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Behaviour of Fibre Reinforced Cement Based Composites

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The complexity of structures and their size have continued to increase, and this has resulted in a greater importance of their strength and deformation characteristics in more serious consequences of their behavior. Creep and shrinkage of High Strength Concrete (HSC) are complex problem because of its brittleness and sensitiveness to cracking. This research deals with experimentally studied mechanical properties of polyvinyl alcohol (PVA) Fiber Reinforced High Strength Concrete (FRHSC). Several kind of concrete mixes have been made adding micro silica and nano silica. The compression and tensile strength, the modulus of elasticity, creep in compression, shrinkage, crack propagation were determined. Wider use of this material permit the construction of sustainable next generation structures with thin walls and large spans that cannot be built using the traditional concrete. The carbon dioxide released into the atmosphere during the cement production process and contributes to the global warming and the development of holes in the ozone layer. This experimental study proves that new elaborated mixes can be successfully used in the production of concrete, thus potentially decreasing the use of cement, which would lead to a reduction of carbon dioxide release into the atmosphere.

Keywords: *crack propagation, compression and tensile strength, fibre reinforced concrete, modulus of elasticity, long term properties.*

1. Introduction

According to Brandt (2008) High Performance Concretes (HPC) is defined as a concrete in which certain characteristics are developed for a particular application and environment; these characteristics are not only strength, but improved durability, increased resistance to various external agents, high rate of hardening, better aspect, etc. The only disadvantage of concrete is its brittleness, i.e. relatively low tensile strength and poor resistance to crack opening and propagation.

Neville *et al.* (1983) and Bazant *et al.* (2013) explain that the deformation characteristics of concrete are important also in the design of sustainable structures because these can significantly contribute to the cracking risk. Fanourakis and Ballim (2003) had mentioned that creep and shrinkage of concrete are a complex problem and those phenomena are often responsible for long-term and sustainable of the structures.

The development of new types of concrete focuses among others on High Performance Fiber-Reinforced Cement Composites (HPFRCC). Prisco *et al.* (2009) expresses that FRC is a composite material that is characterized by an enhanced postcracking tensile residual strength, also defined as toughness in the following, due to the fiber reinforcement mechanisms provided by fibers bridging the crack surfaces. Among researchers there is an argument that fibers in concrete provide improved mechanical and physical properties of the material (Prisco *et al.* 2009, Fischer, Li 2007, Paegle, Fischer 2011, Bajare *et al.* 2012; Pereira *et al.* 2012).

One of the main constituents of concrete is cement. The carbon dioxide released into the atmosphere during the cement production process accounts for approximately 5-10% of the overall CO_2 production in the world. Its release into the atmosphere contributes to the global warming and the development of holes in the ozone layer. If the CO_2 production in cement factories could be decreased by 10%, the overall release into the atmosphere would decrease by 5.2%.

This paper reports on an experimental investigation of the long term deformations and cracking resistance of several types of FRC that are reinforced with PVA fibres. In these composites, part of the cement has been replaced with micro and nano fillers.

2. Methods

The experimental work included the preparation of two FRC compositions with PVA fibres with micro (MS) and nano (NS) silica. For the purposes of this paper, the batches containing microsilica were designated MS, and the ones containing nanosilica – NS. The mix compositions are shown in table 1. PVA fiber properties are listed in table 2.

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*

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

Concrete components were measured out and then mixed in a laboratory twin-shaft mixer for 4 minutes. Standard cube specimens of 100x100x100 mm, beam specimens of 150x150x600 mm and cylindrical specimens of 47x190 mm were produced. Concrete mixtures were cast into oiled moulds without vibrating because this is a self-compacting concrete. After one day specimens were de-moulded. Standard ageing conditions (temperature 20±2°C, RH > 95±5%) were provided during hardening until certain concrete ages were reached.

All tests were carried out Riga Technical University (RTU) and Denmark Technical university (DTU) laboratories.

The **compression strength** was determined in conformity with the standard EN 12390-3:2009. The tests were performed after 7, 28 and 123 days of concrete hardening in standard conditions (see Fig. 2). A compression testing machine with accuracy of ±1% was used and the rate of loading was 0.7 MPa/sec. **The tensile strength** was obtained from single-crack notched coupon specimens after 127 days. The notched coupon specimens were with dimensions 150x50x12 mm and representative cross section of 8x30 mm. Deformation controlled tensile tests (0.3 mm/min loading rate) were conducted using clipgauge measuring the opening displacement of a single crack (see Fig.4) (Paegle, Fischer 2011). **The modulus of elasticity** was obtained after 28 days from cylindrical specimens 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, and **shrinkage** was measured for the same specimens without loading (Rilem 1998; ACI 2005; Balevičius and Dulinskas 2000).

