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# Multiscale experimental characterization of aging basic creep of VERCORS concrete

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## Résumé

*Le retrait et le fluage du béton sont les principaux mécanismes à l'origine des pertes de précontraintes affectant les structures en béton précontraint, comme les enceintes de confinement de centrales nucléaires. L'exploitation à long terme des ouvrages précontraints nécessite ainsi des modèles fiables du comportement différé des bétons les constituant. Afin d'améliorer la compréhension de ces effets différés, et de constituer une base de données expérimentales de validation des modèles de comportement, une campagne expérimentale a été conçue et réalisée. Cette campagne se focalise sur le retrait endogène et le fluage propre. Son originalité réside dans son caractère multi-échelle et dans les nombreux âges de chargement considérés pour les essais de fluage.*

## Abstract

*Creep and shrinkage of concrete are the main mechanisms responsible of prestress losses experienced by prestressed concrete structures, such as containment buildings of nuclear power plants. Relevant and reliable models of the concrete delayed strains are thus of paramount importance for the long term operation of such structures. To improve understanding of this delayed behavior and also to constitute a comprehensive validation dataset for these models, an experimental campaign has been setup and conducted. The latter focuses on autogenous shrinkage and basic creep. The originality lies in both the multiscale nature of the campaign and the multiple loading ages considered for creep tests.*

**Keywords: Autogenous shrinkage, Basic creep, Concrete, Aging behavior, Experiment.**

## 1 Introduction

Civil engineering structures made up of prestressed reinforced concrete can be affected by prestress losses. The main mechanisms responsible of these losses are creep and shrinkage of concrete. It is therefore of paramount importance to have a proper understanding of this delayed behavior, and to be able to model and predict these phenomena.

This communication focuses on the concrete behavior in non-drying conditions: autogenous shrinkage and basic creep. The main originality of the experimental campaign [1] reported here lies in its multi-scale and multi-age nature. The reference material considered is the VERCORS concrete. The VERCORS mock-up [2, 3] is a 1/3<sup>rd</sup>-scaled double walled concrete containment building, built by EDF to better understand the relations between concrete aging mechanisms (such as drying, shrinkage, creep, damage and cracking) and leak-tightness. Tests are also performed on derived mortar and cement paste. The latter are designed to be representative of the matrix embedding aggregates in concrete, and of the matrix surrounding sand grains in mortar. Both autogenous shrinkage and basic creep are measured, in a temperature-controlled lab. Special attention is paid to the leak-tightness of the samples, as parasitic drying can have a dramatic impact on the measured strains [4]. Several creep tests are performed per material, considering 4 to 5 different loading ages ranging between 1 day and 1 year.

The main features of the experimental campaign are first described, then results are presented, and preliminary investigations are discussed. These multi-scale and multi-age results constitute a useful dataset for validation of micromechanical models of concrete creep including aging effects. These results have been contributed to the creep and shrinkage database the ACES European project [5] is building up [6], revamping the creep and shrinkage Northwestern University database [7, 8].

## 2 Materials and methods

### 2.1 Mix designs

The detailed mix designs of the prepared concrete, mortar and cement paste are reported on table 1. Sand and aggregates are oven dried at 105°C before use. The reported amount of water is the water explicitly added during material preparation.

The concrete is the same as the one used to build the VERCORS containment building mock-up [2]. Mortar (resp. cement paste) is designed to mimick, as closely as possible, the matrix embedding coarse aggregates (resp. sand grains) in concrete (resp. mortar). To do so, the same water to cement (considering effective water, that is added water - water absorbed by aggregates + water from admixture) ratio is considered for all materials:  $w/c = 0.525$ . As there is some overlap between the actual particle size distributions of sand G1 and aggregate G2, a maximum size of 2 mm is considered for sand in mortar. The amount of sand G1 reported in table 1 for mortar is the amount of sand once sieved to 0–2 mm. The 0–2 mm sand to cement ratio is the same for concrete and mortar:  $s/c = 2.13$ .

