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The Influence of the Aggregates on the Concrete Mechanical Properties

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1. Introduction

Development Center of Nuclear Technology (CDTN/CNEN) coordinates the CENTENA Project, aiming at the construction of the repository for low and intermediate-level radioactive wastes generated in Brazil. Based on the concept of multiple barriers to retain the radionuclides in the disposal system, the project aims to ensure the efficiency of this system to protect the population and the environment. Thus, concrete is fundamental as a constituent of the engineered barriers, being widely used because of its strength, durability and versatility. These properties make it a study and long-lasting option for numerous industrial and commercial settings. High density concrete as radiation shielding guarantees that people can work safely in buildings where ionizing radiation occurs, e. g., hospitals, laboratories, research institutes, NPPs etc. Although the containers do not have direct contact with the radioactive material, they perform as an important barrier in the case of some contaminant release comes from the waste package [1]. This characteristic is greatly influenced by the coarse aggregates because their high mass to volume proportion. The proposed concrete container, to be used to condition the waste packages of different dimensions, allows the standardization of the packaging and it will be exposed to the environment during at least 60 years operational time of the repository [1]. It is of utmost importance to make the technological control of concrete to guarantee its expected performance in service. The importance of the study is related to the projected concrete service life and the weather aggressiveness coming from environmental exposition, which require a rigorous quality control. In addition of the container structure durability, it should be also evaluated its radionuclides retention capacity.

Among the components of concrete, the aggregates are the materials that contribute significantly to its durability, due to their high resistance to abrasion, with a strong relationship between them and the concrete behavior. It is intended, through a literature review, to study some properties of high-performance concrete with the addition of steel fibers, analyzing the results of the tests: elasticity modulus, tensile strength, and compression strength, evaluating the best alternatives for its application.

2. Methodology

In CDTN research is being conducted to study the different repository barriers, being the concrete container one of these. Considering the complexity of the interaction of the components of the composite mixture (concrete) under study, first the properties to be analyzed and the respective tests were selected. Then a literature review was carried on understanding the influence of each concrete component and the expectance from the established laboratory tests, mainly the behavior of aggregates relating to the modulus of elasticity and resistance to tensile and compressive stresses. The standards NBR 5738 [2] and ASTM C1 [3] were studied to better understand the specimen molding procedure, since it strongly affects the internal distribution of the concrete components in the samples. Subsequently, the properties of aggregates - sand, gravel - and fibers in the mechanical properties of concrete, in the distribution of stresses and the influence in the elasticity modulus were analyzed, according to the standards NBR 8522 [4] and NBR 6118 [5].

3. Results and Discussion

The concrete microstructure showed complex interaction between the components and their interfaces [6]. Considering the number of variables identified in the composition of self-compacting high-performance concrete with addition of steel fibers, it can be stated the complexity level of this special concrete is much higher than that characteristic of the material. The studied concrete is similar to conventional one, composed of cement, water, fine and coarse aggregates, and differing by the use of superplasticizer, steel fibers and activated silica as additives. Each component of the mixture has its intrinsic contribution to concrete performance. The Portland cement with high initial strength is composed predominantly of tricalcium silicate ($3CaO.SiO_2$), which is responsible for the fast setting, high heat of hydration and high initial strength. The aggregates, sand and crushed stone, contribute to the compressive strength and abrasion providing greater durability, and also contribute to reducing shrinkage of the paste. The additives are superplasticizer, fibers and active silica. The first one increases the fluidity of the mixture, ensuring workability and reducing the water/cement factor; the fibers improve the tensile strength and, finally, the active silica contributes to the properties of durability, cohesion, adhesion capacity and minimizes the exudation process.

It is difficult to have cohesion and adherence among the concrete components, which can present problems related to segregation and exudation, besides directly affecting the mechanical response when requested. Even though the concrete in study has self-compacting characteristic, the amount of agglomerant and the low water/cement ratio promotes a combination that favors the incorporation of air into the mixture [7], therefore the dosage control and the efficiency in the concrete placement and compaction was rigorous [8]. The methods established by NBR 5738 [2] and ASTM C31 [3] were studied and it was observed the need to use a less energetic densification, avoiding segregation, considering the fluidity acquired by the superplasticizer, in order to remove only the remaining air incorporated in the mixture. For compression, the loss of cohesion can be attributed to the characteristic fragility of concrete, with the emergence of cracks when the tensile stress is reached, which quickly propagate into a brittle rupture [9]. Among the aggregates, the coarse ones, by having larger diameters, further reduce the effective area of the paste in a given section. Therefore, the gravels influenced a greater stress convergence than the sands.

The stress and its relative deformation can be related in two regimes: elastic and plastic. In the elastic regime, the deformation is not permanent, and a linear relationship is established between them through the modulus of elasticity, which represents the difficulty of deformation, the stiffness of the material. Aggregates are stronger than paste and have great influence on the mechanical response of concrete. From the standard NBR 6118 [5] it was studied the method to estimate the modulus of elasticity, then it was calculated and obtained a stress versus strain plot from the characteristic strength of the concrete under study of 80 MPa for compression, as shown in Fig. 1, and an initial modulus of elasticity equal to 45.13 GPa was obtained. However, since these estimates are for conventional concrete, the influence of steel fibers should be evaluated, given the expectation of increased support to deformation by cracking and the addition of certain ductility.

