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Research Article

Experimental Study of the Creep Effect on the Mechanical Properties of Concrete

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Available researches regarding the effect of a sustained load on concrete are limited and sometimes contradictory. In the specific context of prestressed concrete and more generally for all other concrete structures, the effect of creep on the residual mechanical properties of concrete must be closely studied in order to accurately estimate the residual load capacity of a structure. In this study, therefore, sealed concrete specimens were subjected to sustained compressive and tensile loads; then, at the end of each creep test, the mechanical properties were investigated. Results revealed that when applied at a young age (1 month), the compressive creep load leads to an improvement in both compressive strength and elastic modulus. Conversely, when the load is applied at a later age (3 months), the creep strain acts to lower strength while it has almost no effect on the elastic modulus. The tensile creep was also studied for a single loading age (1 month); creep at this low loading level was found to increase tensile strength yet exerted a negligible visible effect when applied at a high loading level. Hence, the most important conclusion of this study is that the effect of creep on mechanical properties of concrete strongly depends on both loading age and loading direction.

1. Introduction

An evaluation of the behaviour, durability, and serviceability of concrete structures after long-term loading, i.e., creep loading, is critical. Prestressed concrete structures are in fact mainly subjected to compressive stresses. Over time and under a sustained applied load, tensile stresses may occur in the prestressed structure due to the prestressing losses of cables as a result of concrete creep. In the case of repairs, i.e., with increased prestress or structural requalification, it thus becomes necessary to evaluate the residual mechanical properties after creep strain at that point in time.

The effect of creep on the mechanical properties of concrete has been studied in previous works by adopting different conditions, including loading direction, loading level, and loading age. The results published by Roll [1] highlighted that compressive drying creep slightly increases the compressive strength of concrete when creep loading is applied at an age of 28 days for loading levels up to 65%. These results were confirmed by the findings of Sousa Coutinho [2], who studied the effect of basic creep instead of drying creep. Sousa's results revealed that compressive strength rises slightly due to compressive creep at all loading levels under study (from 21% to 89%), with the load being applied at 7 days and sustained for 3 days. In this same study, the effect of loading duration up to 28 days for a loading level of 81% was also investigated: an increase in strength was observed for nearly all the tested loading durations. It should be noted this latter part of Sousa's work was conducted for two loading ages: 7 days and 3 months. In both cases, creep exerts a positive effect on strength, hence prompting the researcher to mention that loading age does not have much influence on concrete strength [2]. The results published by Liu et al. [3], who focused on the basic creep effect, also matched the previous findings. Their experimental study consisted of two types of loading, i.e., biaxial and uniaxial direction, in which the creep load is applied at various loading ages of up to 60 days at a 30% loading level. Liu's study however also featured another test that displayed a compressive strength drop. According to this last test, the creep load is applied in a single direction at an age of 90 days with a 60% loading level. The researcher correlated the strength increase with the modification of hydration product under moderate biaxial compressive loads, especially at an early age [3]. The positive effect of creep was also investigated by Saliba et al. [4], whose paper discusses the effect of basic creep in three-point bending beams loaded at an age of 28 days with an 85% loading level. This study highlighted that creep in bending leads to a strengthening in the compressive zone. Like the study by Sousa Coutinho [2], Asamoto et al. [5] examined the effect of compressive drying creep, but this time, the load was applied at the early ages of 1 day and 7 days with a loading level ranging as high as 40%. As was the case with previous conclusions, the compressive strength and Young's modulus (which was additionally studied herein) of creep specimens exceeded those of unloaded specimens. This same research programme also studied the compressive creep effect on tensile strength. Researchers noted that the tensile strength and Young's modulus in the tensile direction were nearly the same for both unloaded and loaded specimens at loading levels of 20% and 30%, while at the 40% loading level, a decrease in tensile strength could be observed. This latter finding is compatible with a previous study by Liniers [6], who examined the effect of creep at loading levels between 50% and 95%. It was shown that very substantial tensile strength losses occur after a compressive load above 40% of the compressive strength since microcracking takes place under such a load.

The effect of creep in tension was also investigated by Mascarenhas (1977) (cited in [2]), whose work applied a tensile creep load (under drying conditions) at ages of 127 days and 2 months (with a loading level of up to 88%). The results exhibited that creep under tension does not affect the ultimate tensile strength. This outcome is incompatible with that of Saliba et al. [4], who focused on basic creep in bending applied at an age of 28 days with an 85% loading level. Basic creep in bending does indeed cause acoustic events (through the acoustic emission testing) related to microcracking and consequently weakens the tensile zone [4].

As previously mentioned, the available studies regarding the effect of creep on strength are limited and in some cases produce contradictory results. The research has been carried out under different conditions, which complicates any attempt to draw comparisons.

As regards the effect of creep on the elastic modulus, the research comparing the elastic modulus of creep specimens with respect to control specimens of the same age remains insufficient (for instance, Asamoto et al.[5]).

Consequently, the study proposed herein is aimed at providing a better understanding of the creep effect, i.e., whether creep has a beneficial or deleterious impact on concrete. This work experimentally investigates the effect of basic creep on the residual mechanical properties of concrete in using the same type of concrete and same storage conditions for all test series in order to unify the factors affecting creep. The first part of the study reveals the effect of compressive creep on both compressive and tensile strengths, as well as on elastic modulus. The effect of tensile creep on tensile strength is discussed in the following section, while the experimental results are given afterwards. It is noteworthy that, in prestressed structures, applied prestress loads usually do not exceed 50% of the concrete strength. In this paper, high levels of applied creep loads were chosen in order to have significant creep strains during relatively short durations.