Component	Designation	Mix design (kg)		
		Concrete	Mortar	Paste
Cement	CEM I 52,5 N CE CPE NF Gaurain	24.031	5.956	16.495
G1	Sand 0/4 REC GSM LGP1 Varennes	62.331	*12.668	
G2	Aggregate 4/11 R GSM LGP1 Varennes	33.419		
G3	Aggregate 8/16 R Balloy	41.304		
Admixture	Admixture SIKAPLAST techno 80	0.195	0.048	0.134
Water	Added water	14.684	3.160	8.552

\*G1 is sieved to 0–2 mm for mortar.

Table 1: Mix designs of VERCORS concrete and derived mortar and cement paste.

## 2.2 Mechanical tests

For each material, several basic creep tests are performed, at various mechanical loading ages, ranging from 1 day to more than 1 year. To optimize the creep benches usage, creep tests are performed successively for a given material, using samples casted from a unique batch. After unloading, recovery is measured for a short period of time, then the sample is removed and the next one is prepared and loaded. Each sample is thus loaded once, and the test duration depends on the loading age (test has to stop before the next loading age). One notable exception is cement paste: a test at 3 days has been performed in parallel, overlapping the 1 and 7 days test, taking advantage of 2 unused creep benches at this moment. Additionally, autogenous shrinkage is measured during the whole experimental campaign. For each case (autogenous shrinkage and for each basic creep loading age), two samples are tested.

A unique batch is prepared to cast all the samples of a given material. Before testing, specific care is taken to store the samples in as autogenous conditions as possible. After casting, the molds are sealed with plastic stretch film. This curing period lasts 24 h. Once demolded, the samples are placed in waterproof bags, themselves stored in waterproof cans. The efficiency of these conservation conditions is assessed by regularly weighing the samples. These weighings show that after 385 days, the maximum mass loss is 0.03 % of the sample mass. Then, samples are sealed before testing, with self-adhesive aluminum foil and X60 glue around the holes where the instrumentation supports are anchored.

Companion autogenous shrinkage specimen are installed close to the basic creep sample (figure 1 left). Both specimen thus experience similar temperature conditions, which allows to subtract autogenous shrinkage from the strain under load, to get the basic creep strain. Specimen deformations are measured with 3 LVDT displacement sensors, installed at 120° around the specimen (figure 1 right). For the basic creep sample, force is measured from a load cell.

The tests are performed in the creep room of the lab, where temperature and relative humidity are AC controlled at 20°C and 50 %. The loading force at each age is determined from strength measurements on additional samples: to stay in the linear creep regime, the loading stress is lower than 30 % of the compressive strength. The loading and unloading ramps last between 10 and 20 s. During the test, the force is maintained constant with an active regulation process controlling the creep bench loading from the measured force. Each sample is weighed before and after its test.

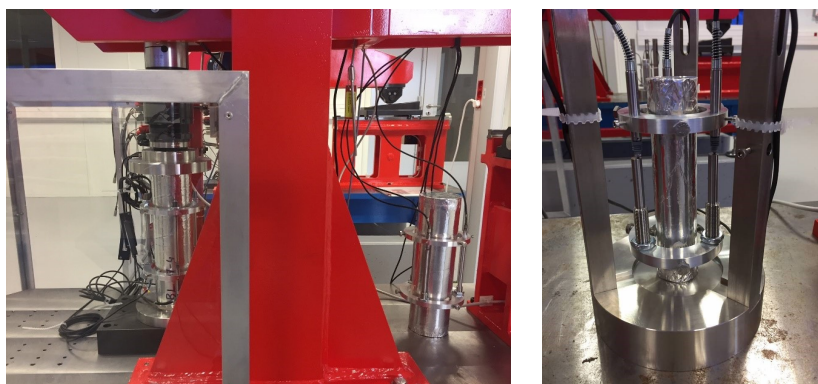


Figure 1: Left: basic creep and autogenous shrinkage concrete samples. Right: autogenous shrinkage cement paste sample.

### 3 Results

Although 2 samples were used for each test, in a few specific cases only 1 result is reported here, due to either severe failures in the force regulation system, or unexpected strain evolutions.

