NBR 7222 standard (ABNT, 2011). At 28 days of age, 2 specimens with 10x20 cm were tested for each mix. Such tests used auxiliary devices in order to guarantee the Concrete Specimen (CS) placement in the testing machine so that the axial plan is in line with load application, as indicated by standard.

3.6 Water absorption and void ratios

The water absorption and void ratios tests were performed according to the NBR 9778 (ABNT, 2009). After 28 days, 2 specimens of 10x20 cm for each mixture were tested.

4 RESULTS AND DISCUSSION

The granulometric analysis of the sand resulted in a fineness modulus (FM) of 2.38 and a maximum characteristic size (MCS) of 2.34 mm. Figure 1 illustrates the grading curve of sand, as well as the acceptable and optimal limits proposed by the NBR 7211 standard (ABNT, 2022).

The sand is located at an "optimal zone" for fine mesh aggregates, which encompasses fineness modulus rates between 2.20 and 2.90. Thus, allowing more particles to be packed into the concrete, which may lead to more compact mixtures, contributing to the evolution of concrete properties due to the fact that it is completely in the usable zone.

Figure 2 displays the concrete consistency test (slump test) performed before the specimens were molded. The results indicated a 70 mm slump for the reference mix (PC III) and a 65 mm slump for the substitution mix (PC III + PC ARI). Therefore, both mixes were classified as

ISSN 2359-4799
Volume 11 / Number 1 / Year 2025 – p. 01-10
DOI: 10.36524/ric.v11i1.2822

REVISTA Ifes ciência

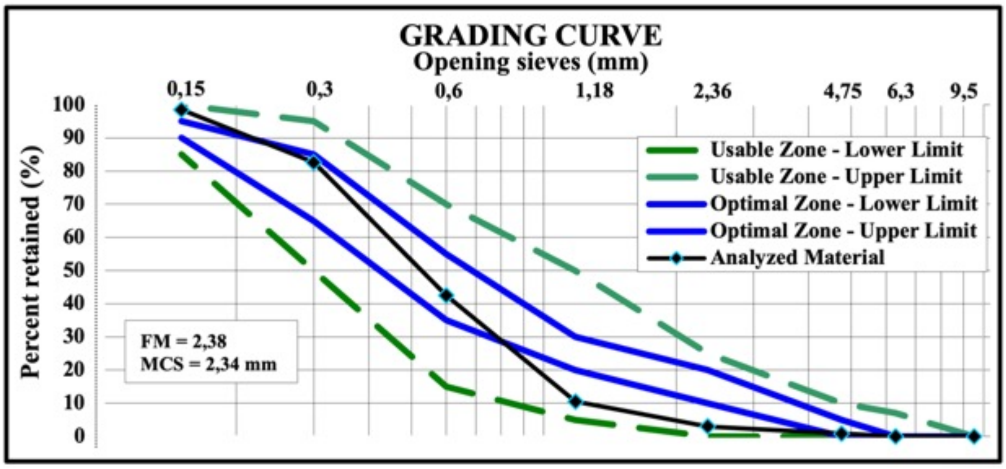


Figure 1. Sand granulometry curve.

S50, in accordance with the NBR 8953 standard (ABNT, 2015).

(a) Reference (b) Substitution

Figure 2. Slump test.

Table 1 illustrates the results of the slump and physical tests performed at the 28th day. We can observe that the reference concrete had a higher rate of water absorption, higher void ratios and, consequently, a smaller specific mass than that of the substitution concrete. This may be caused by the crystallizing process of the PC III cement, which occurs at older stages, that is, after 28 days. As for the substitution concrete, it had a lower rate of water absorption, lower void ratios and a higher specific mass, possibly due to the greater packing ability of concretes with PC ARI in their compositions. This happens because this type of concrete has smaller particles, causing more voids of the concrete matrix to be filled, as well as increasing the hydration speed, which, in turn, contributes to the densification of the samples.

Figure 3 presents the results of the compression strength tests (Fig. 4). We can observe that, at the 7th day, the reference concrete had a compression strength of 25.9 MPa, however, at the 28th day, its compression strength was of 28.3 MPa, indicating an increase by 9.6% in strength. After 91 days, the strength to compression of this concrete was for 48.4 MPa, suggesting a 70% increase in comparison to the result gotten on the 28th day, corroborating the findings present in literature and, after 182 days, the compression strength was of 50.5 MPa, increasing by 4.3% in comparison to the resistance at the 91st day, leading to the hypothesis that resistance gain is stabilized after 182 days.