2. Experimental Programme

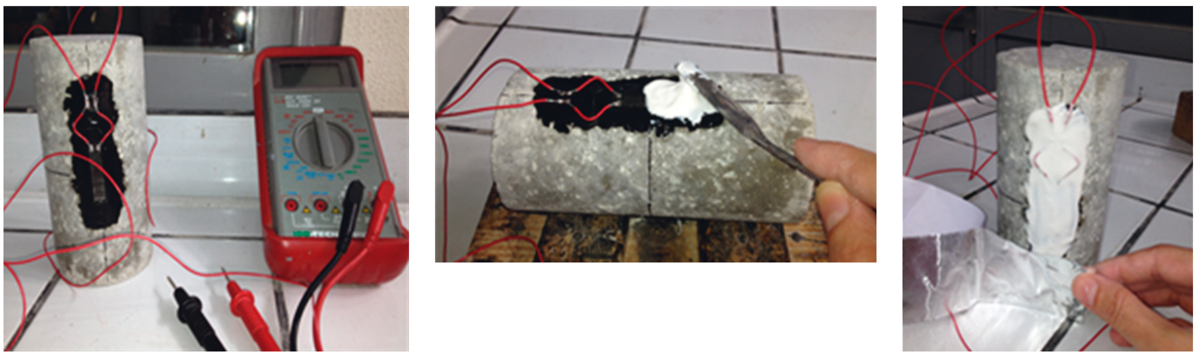
2.1. Concrete Mix Properties. The concrete was cast with a water/cement ratio of 0.5 and cement : sand : gravel proportions of 1 : 2.37 : 2.85, along with a slump of 10 ± 1 cm. Table 1 gives the detailed characteristics of the concrete constituents and of the mix composition. Casting took place in cylindrical moulds 70 mm in diameter by 140 mm high. For each creep test, 6 specimens were casted, 3 of which were loaded while the other 3 so-called control specimens remained unloaded. After 24 hours, the concrete specimens were carefully removed from the moulds and placed in a water tank until the age of loading.

2.2. Specimen Preparation and Storage Conditions. A few days before the age of loading, all the samples were taken out of the water tank. The top and bottom faces of all specimens were then machined in order to allow the applied load to be uniformly distributed over the loading surfaces. To measure the deformation, 28-mm long N2A-06-10CBE-350-type strain gauges were used. The gauges were glued after leaving the samples for 1 day in open air at about 20°C and 50% RH, to slightly dry the sample faces. Two gauges were glued vertically on opposite sides of lateral faces, while another one was applied circumferentially, both on the loaded and unloaded specimens. The specimens were then left for 1 day in air to ensure the glue had hardened. After connecting the wires to the strain gauges, a CAF4-type paste was applied on the gauges as well as on the parts of wires connected to them, in order to protect them from humidity (Figure 1). After the drying of the paste for at least 6 hours, all specimens were once again immersed in the water tank. When the loading age had been reached which was decided to be 30, 60, or 90 days (depending on the type of test), specimens were removed from the water. Thereafter, all specimens (i.e., both creep and control specimens) were wrapped in 2 layers of aluminium scotch tape to limit evaporation to maximum. These specimens were stored in air under controlled conditions of $20^\circ \pm 1^\circ$C and 50 ± 5% RH throughout the test period, which lasted 30 days for each one of the creep series. Control samples were stored in the exact same conditions as the loaded ones in order to measure the strains taking place in the absence of an external load, i.e., due to thermal expansion and/or shrinkage.

2.3. Test Apparatus and Strain Measurements. The compressive strength test was conducted using a Schenck device,

Table 1: Properties and quantities of concrete compositions.

Concrete compositions and properties	Quantities and values
Water	174 kg/m^3
Cement (CEM I B 52.5)	348 kg/m^3
Sand (1.8 mm)	826 kg/m^3
Gravel (0.5/8 mm)	991 kg/m^3
Concrete compressive strength at the age of 30 days	42.1 MPa



(a) (b) (c)

Figure 1: (a) Setting the wires and verifying conductivity by using a multimeter, (b) applying the CAF4 paste, and (c) covering the specimen with an aluminium scotch tape.

which is a 1-MN capacity servo-hydraulic press with fully hydraulic controls.

Axial strains were recorded by means of an extensometer (Figure 2): this equipment is composed of 3 LVDTs fastened on two metallic belts (spaced 7 cm apart) and linked to the specimen by conical end screws holding springs to allow for specimen dilation due to the Poisson effect. This dilation can also be determined through the fourth LVDT (placed tangent to the specimen) so as to acquire the diametrical evolution.

The Brazilian test was employed to obtain the tensile strength. An apparatus was specially designed to affix a cylindrical specimen and allow for the repeated placement of a specimen (Figure 3) (this apparatus was originally invented to hold the specimens prepared for conducting the indirect tensile creep test, as will be illustrated further below (Figure 4)). This device is furnished with screws for positioning the specimen at the centre of the device. These screws are released once the Schenck device jack touches the upper lateral side of the specimens in order to prevent any lateral confinement.