#### 3.1 Autogenous shrinkage

As expected, the autogenous shrinkage strain is lower for concrete, than for mortar, than for cement paste (figure 2). Unfortunately, some failures of the AC unit induced short temperature peaks (around 30°C instead of the regulated 20°C). These accidental temperature peaks affect autogenous shrinkage strains negatively for cement paste and mortar, and positively for concrete. The impact seems to be delayed for both concrete and mortar, while being nearly instantaneous on cement paste. This could be due to coefficients of thermal expansion which are different for paste and aggregates, inducing creep in cement paste around aggregates. Nevertheless, trying to correct the influence of these accidental temperature evolutions would require advanced modeling of both the experimental setup and the material constituting the sample. This is beyond the scope of this communication, whose aim is to report raw results from the experimental campaign.

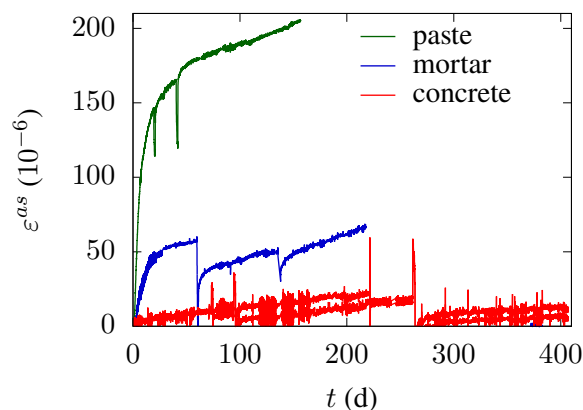


Figure 2: Autogenous shrinkage of paste, mortar and concrete.

#### 3.2 Basic creep compliance

The basic creep strain is obtained subtracting autogenous shrinkage from the strain measured under mechanical loading. More precisely, the subtracted autogenous shrinkage is the amount developed from the time of loading. Then, the basic creep compliance is obtained dividing the basic creep strain by the loading stress, which is assumed to be constant. Results are not corrected from the influence of accidental temperature peaks or loading stress fluctuations.

Basic creep compliances tend to reach a log-like evolution with respect to time since loading (figure 3). As expected, the basic creep compliance is lower for concrete, than for mortar, than for cement paste. Also, it is lower when the material is mechanically loaded at a later age. More specifically, the creep of cement paste shows an important aging behavior both on the initial strain and the delayed behavior, when loaded between 1 and 90 days. Creep of mortar shows an aging behavior, when loaded between 7 and 90 days. It is also the case for concrete, when loaded between 2 and 90 days.

