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Drying creep in cyclic humidity conditions

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ABSTRACT

The paper deals with the dimensional variations of High Performance Concretes subjected simultaneously to cyclic water exchanges and loading. The aim is to quantify the drying creep amplitude in the case of variable humidity comparatively to a constant humidity. The tests are performed between 98% RH and 50% RH. Comparison between samples subjected to constant and cyclic humidity shows that, under loading, the deformations induced by hydric cycles are reversible whatever the drying history before loading. Moreover, the wetting cycles lead to progressive erasing of pre-loading drying effects. Specimens subjected to wetting cycles after loading present the same final drying creep as specimens that were not dried before loading, while specimens dried before loading and not subjected to a wetting cycle present less final drying creep. Therefore, results confirm that drying creep amplitude is reduced if concrete is partially dried before loading, but this reduction disappears if concrete is rewetted.
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Contents

1. Introduction

This research was conducted in the context of the study on High Performance Concretes (HPC) envisioned for future storage structures for Intermediate Level Long-life Nuclear Wastes of Andra (the French agency for nuclear waste management). During their service life, these structures will be subjected to various environmental conditions, in particular variable humidity coupled with mechanical loading. However, although its creep behavior under constant humidity has been widely investigated, the long-term deformation of such concrete under hydric cycles remains rather unknown. In previous works concerning the same context, Ladaoui et al. [1,2] performed studies of basic creep at three different temperatures: 20 °C, 50 °C and 80 °C. They showed that basic creep increased exponentially with temperature and that thermal damage occurred beyond 50 °C, revealed by a decrease in the modulus of elasticity. Concerning humidity effects, studies have mainly investigated desiccation creep under constant humidity. When concrete is subjected to drying and loading simultaneously, the resulting deformation is much greater than the sum of basic creep and autogenous shrinkage [3,4]. The supplementary deformation, called drying creep or Pickett's effect, exists when drying occurs under loading. Drying creep has been physically explained by several phenomena such as microcracking or stress-induced shrinkage [5–13] but these explanations generally do not include discussions of the uniqueness

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Table 1
Abbreviations used for shrinkage and creep samples.

ULCS	UnLoaded Continually Sealed	SLVD	Simultaneous loading in Variable Drying
ULCD	UnLoaded in Constant Drying	DLCS	Delayed Loading Continually Sealed
ULVD	UnLoaded in Variable Drying	DLCD	Delayed Loading in Constant Drying
SLCS	Simultaneous loading Continually Sealed	DLVD	Delayed Loading in Variable Drying
SLCD	Simultaneous loading in Constant Drying		

and the reversibility of phenomena. However, in many structures, concrete can be subjected to non-negligible hydric cycles under loading. Very few studies deal with concrete behavior under variable humidity [14–17] and those that exist generally conclude that swelling occurs when the water content increases. However, these experimental tests were carried out on samples without mechanical loading. Therefore, the long-term mechanical behavior of concrete under cyclic hydric conditions coupled with loading remains unknown and merits investigation.

The experimental program presented in this study was designed to provide strain variations of unloaded or loaded concrete subjected to constant or cyclic humidity. Some concrete samples were never loaded and were kept in constant or variable humidity. Other samples were simultaneously loaded and dried at 50% RH. Among the latter, some were kept at constant humidity (50%) while the others were subjected to humidity that cycled between 50% and 98% RH.

2. Experimental program

2.1. Objectives and description of the program

The objective was to quantify the effects of humidity variations on long-term concrete behavior, more specifically the effects of drying prior to loading and of humidity cycles during uniaxial compressive creep loading.