Creep loading is performed by the device shown in Figure 5. As it is illustrated in Figure 6, the dead load (F_1) is transformed into a moment, thanks to a multiplier system. The resulting load applied on the concrete specimens (F_3) equals approximately 200 times F_1.

The Brazilian tensile test principle was adopted in order to conduct the indirect tensile creep test. Since 3 specimens are naturally required to execute a strength test (as that is needed to carry out at the end of each creep test), it was obligatory to apply creep loading on 3 specimens together. It is well known that placement difficulties may arise during the Brazilian test where the load is being applied on only 1 cylindrical specimen. It was thus necessary to design a frame

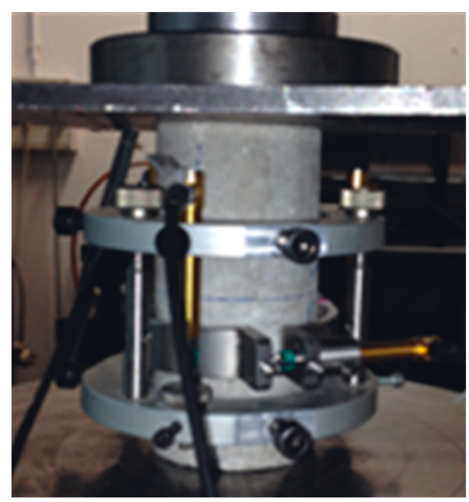


Figure 2: Specimen equipped with an extensometer during the compressive test.

capable of holding 3 specimens throughout the indirect tensile creep test. The apparatus illustrated in Figure 4 was therefore developed to enable performing the indirect tensile creep test. The specimens are arranged laterally (with the specimen axis perpendicular to the applied load) one over the other throughout the test, which is carried out by placing this apparatus into the same creep device used for conducting the compressive creep test (Figure 4(c)).

2.4. Experimental Procedure of the Creep and Quasi-Instantaneous Preloading Tests. The experimental programme is summarised in the flowchart presented in Figure 7. The experimental work consists of the following series:

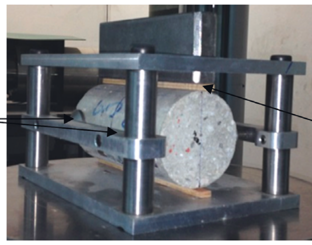


Figure 3: Apparatus used to hold the concrete specimen at the beginning of the indirect tensile test.

(1) Compressive strength and elastic modulus: these two phenomena were studied at 2 creep loading ages and in adopting two loading levels for each age.

  (i) During the first test, the creep load was applied at an age of 1 month in adopting 2 loading levels, i.e., 50% and 65%.

  (iI) During the second test, the creep load was applied at an age of 3 months in selecting 2 loading levels, 50% and 80%.

At the end of each creep test, the compressive strength test was carried out on both the creep and control specimens; afterwards, the results were compared.

(2) The compressive creep effect on tensile strength: the compressive creep test was conducted at an age of 2 months with a loading level of 80%. At the end of creep loading, the Brazilian test was executed on both loaded and unloaded concretes.

(3) The tensile creep test was performed at an age of 1 month in adopting 3 loading levels of 50%, 80%, and 90%. The Brazilian test was carried out upon completion of creep loading on both the creep and control specimens.

It is worth mentioning that, for each series, 3 specimens were loaded together and the creep-loading duration was 30 days. Since 30 days is a too short period to represent a real structure aging, high creep-loading levels were used, to accentuate creep strains and to better evaluate their effects on concrete strength evolution.

(4) The last test pertains to the effect of quasi-instantaneous preloading (in compression) on tensile strength. This test was conducted at an age of 1 month in adopting 3 loading levels (80%, 90%, and 95%). The specimens were loaded until reaching the given loading level, and then, the Brazilian test was performed on these preloaded specimens as well as on the unloaded ones.

3. Results

The amount of creep strain is obtained by subtracting the initial elastic strain (this strain occurs immediately due to the applied load) from the total strain due to loading (as measured from the loaded specimens). The thermal and autogenous shrinkage strains are also removed via the unloaded specimens, which are stored under the same curing conditions.

The strain measurements during a creep test exhibit (as would be expected) a nonlinear evolution. A high strain rate over the first few days is observed, followed by a decreasing trend. In Figure 8, each curve depicts the mean values of 4 strain gauges, in recognising that the experimental variation between each pair of strain gauges, glued onto opposite sides of each individual specimen, does not exceed 15%.

At the end of each creep test, the compressive strength test was carried out, followed by a comparison drawn between the strengths obtained for the creep and control specimens (Figure 9).

The modulus of elasticity was computed with the average strain derived from displacements measured by the 3 axial LVDTs with the corresponding applied stress. This modulus was found to lie within a range from 22 to 28 MPa, with an elastic modulus plateau being observed as shown in Figure 10, which pertains to an arbitrarily chosen specimen. This range was determined to reveal the most stable results, as obtained from the relation of elastic modulus derivations versus compressive stress applied throughout the entire compressive strength test (Figure 11). Thereafter, at the end of each test series, the compressive strength and elastic modulus of both creep and control specimens were compared.

Poisson's ratio provides the comparative value of the lateral strain to the longitudinal strain; moreover, it is typically calculated in the elastic zone. The effective Poisson's ratio value is obtained by dividing the combined elastic and creep lateral strains by the longitudinal strain.