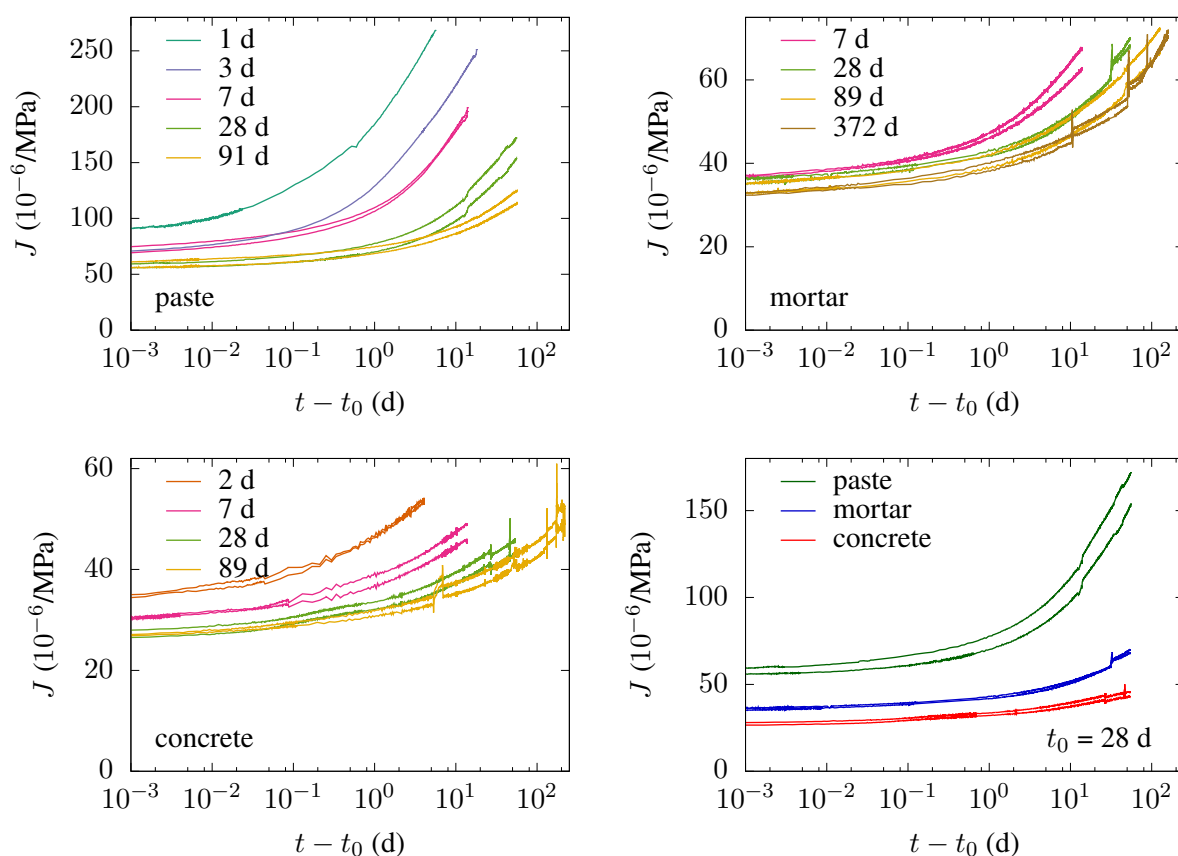


Figure 3: Basic creep compliance for each loading age  $t_0$ , one plot per material: paste, mortar and concrete. Comparison of basic creep compliance of paste, mortar and concrete, loaded at 28 days.

## 4 Discussion

### 4.1 Analysis of compliance rate

The compliance rate evolution of concrete creep is often investigated on a log-log scale, see for example [9, 10, 11, 12]. The compliance rate is evaluated after smoothing the compliance evolution through a data binning scheme. In log time scale, each decade (time unit being days) is subdivided into 50 intervals. The points falling into each interval are replaced by their arithmetic mean. The compliance rate is then evaluated from central differences, and represented as dots on figure 4. Despite this straightforward smoothing scheme, the compliance rate evolution is still affected by noise.

To investigate the long-term creep kinetics, for each loading age, affine (in log-log scale) fits are computed from the last  $1/10^{\text{th}}$  of the test period. Consistently with the log-like compliance evolution that might be expected at long term, the slope is constrained to -1. These fits are represented as straight lines on figure 4. The  $y$ -intercept is found to significantly depend on the loading age for paste, while for mortar and concrete, it hardly depends on the loading age. These results only constitute a first approach of long-term creep kinetics investigation, as the tests may not be long enough to actually reach long-term kinetics.

