CREEP BEHAVIOR OF HIGH PERFORMANCE FIBER REINFORCED CONCRETE (HPFRC)

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ABSTRACT

The challenge of the present investigation is to evaluate the possibility of using micro- and nano- fillers as active additives in concrete composition for the replacement of cement and elaborating a new concrete. This paper examines experimental test results carried out with the aim to evaluate the long-term deformations – creep of elaborated concrete composition. Two kinds of fiber-reinforced high performance concrete mixes using those additives and a cocktail of polyvinyl alcohol (PVA) fibers have been developed and prepared. The cubes and cylindrical specimens were prepared for each composition and tested. Cylindrical specimens were put into a creep lever test stand and subjected to a uniform compressive load kept constant over a long period in constant room temperature and level of moisture. This study was carried out in two different extreme environments: in one case they were kept in 100% humidity ensured by preventing the desiccation of the concrete and in the other case samples were air-dried. Compressive strength and modulus of elasticity were determined for each concrete composition. The results of the experiments allow the authors to predict long-term deformations of the concrete.

Key words: cement composites, PVA fibers, silica particles, long-term behavior

INTRODUCTION

Scientists and concrete technologists have been working on the development of new types of concrete. One of the most perspective products is fiber-reinforced high performance concrete (HPFRC). Fibers in concrete provide improved mechanical and physical properties for the material.
One type of strain that plays a major role in successful and continuous use of structures is creep – deformations that appear due to long-term loading of a structural element. Under constant mechanical loading, the strain of concrete increases significantly with loading duration, the increase often reaching 2 to 3 times the value of the instantaneous strain (Rilem TC 107-CSP, 1998). The deformation characteristics of concrete are important in the design of sustainable structures. Therefore, designers and engineers need to know the creep properties of concrete and must be able to take them into account in the structure analysis (Neville et al., 1983).
This paper introduces the recent state of research on elastic and time-dependent deformations of new high performance cement composite materials (FRCC) that are reinforced with PVA fiber and subjected to long-term, uniform, constant compressive load. In these composites, part of the cement has been replaced with micro and nano fillers. The experimental studies of creep in compression were performed. The results of the experiments allow us to predict long-term deformations of concrete.

MATERIALS AND METHODS

Preparation of the specimens

The experimental work included the preparation of two HPFRCC compositions with polyvinyl alcohol (PVA) fibers constituting 2% of the total amount of cement with and without nanosilica. For the purposes of this paper, the batches containing microsilica were designated SF, and the ones containing nanosilica – NN. The mix compositions are shown in Table 1. PVA fiber properties are listed in Table 2.
Raw components of the concrete were measured and then mixed in a laboratory conic rotation mixer for 4 minutes. Standard sample cubes 100x100x100 mm and cylindrical specimens 47x190 mm were produced to investigate the mechanical characteristics of the material. Concrete mixes were cast into oiled steel moulds without vibration because the composite is a self-compacting HPFRC. After one day the specimens were removed from the moulds (Fig. 1). Standard curing conditions (temperature 20±2ºC, RH > 95±5%) were provided during hardening until certain concrete ages were reached.

Table 1

Concrete mix composition

Component [kg/m³]	SF	NN
Cement Aalborg white CEM I 52,5 N	1000	1000
Quartz sand 0-1mm	260	260
Quartz sand 0.3-0.8mm	400	400
Quartz sand 0-0.3mm	300	300
Silica fume Elkem 971 U	150	150
Plasticizer Sikament 56	30	30
Nanosilica	0	20
Water	195	195
PVA fibers MC 40/8	10	10
PVA fibers MC 200/12	10	10
W/C	0.19	0.19

Table 2

Properties of PVA fibres

Fiber type	Ø [μm]	L [mm]	f_t [GPa]	E [GPa]
MC 40/8	40	8	1.6	42
MC 200/12	200	12	1.0	30

Figure 1. Demolded specimens

Test procedure

Cylindrical and cubes compressive strength, modulus of elasticity and creep tests were performed. The compressive tests were completed after 7, 28 and 123 days of concrete hardening in conformity with the standard EN 12390-3:2002. The modulus of elasticity was obtained from samples loading during creep tests. The creep was measured for hardened concrete specimens subjected to a uniform compressive load which was kept constant over a long period of time (Rilem TC 107-CSP, 1998; ACI Committee 209.1R-05, 2008). The constant with time stress level of all specimens was 25% of the maximum strength of the concrete, which had been determined during destructive tests carried out on cube specimens. The load was applied gradually in four steps and as fast as possible. Specimens were kept under a constant load for 90 days, and for recoverable creep they were kept without load for 30 days.