Poisson's ratio is a key parameter for learning about the effect of axial compressive load on lateral strain. The importance of this ratio is manifest when the prestress is applied in two directions on a structural member, as cracks propagate over a loading range wider than that of a uniaxial prestress. To understand the effect of compressive creep loading on the lateral strain, the so-called effective Poisson's ratio has been evaluated here.

Among the creep tests performed, the effective Poisson's ratio for two cases (specimens with a 65% loading level applied at an age of 1 month and with an 80% loading level applied at 3 months) yielded a value of approx. 0.2 after several days of loading. This value is similar to Poisson's ratio of concrete measured in the elastic zone (Figure 12).

4. Discussion

The results compiled indicate that when compressive creep load is applied at an age of 1 month, it leads to an increase of 11.8% and 5.7% in compressive strength and 13.2% and 10.8% in elastic modulus for the two considered loading levels of 50% and 65%, respectively (Figures 13 and 14) (an increase in strength (or elastic modulus) = $100 \times [F_c$ (or E) of creep specimens $- F_c$ (or E) of control specimens$]/[F_c$ (or E) of control specimens]). This conclusion corresponds to the results derived by Roll [1], Sousa Coutinho [2], Liu et al. [3], Asamoto et al. [5], and Saliba et al. [4]. The findings of all these studies agree that concrete subjected to a sustained

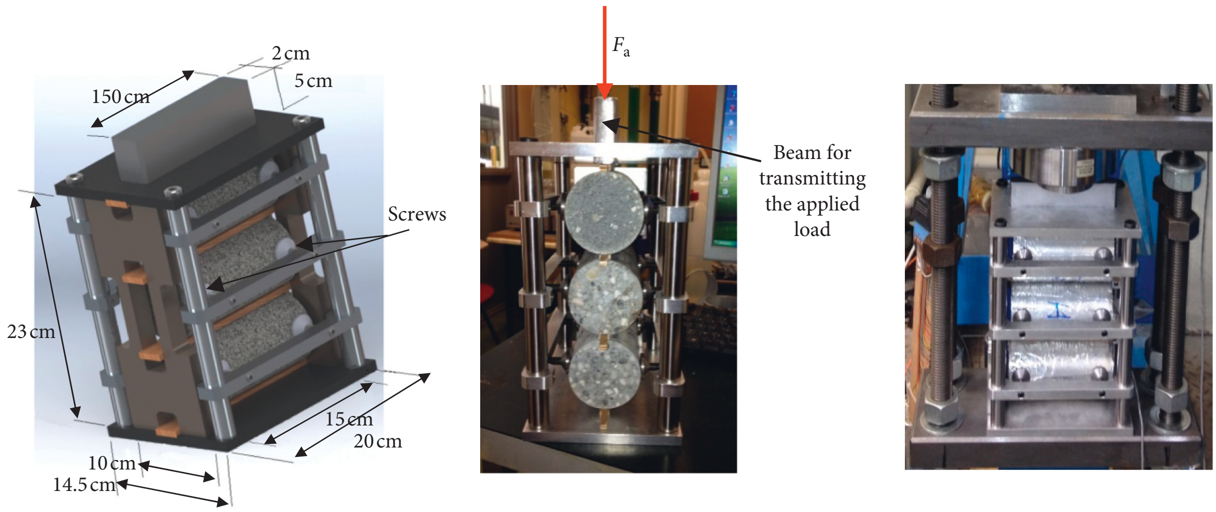


FIGURE 4: Apparatus specifically developed to hold 3 specimens throughout the indirect tensile creep test: (a) design drawing of the device; (b) front view of the driven specimens; (c) (sealed) specimen placed into the creep framework.

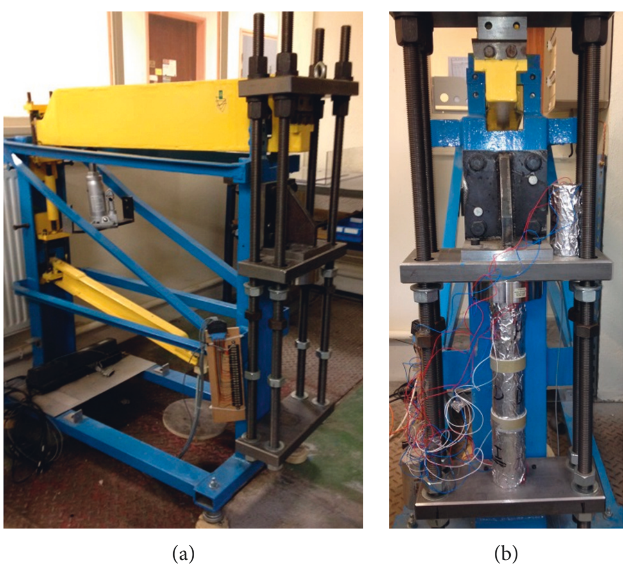


FIGURE 5: (a) Side view of the creep device; (b) front view of the creep device with a column arrangement containing 3 specimens.