ISSN 2359-4799
Volume 11 / Number 1 / Year 2025 – p. 01-10
DOI: 10.36524/ric.v11i1.2822

Table 1. Slump and physical tests

TYPE	REFERENCE	SUBSTITUION
WATER/CEMENT RATIO	0,45	0,45
SLUMP (mm)	70	65
CLASS	S50	S50
WATER ABSORPTION (%)	5,67	4,52
VOID RATIO (%)	12,98	10,43
SPECIFIC MASS (Kg/m³)	2,29	2,31

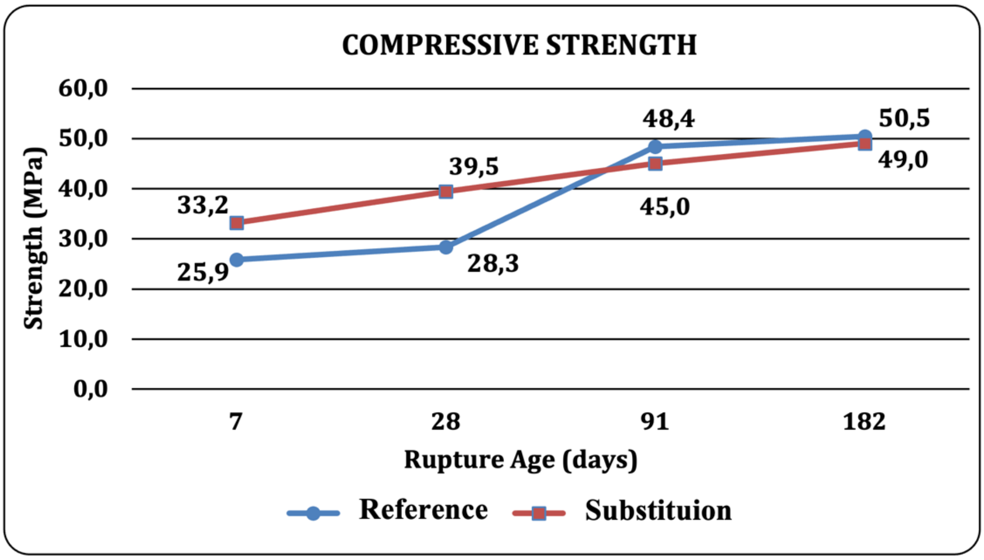
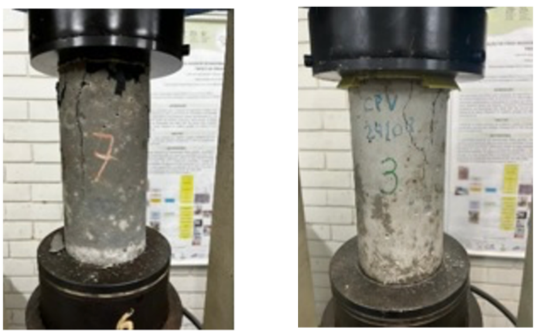


Figure 3. Compressive strength.



(a) Sp. Subs. 28 days (b)Sp. Ref. 182 days

Figure 4. Compressive Strength.

As for the substitution concrete, its strength to compression at the 7th and 28th days were, respectively, 33.2 MPa and 39.5 MPa, indicating an increase by 19%. Meanwhile, after 91 days, the concrete's strength was of 45 MPa, representing an increase by 14% in comparison to the result obtained on the 28th day. After 182 days, the compression strength was of 49 MPa, increasing by 8.9% from the previous age tested, suggesting that strength gain remains constant until a certain age. This indicates higher strength at early stages and decreasing numbers of strength at older stages, displaying a tendency of achieving stability.

The reference concrete reported a small increase in compression strength in the early stages and great variation at older stages, that is, at the 128 days, its compression strength was 78% percent higher than at the 28th day. Differently, the substitution concrete with PC ARI reported more strength until the 28th day, however, at an older stage, after 182 days, its strength suffered little variation, increasing by 24% in comparison with the first 28 days, presenting a value smaller than that of the reference concrete and with a tendency to stabilize its strength. PC ARI's fineness, combined with its chemical composition, may have contributed to its faster development of mechanical strength in comparison to PC III.

The test performed at the 7th day indicated that the substitution concrete was 28.2% more resistant than the reference concrete. However, when the same test was performed at the 28th day, it indicated that the substitution concrete was 39.6% more resistant. According to reports found in the literature, it is expected that, at older stages, the Reference concrete's (PC III) strength exceeds that of the substitution concrete (PC III + PC ARI). This was seen when the strength was tested at the 91st day, resulting in a strength 7.6% higher from the Reference concrete than that of the Substitution concrete. This is due to the fact that PC ARI has higher levels of C_3S and C_3A, which influences the increased resistance in the concrete's first days. On the other hand, PC III has higher levels of C_2S, which provides increased resistance at older stages, as observed, for example, by Castro et al. (2011). In addition, by comparing the data from the physical tests on Table 1 to the results of the compression strength test on Figure 2, it becomes clear that after 28 days the Reference concrete displays higher void ratios, smaller specific mass and a higher rate of water absorption, which may have led to less axial strength at the 28th day. Whereas the Substitution concrete displays better physical results and, consequently, higher strength to compression.

We also performed a test of tensile strength by diametrical compression on the 28th day, which is illustrated in Figure 5 and which the results are displayed in Table 2. Although the individual values of the Substitution concrete indicate a smaller deviation, both concrete mixes displayed a tensile strength to average of 3.3 MPa.