Concrete has low tensile strength and the addition of steel fibers in the mixture is an option to increase it, since steel has good tensile strength, expansion coefficient similar to the mixture and concrete protects it from corrosion, being an efficient association. However, the mechanical behavior of the fibers depends on their dispersion, the applied load, and the transmission of tension between the matrix and the fibers [10]. The concrete under load, the fibers absorb the stresses along their longitudinal length, contributing for the tension reduction on the matrix, since the rupture by tension occurs in the binder phase.

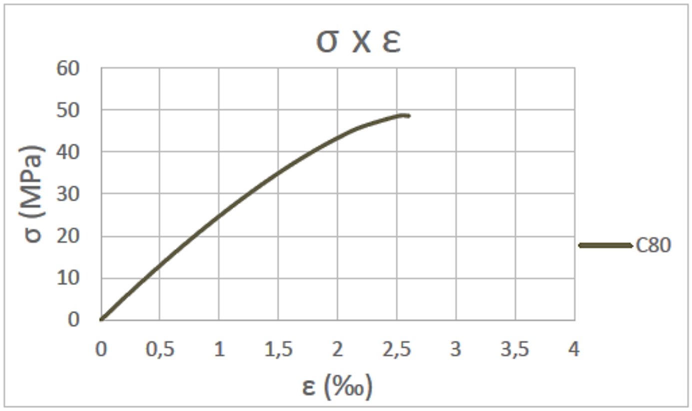

Figure 1: Idealized stress-strain diagram, calculated according to NBR 6118 [5] for compression of concrete with characteristic strength of 80MPa (C80).

Concrete is a fragile material and has a small stretch over the plastic regime. For this reason, steel fibers were added, so that there is an extension of this stretch, allowing for greater absorption of energy, increasing the ductility and toughness of the concrete before the rupture, postponing it, that provided a greater resistance to cracking of the matrix. It is important to properly control the cracking, so that there is no interference in the performance of the material on service and avoid the entry of deleterious agents, which could allow the degradation of the structure [5].

4. Conclusions

The high-performance concrete with fibers is a complex material and it requires technological control in the stages of its production so that it is possible to achieve and ensure the required properties. This literature review focused on the properties: modulus of elasticity, compressive strength and tensile strength of the special concrete.

From this study was pointed out that the test specimens should be carefully prepared, and low energy compaction should be applied to avoid segregation, being the hand densification used to remove the remaining incorporated air and to homogenize the mixture. Since good compressive strength results depend on the response of the paste interaction with the aggregates, a sufficiently homogeneous mixture should be prepared, so that the concrete containers meet the requirements for the operation.

In the tension x deformation graph, it was intended to evaluate the interference of steel fibers in the behavior of the concrete, using the model presented by NBR 6118 [5]. After the tests in laboratory this model was validated, verifying that the special concrete resisted greater deformation with the addition of fibers when loaded.

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References

[1] B. L. Tavares, *Contêineres de concreto para acondicionamento de rejeitos radioativos*, MSc Dissertation (Science and Technology of Minerals and Environment), Nuclear Technology Development Center, Belo Horizonte, Brazil, 2019.

[2] Associação Brasileira de Normas Técnicas (ABNT). *NBR 5738: Concreto – Procedimento para moldagem e cura de corpos de prova*. ABNT, Rio de Janeiro, Brazil, 2015.

[3] American Society for Testing and Materials (ASTM). *C31: Making and curing concrete test specimens in the field*. ASTM, Philadelphia., United States, 2017.

[4] Associação Brasileira de Normas Técnicas (ABNT). *NBR 8522: Concreto – Determinação dos módulos estáticos de elasticidade e de deformação à compressão*. ABNT, Rio de Janeiro, Brazil, 2017.

[5] Associação Brasileira de Normas Técnicas (ABNT). *NBR 6118: Projeto de estruturas de concreto – Procedimento*. ABNT, Rio de Janeiro, Brazil, 2014.

[6] Instituto Brasileiro do Concreto (IBRACON). *Materiais de construção civil e princípios de ciência e engenharia dos materiais.* IBRACON, São Paulo, Brazil, 2017.

[7] M. M. Buttignol; et al. *Ultra high-performance fiber-reinforced concrete (UHPFRC): a review of material proprieties and design procedures.* Structures and Materials Journal, v. 10, p. 957–971, 2017.

[8] J. S. Barbar. *Influência do teor de ar incorporado no desempenho de concretos com diferentes teores de agregados.* MSc Dissertation (Archtitecture), University of São Paulo, São Paulo, Brazil, 2016.

[9] R. C. Hibbeler. *Resistência dos materiais*, Pearson, São Paulo, Brazil, 2010.

[10] W. D. Callister. *Ciência e engenharia dos materiais: uma introdução*, LTC, Rio de Janeiro, Brazil, 2016.