Six aluminium plates had been symmetrically glued onto three sides of the creep specimens in order to provide a basis for the strain gauges. The distance between the centers of the two plates was 50 mm. Three ±0.001 mm precision strain gauges were symmetrically connected to each specimen and then the specimens were put into a creep lever test stand and loaded (Fig. 2). The samples were tested in two extreme conditions: in one case they were kept in 100% humidity ensured by preventing the desiccation of the concrete and in the other case samples were air-dried. All specimens were kept in a dry atmosphere of controlled relative humidity in standard conditions: temperature 20±1ºC and relative humidity 48±3% (Gilbert et al., 2011). After creep tests the cylindrical compressive strength of the specimens at the age of 123 days was also determined.

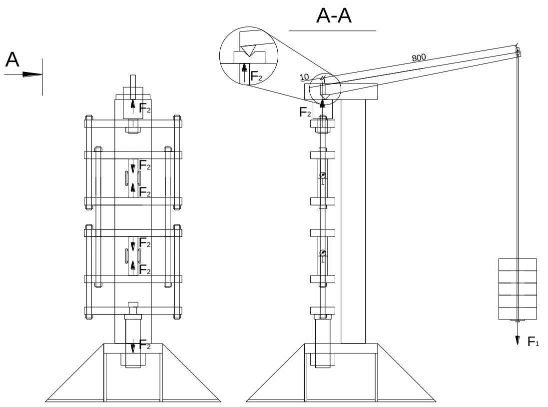

Figure 2. Creep lever test stand

The classification of deformations is shown in Fig. 3 and already described in papers (Gilbert et al., 2011; Sprince et al., 2011).

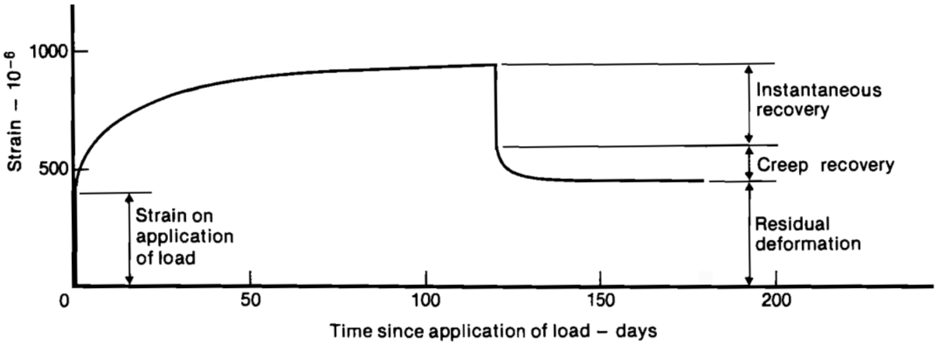

Figure 3. Classification of deformations (Neville et al., 1983)

RESULTS AND DISCUSSION

High cement content and low water/cement ratio provides a rapid concrete hardening process with high strength gain. A slightly higher cubic compressive strength was exhibited by the micro silica specimens after the 28th day. The cube compressive strength for specimens with micro and nano silica after 28 days had reached 100 MPa. After the creep test (123 days later) the cubes compressive strength for both type of specimens was 150 MPa.

During creep tests, the modulus of elasticity was obtained according to Hooke's law by measuring the deformations on the sides of the specimens during the first loading. It was observed that the modulus of elasticity in the both conditions is similar for both mixes and it was 45 GPa.

The total creep strains are given in Fig.4. The creep tests results of the HPFRC indicate that the highest creep strain was observed for micro silica specimens in the dry condition but the lowest ones were for specimens with nano silica in moist conditions. The average difference between specimens with micro silica hardened in moist and in dry conditions was approximately 11%, but for specimens with nano silica hardened in moist and in dry conditions the difference was 34% respectively.

