INFLUENCE OF THERMAL AGING ON DIFFERENT CONCRETE CLASSES USED IN NUCLEAR CONSTRUCTIONS

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Abstract

Exposure to high temperatures is one of the degradation factors of concrete structures and its behaviour is difficult to characterize, because the thermal properties of the concrete are more complex than for other materials, not only because it is a composite material and the properties of its constituents are different, but also because its properties depend on humidity and porosity. Due to the change of properties over time and depending on the conditions in service, it is necessary to evaluate the effects of the degradation factors on concrete and its performances. This paper aims to evaluate the influence of different temperature levels that may occur in the operation of a CANDU type nuclear power plant, on the properties of the most often concrete classes used in nuclear constructions. For this, C32/40, C25/30, C18/22.5 concrete samples were subjected to accelerated thermal aging treatments for ~ 1 year. At the end of the treatment period, the impact of the temperatures on the mechanical properties providing information on concrete durability was studied.

Keywords: *concrete, nuclear constructions, thermal aging, degradation*

Introduction

The existing CANDU nuclear power plants are approaching their end of initial designed life, and for this reason, measures for extending their operational life are taken. For this, CANDU NPP (Nuclear Power Plants) owners must demonstrate that the structures that have a nuclear safety role will be capable to fulfil the design requirements, in order to obtain the life extension licence.

Among the structural components of the Reactor Building (classified by the U.S. Nuclear Regulatory Commission as Category I concrete structure, based on its safety significance) the most important is the containment, which has as main purpose the prevention of any release of fission products in the environment, in case of a Loss Of Coolant Accident in the primary system. This structure is also a screen against the radiations, in a normal operating regime of the NPP (separates the reactor and other important security systems from the environment) [1].

A much better knowledge of the performances and durability of NPP's concrete structures, taking into account all the design conditions and the impact of aging [2], will help in extending the lifetime of the plant, ensuring the structural integrity and strengthening the public acceptance related to the fact that it will continue to operate in safety conditions.

In this context, RATEN ICN Pitesti brings its contribution in developing an aging management program for the concrete structures of Cernavoda NPP, by theoretical and experimental studies, in order to know the thermal aging effects on the properties and durability of concrete.

The paper aims to investigate potential transformations which can take place regarding the parameters of interest in evaluating concrete's degradation (such as compressive strength, permeability, modulus of elasticity and also the density changes that occur in concrete samples) after exposing some concrete samples at accelerated thermal aging treatments.

Experimental set-up

Most of the NPPs are almost touching their designed limit of lifetime, so the emphasis is now on the programs for extending their lifetime. With NPPs aging, it was observed that there is a necessity for a proactive approach in order to identify and remediate the degradation of structures, before the capability of meeting the designed requirements is affected.

Samples preparation

As it is mentioned in [3], according to the destination of the concrete, at the Cernavoda NPP different classes of concrete are used. Three of these are of major importance:
- *C32/40* (used at the reactor base, perimeter wall, ring beam, domes and the internal structures of the reactor),
- *C25/30* (used at the internal structures of the reactor, the reactor and service buildings infrastructures and at slope and finishing concrete),
- *C18/22.5* (used at the reactor sub-base and the internal structures of the reactor).

The before mentioned classes of concrete were all used in this study, the samples being prepared according to the requirements given in [3].

The following raw materials were used in manufacturing the concrete samples: water - from the drinking water network, aggregates - from 0-4 mm to 16-31.5 mm granularity, cement with low hydration heat – *CEM II/A-S 32.5 N–LH* Portland cement, and SikaViscocrete additive. The water/cement ratio for the studied concrete classes was, as follows: w/c = 0.43 for C18/22.5, w/c = 0.36 for C25/30 and w/c = 0.31 for C32/40, respectively.

After mixing the concrete components, determinations imposed for fresh concrete were made [4-6], and then the concrete was casted in cubic shapes, with 150 mm (used for permeability and compressive strength tests) and 200 mm (used for modulus of elasticity test), and stored in water pools, for a period of 28 days, according to standards. After this period, determinations for hardened concrete were performed [7-10], to verify if the class of concrete was accomplished. For each test, 3 samples were used, the results presented in the present work being the arithmetic mean of these samples.