(a) Test

(b) Specimen ruptured

Figure 5. Tension strength by diametrical compression.

Table 2. Tensile strength by diametrical compression.

SPECIMENS	REFERENCE (MPa)	SUBSTITUION (MPa)
1	3,6	3,2
2	2,9	3,4
MEDIAN	3,2	3,3

Such behavior was expected since concrete tends to resist to traction according to 10% of its compression resistance. This result demonstrates a lack of significant differences in resistance to traction, regarding to the use of these two types of cement in concrete, while also not causing significant interferences to the concrete's tensile strength.

5 CONCLUSIONS

With the results obtained in the present study, we conclude that the behavior of the concrete was as expected from the available literature on the theme. This way, until the 28th day, the substitution concrete displayed higher strength to axial compression than the reference concrete, indicating that PC ARI achieved high early strength due to the fact that this cement has higher levels of C_3S and C_3A and its fineness. Thus, we observe that PC ARI can foster better conditions for protension due to its higher strength rates at early stages of the concrete, enabling the traction of wire ropes at the earliest stages possible.

Likewise, at older stages, after the first 28 days, the reference mix displayed higher compression strength than that of the substitution concrete because PC III has higher levels of C_2S in its composition.

In conclusion, according to the information exposed in the present research, future analysis on this theme are necessary, considering the older stages of concrete, different levels of substitution and, additionally, performing physicochemical analyses of the concrete, such as SEM - scanning electron microscopy - and XRD - X-ray diffraction - as means to better comprehend the behavior caused by the substitution of PC III by PC ARI in concrete.

ACKNOWLEDGMENT

We would like to thank the Federal Institute of Espírito Santo (IFES), teachers Alessandra Savazzini dos Reis and Georgia Serafim Araújo for their guidance in this research and laboratorian Márcio Verdin Tavares for supporting the development of this research.

REFERENCES

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **ABNT NBR 5738:** Concrete - Procedure for molding and curing concrete test specimens. Rio de Janeiro: ABNT, 2016.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **ABNT NBR 5739:** Concrete - Compression test of cylindrical specimens. Rio de Janeiro: ABNT, 2018.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **ABNT NBR 7211:** Aggregates for concrete - Requirements. Rio de Janeiro: ABNT, 2022.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **ABNT NBR 7222:** Concrete and mortar - Determination of the tension strength by diametrical compression of cylindrical test specimens. Rio de Janeiro: ABNT, 2011.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **ABNT NBR 8953:** Concrete for structural use - Density, strength and consistence classification. Rio de Janeiro: ABNT, 2015.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **ABNT NBR 9778:** Hardened mortar and concrete - Determination of absorption, voids and specific gravity. Rio de Janeiro: ABNT, 2009.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **ABNT NBR 16697:** Portland cement - Requirements. Rio de Janeiro: ABNT, 2018.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **ABNT NBR 16889:** Fresh concrete - Slump test. Rio de Janeiro: ABNT, 2020.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **ABNT NBR 17054:** Aggregates - Determination of granulometric composition - Test method. Rio de Janeiro: ABNT, 2022.

de CASTRO, A. L.; LIBORIO, J. B. L.; PANDOLFELLI, V. C. **A influência do tipo de cimento no desempenho de concretos avançados formulados a partir do método de dosagem computacional.** Cerâmica, vol. 57, no. 341, Mar, 2011.

CAMPOS, F.; GOINSKI, A.; SCHORR, C.; YOSHIKAWA, G.; VOZINIAK, R.;

WEBER, S. **Análise da capacidade de influência de aditivos superplastificantes em pastas cimentícias com cimentos CP IV e CP V - ARI.** 64CBC2023. Florianópolis. Outubro, 2023. ISSN: 2175-8182.

KIHARA, Y.; CENTURIONE S.L. **O Cimento Portland. Concreto : ensino, pesquisas e realizações.** IBRACON, vol. 10, pp. 295-321, 2005. Access in: mai, 4, 2024. Available at: https://repositorio.usp.br/item/001616688.

LI, X.; BIZZOZERO, J.; HESSE, C. **Impact of C-S-H seeding on hydration and strength of slag blended cement.** Cement and Concrete Research, v. 161, 2022.

LIMA, F.M. **Comportamento do concreto com substituição parcial do CP III por CP ARI em idades avançadas.** Espírito Santo: Vitória, (2024).

OLIVEIRA, F.B.; PEREIRA, M.B. **Influência do tipo de Cimento Portland na consistência de pastas cimentícias.** Rio Grande do Norte: Mossoró, (2021).

Pós-Tensão Engenharia, PTE. Folheto Institucional. Espírito Santo, 2020. Access in: mai 4, 2024. Available at: https://issuu.com/plastfer/docs/folheto_institucional_revisado.

VERÍSSIMO, G.S; CÉSAR JR.; KLÉOS M.L. **Concreto protendido fundamentos básicos**. Minas Gerais: Viçosa (1998).