After 90 days of loading, the load was removed. The creep recovery was measured 30 days after the loading period. The largest part of recoverable creep strain is instantaneous. For both mixes the larger difference of irrecoverable creep strain was exhibited by moisture-hardened specimens. The highest residual creep strains were observed for specimens with micro silica. The average difference between specimens with micro silica hardened in moist and in dry conditions is approximately 1% but for specimens with nano silica hardened in moist and in dry conditions the difference is 17% respectively.

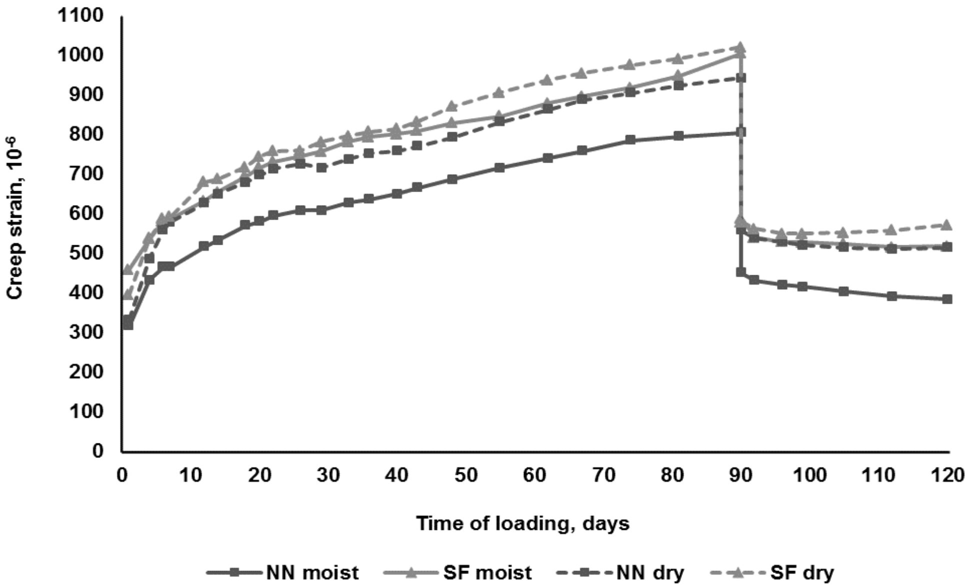

Figure 4. Creep strain of HPFRC at air-drying and moist conditions

The final creep coefficient is a useful measure of the creeping capacity of concrete and increases with time at an ever-decreasing rate. The creep coefficient reduces significantly with the growth of the concrete strength. The highest creep coefficients were established for concrete specimens with micro silica in the both conditions and it reached 3.2. The lowest creep coefficient was exhibited by the specimens with nano-silica. In both conditions it was 2.8.

CONCLUSIONS

Two fiber-reinforced concrete compositions (HPFRC) with micro and nano-silica as active additives were prepared for laboratory examination. The cube compressive strength, modulus of elasticity and creep strain were determined.

The compression strengths before and after the creep test (123 days old) were established.

During creep tests, the modulus of elasticity was obtained. It was observed that the modulus of elasticity in both conditions is similar for both mixes.

Concrete specimens were tested on creep. All specimens were loaded with an equal stress level of 0.25. The load was applied for 90 days and the long-term deformation responses were measured. The highest creep strain was observed for micro silica specimens in dry conditions but the lowest ones were for specimens with nano-silica in moist conditions. The creep recovery was observed over a time period of 30 days. The creep deformations were found to decrease with concrete aging and time. The largest part of recoverable creep strain is instantaneous. For both mixes the larger difference of irrecoverable creep strain was exhibited by moist-hardened specimens. The highest residual creep strains were observed for specimens with micro silica.

The creep coefficient reduces significantly with the increase in concrete strength. The highest creep coefficients were established for concrete specimens with micro silica and the lowest creep coefficient was exhibited by the specimens with nano-silica.

In the future, the physical and mechanical properties of new FRCC containing micro and nano-silica should be investigated in a more detailed way.

The obtained results indicate quite high dispersion of experimental data. In order to decrease the dispersion of results, the number of specimens and tests should be increased.

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