Applied treatments

The interest in this paper was to see if the concrete will degrade over time and at the temperature conditions of normal and abnormal operation of the reactor. The experimental program applied for this involved the acceleration of the degradation processes by simulating the conditions at which the concrete structures could be exposed, but compressing the time period. The important feature of these aging tests is that they focus the main mechanisms involved in the degradation processes.

The chosen temperatures for the experimental study were: *65°C* (temperature up to which the containment of the NPP can be exposed under normal operating conditions [11]), *80°C* and *100°C*, respectively, in order to observe the changes that occur if the temperature limit is exceeded when operating under abnormal conditions [11].

In order to accelerate the processes, the samples were subjected to the mentioned temperatures for a period of about *1 year* continuously (*24 hours a day*), in laboratory drying chambers (see Fig. 1).



Fig. 1. Samples disposal for thermal treatments

During the treatments, gravimetric and dimensional determinations were monthly performed on the concrete samples, in order to study the density changes. At the end of the thermal degradation treatments, the mechanical properties of concrete (such as compressive strength, permeability and modulus of elasticity) were determined, analyzing then the changes that occurred compared to the values obtained before applying the treatments.

Results and discussions

Fig. 2 presents the density variations for all the three classes of concrete studied, and all types of thermal stresses applied. After 28 days of storage in water pools, before starting the experimental program, and then, in every month, the mass and dimensions of the samples were measured.

Density is the ratio between the mass and volume of the sample. As it can be seen, there is a very slightly decrease in density between the measurements performed at 28 days and the reference (tested at ~130 days).

A much drastically decrease (~ 0.1 g/cm^3) is observed after the first two months of treatments. This fact can be attributed to the thermal shock and the loss of evaporable water from the concrete's pores. After this period, it can be seen that the density of the samples tends to stabilize, pattern seen for all types of applied treatments. From the measurements, the highest contribution at the density changes is given by the mass variations of the samples.

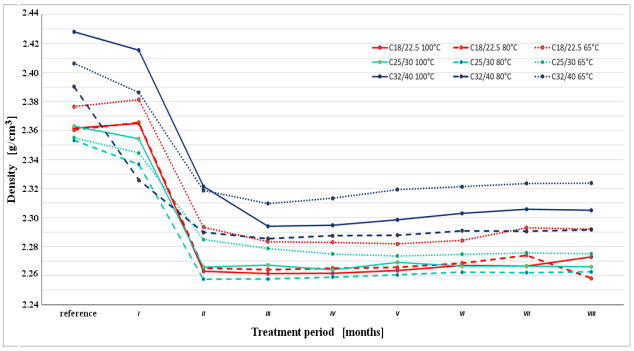


Fig. 2. Density variations for all classes of concrete studied

As it can be seen from Fig. 3, all the samples attained the required ***compressive strength*** imposed by the Task Book used for execution of concrete works for Nuclear Buildings in Cernavoda NPP [3].

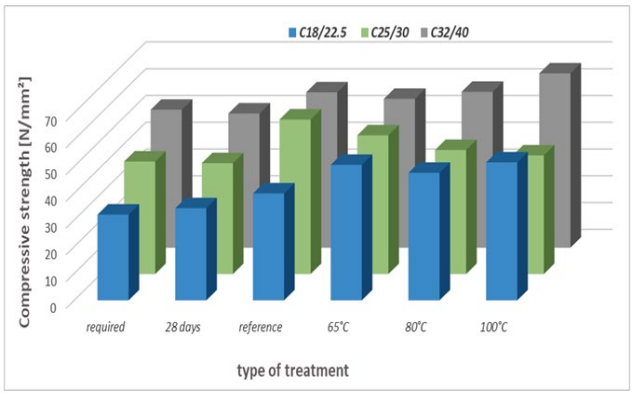


Fig. 3. Density variations for all classes of concrete studied

There are slightly differences, compared to the reference samples, after applying the thermal treatments.

It cannot be said that, after the period of time investigated in this study, variations present a trend. For some of the samples, temperature seems to help the strength increase.

For the treatments performed at 100°C (the severe temperature chosen in this study), the compressive strength is situated in the interval 50-60 N/mm^2, depending of the concrete class, values which are over the imposed requirements.

These changes in mechanical strength are, most likely, due to the continuous microstructural changes of the cement paste (decrease in the content of hydration compounds).