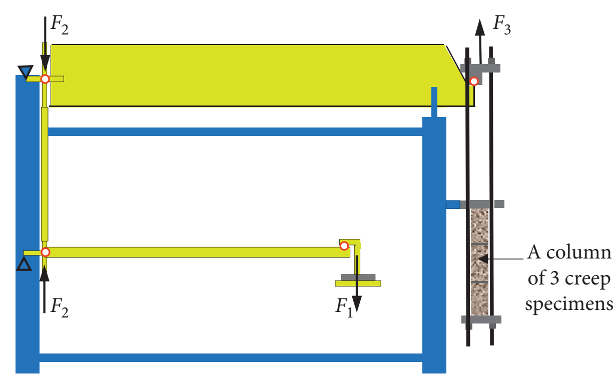


FIGURE 6: Creep device concept: F_1: force of suspension weights; F_2: force transmitted by the moment arm; F_3: force applied on the creep specimens.

compressive load at early or young ages displays higher compressive strength (and higher elastic modulus according to the work by Asamoto et al. [5]).

In contrast, as shown in Figure 13, when the specimens were loaded at 3 months, the compressive creep led to a decrease in compressive strength. It should also be noted that, at this late age (3 months), the loading level has practically no effect on compressive strength. However, the creep load is exerting barely any effect on the elastic modulus at this loading age for both tested levels (50% and 80%) (Figure 14). Yet, Sousa Coutinho [2] found that, with concrete being loaded at different levels (from 21% to 89%), compressive creep at an age of 3 months leads to a slight increase in compressive strength.

Several explanations can be provided here relative to the results obtained. Liu et al. [3] stated that when concrete is subjected to an external sustained moderate compressive load, the hydrated grains around the cracks will come closer to one another with the presence of humidity, while new or further hydration may take place and actually close the cracks. Researchers have tied the increase in strength to a binary compressive loading [3]. As regards the results of this study however, it would seem that such a phenomenon remains valid even under a uniaxial creep load.

According to the theories attributing creep to water diffusion (e.g., Ulm and Acker [7] and Reynouard and Pijaudier-Cabot [8]), when concrete is loaded, the gel water diffuses from narrow spaces between cement layers toward larger capillary pore spaces, thus resulting in a smaller distance between these layers. In relation to the present study, when concrete is being loaded at an age of 1 month, the cement layers become closer (due to water diffusion). Hence, the creep specimens become denser and display greater strength than the unloaded specimens. Nevertheless,

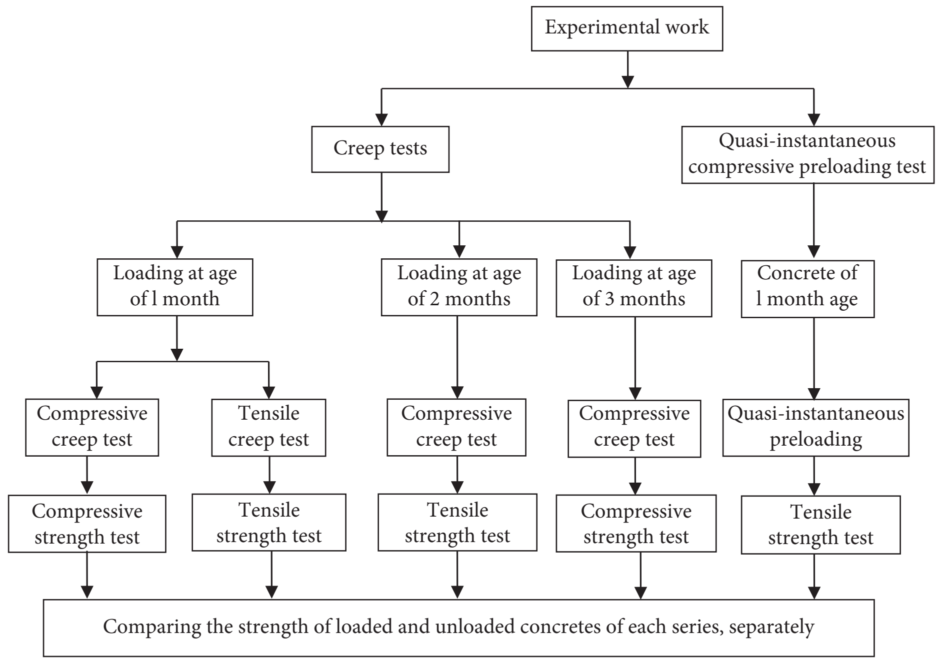


Figure 7: Flowchart of the experimental procedure.

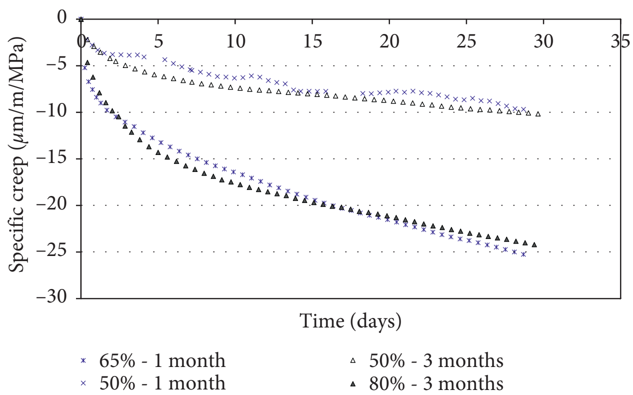


Figure 8: Axial specific creep strain vs. time.

when concrete is loaded at the later age of 3 months, more parts of the capillary pores would have already been filled by cement hydration products. Consequently, when a load is applied at this later age, the capillary pores will contain fewer spaces for the water to diffuse. Diffusing water thus imposes a deleterious force on the hardened cement and leads to its damage (occurrence of microcracking).