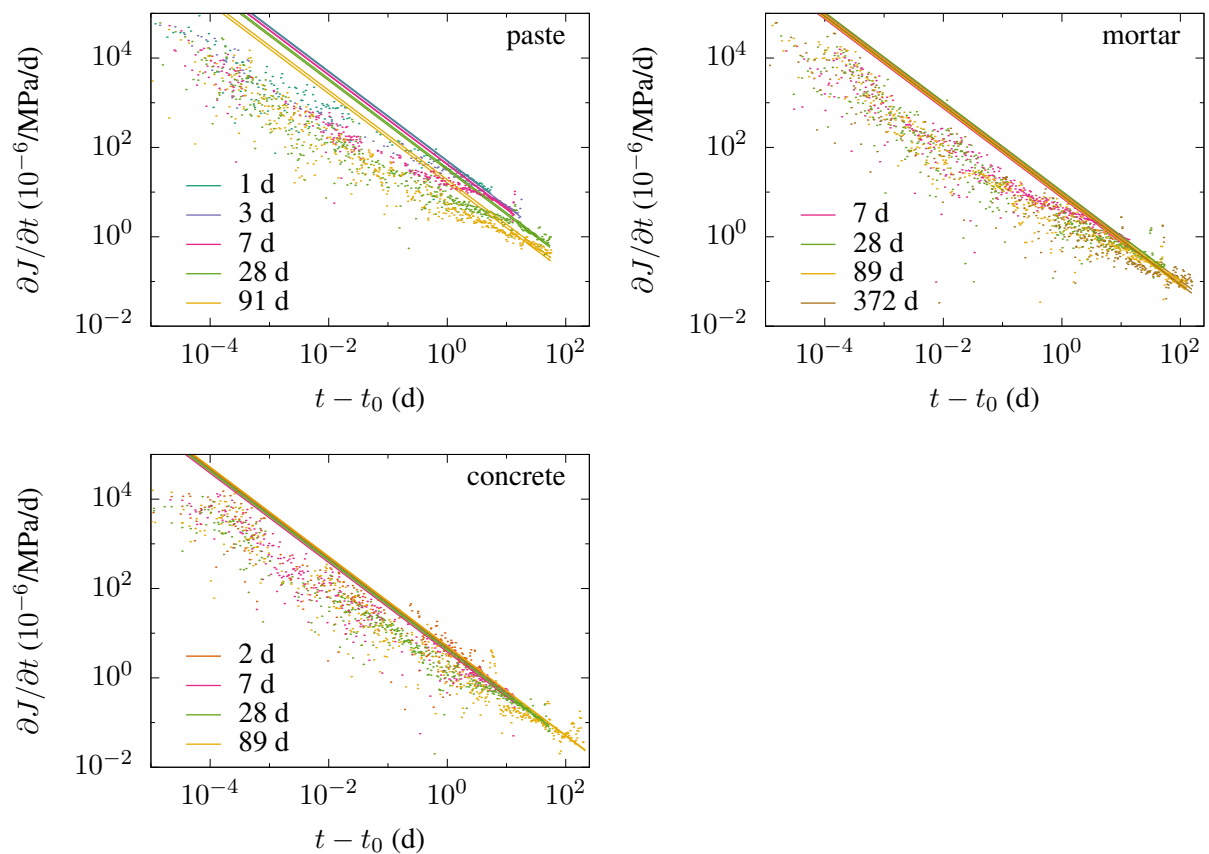


Figure 4: Dots: basic creep compliance rate of paste, mortar and concrete, for each loading age. Lines: -1 sloped affine (in log-log scale) fits on the last 1/10<sup>th</sup> of the test period.

## 4.2 Estimation of Young's modulus evolution

The current Young's modulus can be evaluated from the loading and unloading ramps, considering creep as negligible. Despite some dispersion, the expected tendencies are retrieved (figure 5): concrete is stiffer than mortar, which is stiffer than cement paste. The Young's modulus increases with time at early age, then seems to stabilize after several tens of days, but this is difficult to appreciate due to experimental dispersion.

These estimates can be compared to direct measurements of the Young's modulus from standard compressive tests (see points marked as EDF, CEA and CEBTP on figure 5). The estimates from the creep experimental campaign are found to be consistent with these standard measurements.

## 5 Conclusion

This experimental campaign was aimed at characterizing the autogenous shrinkage and the aging basic creep of VERCORS concrete, in a multiscale context. Raw results are reported, for concrete, mortar and cement paste. Additionally, the compliance rate is investigated, and the evolution of the Young's modulus is post-processed from creep results. These experimental results constitute datasets useful for comparison to micromechanical models which have been developed in parallel to the experimental campaign. The latter take advantage of recent developments on mean field homogenization of aging linear

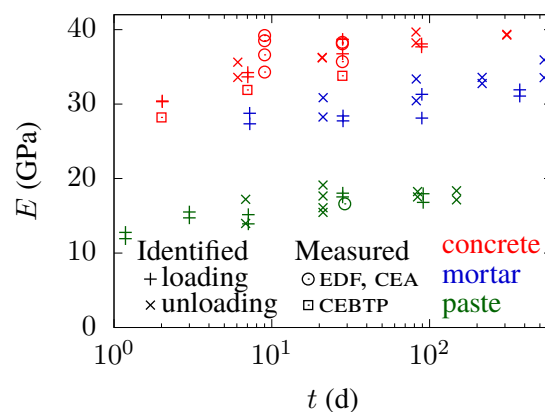


Figure 5: Young's modulus identified from loading and unloading periods.

viscoelasticity: starting from straightforward spheres-based morphologies [13], up to generalization of the Eshelby elastic result in a simplified context [14, 15] then in a complete way [16], to morphologically representative patterns based on n-layered spheres [17], and to more comprehensive homogenization schemes [18]. These approaches can be used to estimate the effective compliance of composite materials whose microstructure evolves with time [19], and have been applied to cementitious materials [20].

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