After studying the breaking surfaces of the samples, subsequent the compressive strength tests, it was observed that the breaks occurred at the interface between the aggregates and the cement matrix. This fact shows that, even after the stressors applied, the cement matrix continues to maintain its strength role.

It is well known that the density of concrete is inversely proportional with its ***permeability***. This parameter is expressed by the depth of water penetration, under certain pressure, depending on the class of concrete tested.

It can be seen, from Fig. 4, that the temperature has a negative effect for the samples with a smaller w/c ratio (C25/30 and C32/40). This can be due to the apparition of small voids created in the concrete by the evaporation of free water.

However, none of the samples attained the maximum depth of water penetration accepted (10 mm), remaining in the range of 2-4 mm penetration.

Compared to the reference samples, it is observed that all thermal treatments conducted to a increase of permeability.

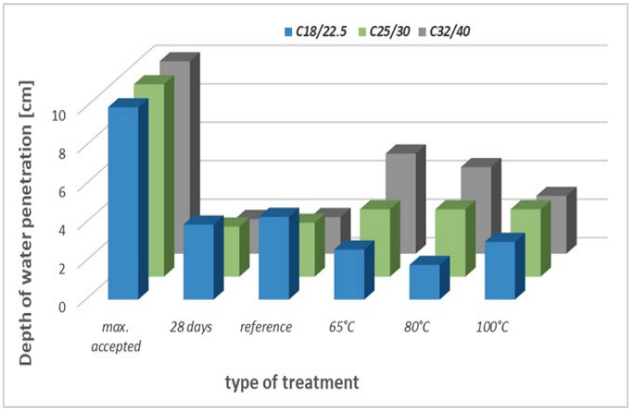


Fig. 4. Permeability for all classes of concrete studied

The values for ***modulus of elasticity*** were obtained based on the speed of ultrasounds through the concrete samples.

As it can be seen from the graph represented in Fig. 5, where the variation of the secant elastic modulus is illustrated, the stiffness of the samples decreased for all the applied thermal treatments. This decrease shares a similar tendency with the other two parameters that have impact on the stiffness: permeability and density.

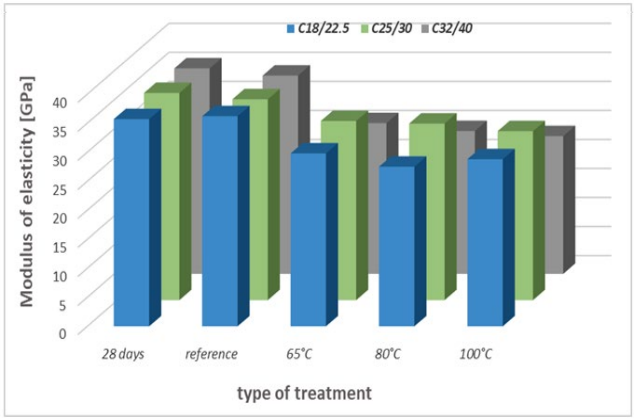


Fig. 5. Modulus of elasticity for all classes of concrete studied

Conclusions

The performances of concrete at elevated temperatures are difficult to characterize. The thermal properties of concrete are more complex than in case of other materials, not only due to the fact that it is a composite material and its constituent properties are different, but also because its properties depend on humidity and porosity. Exposing the concrete at high temperatures affects it mechanical and physical properties; due to the time dependent changes and service conditions, it is important to evaluate the effects of degradation factors on the concrete's performances.

The paper aimed to study the behaviour of the types of concrete used at Cernavoda NPP nuclear structures, in accelerated thermal aging conditions. The samples (three classes of concrete) were exposed at long term treatments, at three different temperatures, monitoring during the whole period the gravimetric changes. At the end of the treatments, macroscopic properties such as: compressive strength, permeability, modulus of elasticity were determined and correlations between them and the applied treatments were made.

Based on the performed determinations and the obtained results, we can conclude that, in the considered conditions, the investigated classes of concrete are not yet affected by the chosen temperatures and duration. Given the imposed requirements for each class of concrete, it can be said that the obtained results do not endanger the concrete, the degradation being insignificant. Based on this fact, is expected that the concrete will continue to ensure a high level of nuclear safety and will resist at this kind of thermal stresses which can result from the NPP operation.

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