An additional explanation here may relate to the strain incompatibility between cement paste and aggregate. In general, under a creep load, only the cement paste creeps while the aggregate acts as an obstacle to this creep due to its relatively high stiffness. The tensile stresses therefore evolve at the aggregate-cement paste interface. At the mesoscopic scale, when concrete is loaded at an age of 1 month, these tensile stresses might be more easily relaxed due to water movement. Conversely, when concrete is loaded at 3 months, the water movement is somewhat hindered (by cement hydration products), i.e., water cannot move easily due to the applied load. Hence, tensile stresses at the aggregate-cement paste interface will not be relieved, leading to microcrack evolution in this zone. Consequently, the creep specimens become weaker and exhibit less strength than the control specimens.

In considering these outcomes, it would appear that when the compressive creep test is carried out at an age of 2 months with an 80% loading level, it exerts basically no effect on tensile strength (Figure 15).

These results are in agreement with those published by Asamoto et al. [5], in which the effect of compressive creep on tensile strength (using a direct tensile strength test) was studied. The study findings indicate that tensile strength remains nearly the same for both control and creep specimens at compressive creep loading levels of 20% and 30%. Loading concrete at a 40% level, however, engenders a decrease in tensile strength [5]. This last result resembles that of a previous study by Liniers [6], which investigated the effect of compressive preloading (for a loading duration of up to 7 days) on tensile strength by means of the Brazilian test. The data obtained from this study showed that very significant tensile strength losses are induced at creep loading levels in excess of 40% due (in the author's opinion) to microcracking taking place under such loading levels.

Regarding the present study, as was explained for the compressive creep effect when the load is applied at an early age of 1 month, the effect on strength is a positive one; in contrast, strength decreases when the load is applied at the later age of 3 months. Hence, in the case of concrete being loaded at the relative late age of 2 months, the negative effect (cracking evolution) offsets the positive effect, thus making the tensile strength of creep specimens equal to that of the unloaded specimens.

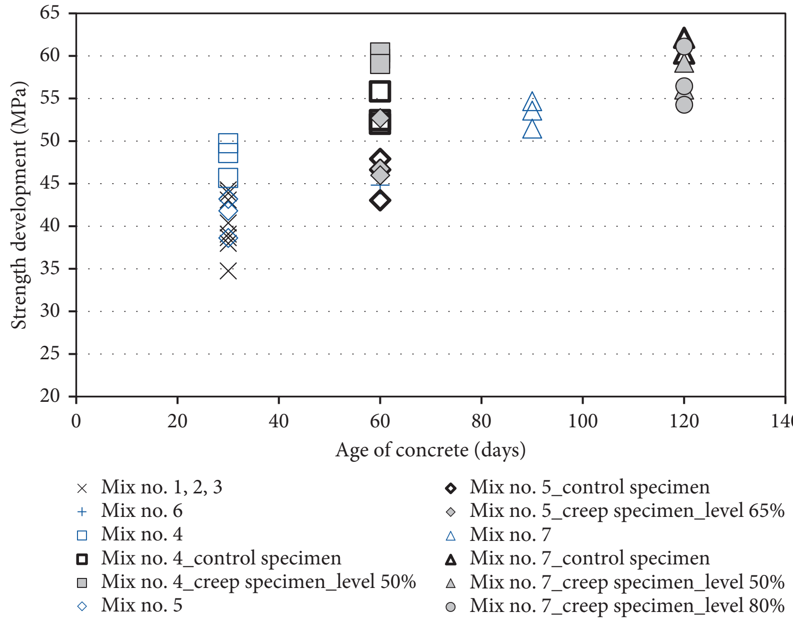


Figure 9: Compressive strength development of unloaded specimens and creep specimens (after 1 month of sustained load applied at ages of 1 month and 3 months) vs. concrete age (Mix nos. 1, 2, and 3 were generated to investigate the effect of quasi-instantaneous compressive preloading (at levels of 80%, 90%, and 95%, respectively) on tensile strength. Mix no. 6 was produced to study the impact of compressive creep on tensile strength. The influence of compressive creep on compressive strength was assessed by casting mix nos. 4 and 5 for a 1-month loading age (levels of 50% and 65%, respectively) and by introducing mix no. 7, with the load being placed at an age of 3 months (for both, 50% and 80% loading levels)).

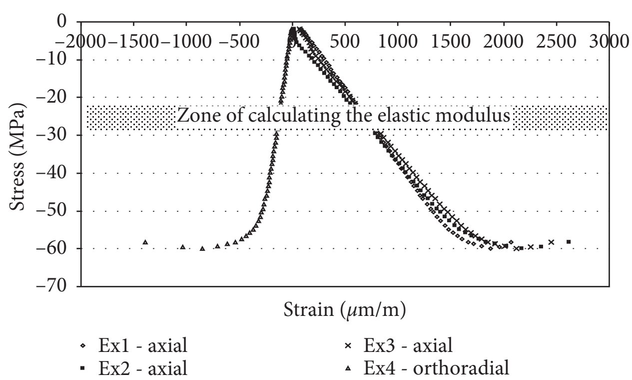


Figure 10: Stress vs. strain of the compressive strength test for an arbitrarily chosen specimen.