Six different test conditions were applied to achieve this objective: each test allowed a specific part of the total deformation to be observed, by direct measurement or, more often, by combination with the other tests. The notation system of the six tests is defined in Table 1. The first letters correspond to the loading conditions: UL stands for UnLoaded; SL for Simultaneously Loaded and dried; and DL for Delayed Loading in relation to drying, which starts before loading. The last letters stand for the humidity conditions: CS for Continually Sealed (sealed condition), CD for Constant Drying at 50% RH and VD for Variable Drying (between 50% and 98% RH). The start time for the strain record was always 24 h after concrete pouring (time of demolding). The letters H and M located on the vertical axis of Figs. 1 to 7 stand for Hydric and Mechanical conditions respectively. All the tests with hydro-mechanical configuration details after water curing are briefly described below:

- UnLoaded samples stored either in constant drying conditions (ULCD) or in sealed conditions (ULCS) allowed drying shrinkage and sealed shrinkage to be obtained respectively (Fig. 1);
- UnLoaded samples in variable drying (ULVD) (Fig. 2) allowed free deformations induced by humidification cycles to be measured;
- Samples loaded with a simultaneous constant drying condition (SLCD) or in a sealed condition (SLCS) (Fig. 3) allowed basic creep and drying creep to be measured in constant hydric conditions;
- Samples loaded with simultaneous drying and then subjected to humidification–drying cycles (SLVD) (Fig. 4) allowed deformation changes to be quantified during humidification occurring under loading;
- Samples free to dry at constant humidity and loaded after 43 days of constant drying condition (DLCD) or samples continually sealed and loaded after 43 days (DLCS) allowed the influence of sealed condition before loading to be captured (Fig. 5);
- Samples loaded after 43 days of drying (DLVD) and then subjected to humidification and drying cycles were used for comparison with the behavior of concrete not initially dried (Fig. 6).

Table 1 recapitulates the abbreviations defined above.

All cylindrical specimens (diameter = 118 mm, height = 225 mm) were cured under water (20 °C) for at least 90 days before any test in order to achieve hydration and saturate the porosity. Therefore, initial conditions could be considered as identical for all specimens. The uniaxial compressive load corresponded to 30% of the compressive strength, f_{cm}, measured at the date of creep loading. Fig. 7 describes the chronology of hydric variations during a drying and a humidification cycle. To limit the consequences of a large hydric gradient (notably surface cracking), samples were dried gradually from 98% to 60% of relative humidity by steps of 10% RH for 7-day long for each step. Thus, they were kept at 50% RH to obtain the same mass loss between constant and variable drying (Fig. 14).

Comparing ULCS and ULCD (Fig. 1) gives the shrinkage induced by drying.

Comparing ULCD (Fig. 1) and ULVD (Fig. 2) gives the difference of final shrinkage for free specimens stored in different humidity conditions.

Comparing SLCD (Fig. 3) with SLVD (Fig. 4), and DLCD (Fig. 5) with DLVD (Fig. 6), allows the effect of drying and humidification cycles on creep to be assessed, together with the possible reversibility of strains. Comparing SLCD (Fig. 3) with DLCD (Fig. 5), and SLVD (Fig. 4) with DLVD (Fig. 6) gives the influence of initial drying on the long-term behavior of concrete, coupled with constant or variable humidity.

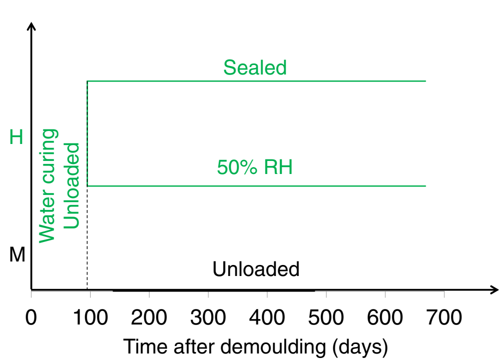

Fig. 1. UnLoaded Continually Sealed (ULCS) and UnLoaded at Constant Drying (ULCD).

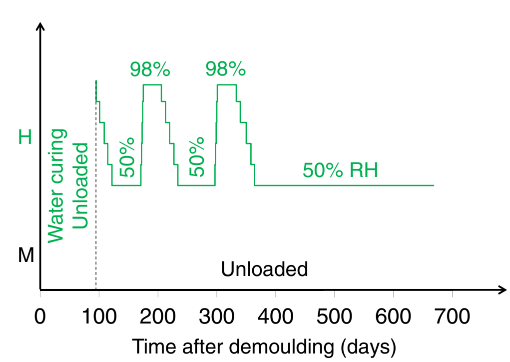

Fig. 2. UnLoaded in Variable Drying (ULVD).

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