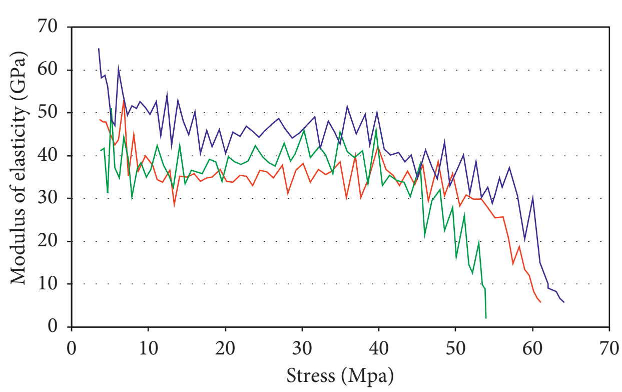


Figure 11: Derivation of the elastic modulus vs. stress of three arbitrarily chosen specimens.

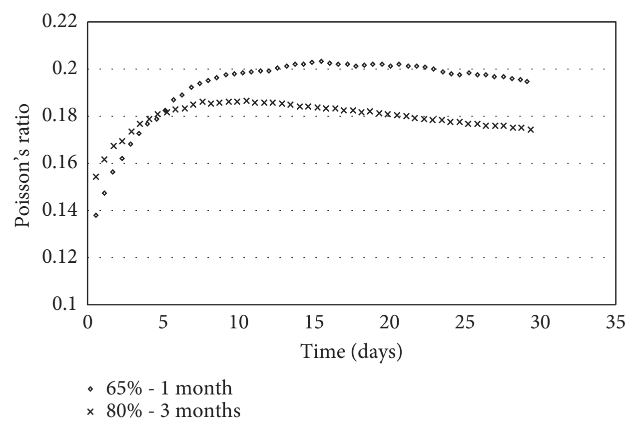


Figure 12: Effective Poisson's ratio calculated from combined elastic and creep strains vs. time.

The tensile creep load was applied at an age of 1 month with 3 loading levels. Tensile strength results reveal that tensile creep at a 50% loading level leads to an increase in concrete tensile strength by some 20%. However, when the tensile creep level is raised to 80% and 90%, the tensile strength is nearly equal for both the creep and control specimens (Figure 16).

In reference to the quasi-instantaneous compressive preloading that lasted roughly 15 minutes, three preloading levels were investigated at an age of 1 month. It can be observed from Figure 15 that the 80% preloading level has no significant influence, while the higher preloading levels of 90% and 95% lead to a decrease in tensile strength of approx. 20%.

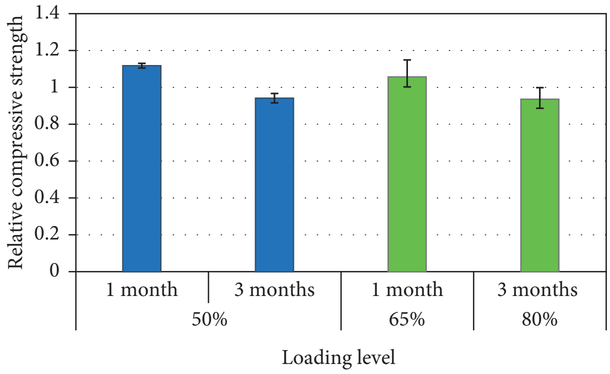


FIGURE 13: Compressive strength of creep-loaded specimens (relative to the average unloaded specimens) vs. the creep loading level for two loading ages (1 and 3 months). The error bar represents the maximum and minimum relative strength values (for 3 specimens). The variabilities of 3 accompanying control specimens ranged between +0.04 and −0.06 for a specimen loading level of 65%; +0.04 and −0.03 for a 50% loading level applied at an age of 1 month; and ±0.02 for 50% and 80% loading levels applied at an age of 3 months.

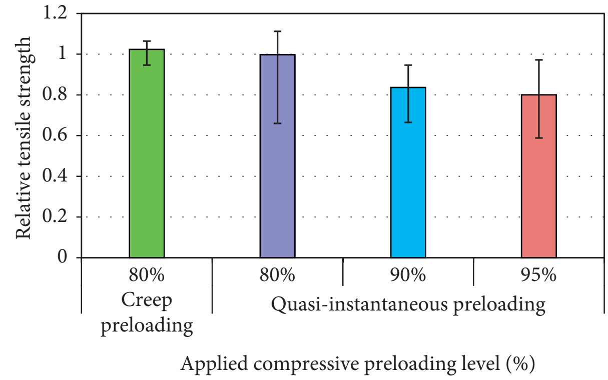


FIGURE 15: Tensile strength (relative to the average unloaded specimens) vs. the creep loading level and quasi-instantaneous preloading of specimens. The error bar represents the maximum and minimum relative strength values (for no less than 3 specimens). The variabilities of 3 accompanying unloaded specimens with respect to the creep-loaded specimens ranged between +0.14 and −0.16, whereas the variabilities (no fewer than 3 accompanying specimens) correlated with quasi-instantaneous preloading were between +0.2 and −0.3.

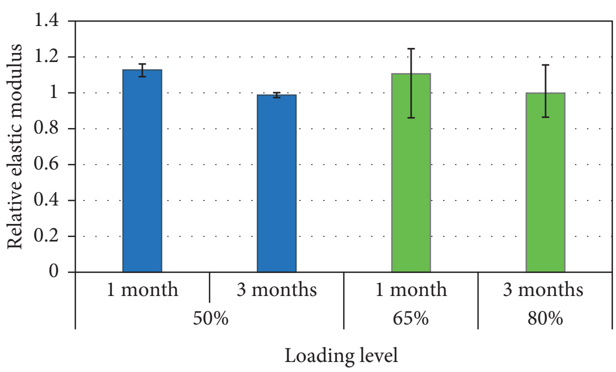


FIGURE 14: Elastic modulus of creep-loaded specimens (relative to the average unloaded specimens) vs. the creep loading level for two loading ages (1 and 3 months). The error bar represents the maximum and minimum relative strength values (for 3 specimens). The variabilities of 3 accompanying control specimens ranged between +0.17 and −0.1 for a specimen loading level of 65%; +0.16 and −0.18 for a 50% loading level applied at an age of 1 month; and ±0.03 for 50% and 80% loading levels applied at an age of 3 months.

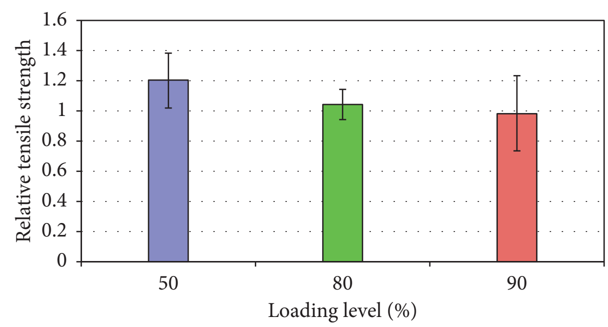


FIGURE 16: Tensile strength of creep-loaded specimens (relative to the average of the unloaded specimens) vs. the creep loading level. The error bar represents the maximum and minimum relative strength values (for 3 specimens). The variabilities of 3 accompanying control specimens ranged between ±0.02 for a 50% loading level; +0.20 and −0.16 for an 80% loading level; and +0.12 and −0.09 for a 90% level.

This last result confirms the findings of a previous study by Liniers [6], which was carried out with a loading duration of up to 7 days (this duration range includes the 15 minutes of time for the current study). Liniers [6] results indicated however that tensile strength decreases after a compressive load in excess of 40%, whereas in the current study, the 80% preloading level has no effect on tensile strength. Since concrete is a quasibrittle material, the extension occurring in the transverse direction due to Poisson's ratio effect actually generates microcracks in the direction parallel to the applied load. This microcracking increases with the applied loading level until reaching a failure level (i.e., loading level equals to 100%). Hence, when the compressive preloaded concrete specimen is subjected to the Brazilian test, it fails with a loading value less than that applied to the sound concrete specimen.

As regards the effective Poisson's ratio of both considered series (i.e., loading applied at an age of 1 month with a 65% level and at 3 months with an 80% level), the value climbed to about 0.2 after several days of loading. This result is quite similar to that obtained by Gopalakrishnan [9], who applied the load in 3 directions; moreover, it matches the result of Kim et al. [10], who applied the load in 1, 2, and 3 directions. In the work conducted by Parrott [11] pertaining to loads applied in a single direction on cement paste, a close value (0.19) was also observed. Unlike previous studies, other research has yielded effective Poisson's ratio values of around zero (see, for instance, Hilaire [12] and Charpin [13]).

5. Conclusions

The context of this study has been to experimentally determine the effect of basic creep on the residual mechanical properties of concrete. To achieve this objective, concrete specimens were subjected to various levels of creep loading applied at different concrete ages, in both the compressive and tensile directions. To evaluate the effect of creep on concrete, the strength test was performed on creep and unloaded specimens (of the same age). The effective Poisson's ratio was also calculated thanks to longitudinal and lateral strain gauges (affixed to specimens) throughout the compressive creep test.

To conduct the tensile creep test, an apparatus was specially invented. This equipment operates according to the same principle as the Brazilian test, but with creep loading applied on three specimens together instead of just one.

From the results obtained, it can be concluded that compressive creep has different effects on the mechanical properties of concrete depending on the age of loading application. When concrete is loaded at an early age (1 month), concrete creep promotes both compressive strength and elastic modulus. In contrast, when concrete is loaded at a later age (3 months), the creep leads to a deterioration in compressive strength while exerting no effect on elastic modulus. With respect to tensile strength, compressive creep has zero effect when the load is applied at an age of 2 months.

Creep in tension was carried out at 1 month. With a low loading level (50%), creep enhances the tensile strength while this effect is reduced nearly to zero with high loading levels (80% and 90%).

Quasi-instantaneous preloading in compression serves to reduce tensile strength with loading levels above 80%, whereas preloading has practically no effect on tensile strength when applied with an 80% level.

This study has demonstrated that the effective Poisson's ratio value identified through a 2-series creep test is similar to that measured in the elastic zone (i.e., 0.2).

Data Availability

The data are available, and researchers just have to ask for them by e-mail.

Disclosure

This manuscript is partly based on the doctoral thesis of Dr. Zainab Kammouna.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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