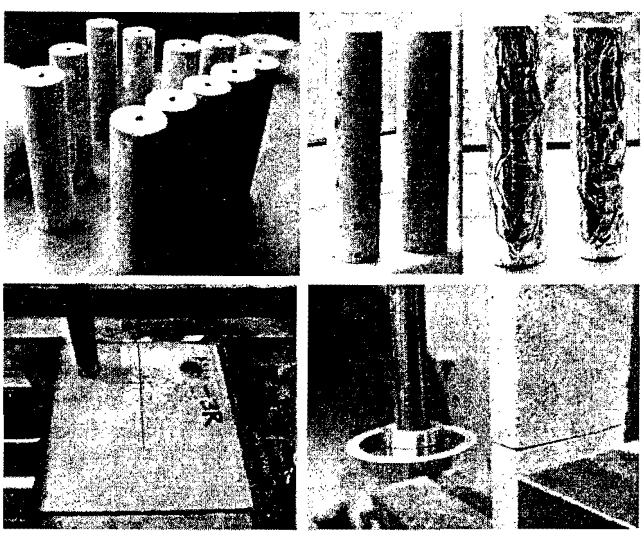

Fig. 1. Preparation of different kind of specimens (RTU and DTU laboratories)

During the creep test, the stress level of both mixes was 25% of the maximum strength of the concrete, which had been determined during destructive tests. 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 centrally and symmetrically glued onto three sides of the creep specimens in order to provide a basis for the strain gauges. The distance between the centres of the two plates was 50 mm (see Fig.1). 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 (see Fig.2, 3). Two steel plates had been centrally and symmetrically glued onto ends of the shrinkage specimens (see Fig.1) and strains were measured with a shrinkage clamp (see Fig.2).

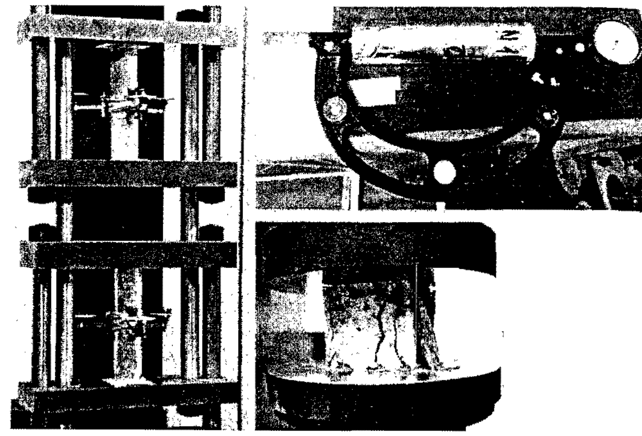

Fig. 2. Test setup of creep and shrinkage experiments and cube compression specimen collapse (RTU laboratory)

The creep 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. (Sprince *et al.* 2011). All specimens were kept in a dry atmosphere of controlled conditions: temperature 20±1°C and relative humidity 48±3% (Rilem 1998; ACI 2005). After creep and shrinkage tests the cylindrical compressive strength of the specimens at the age of 123 days was determined.

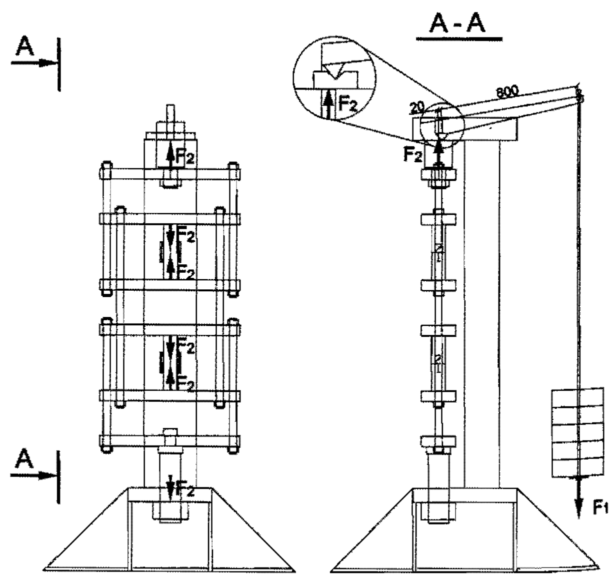

Fig. 3. Creep test lever stand (RTU laboratory)

The creep (time-dependent strain) was measured in hardened concrete specimens.

The instantaneous strain that occurs immediately upon application of the stress may be considered to be elastic at low stress levels, and therefore:

$$\varepsilon_{e(t)} = \sigma_{c0} / E_{c(t0)} \tag{1}$$

where: $E_{c(\tau 0)}$ - the elastic modulus at time τ_0; $\varepsilon_{e(t)}$ - the instantaneous strain; σ_{c0} - the compressive stress.

The capacity of concrete to creep is usually measured in terms of the creep coefficient, $\varphi_{(t,\tau)}$. In a concrete specimen subjected to a constant sustained compressive stress, $\sigma_{c(\tau)}$,first applied at age τ, the creep coefficient at time t is the ratio of the creep strain to the instantaneous strain and is given by:

$$\varphi_{(t,\tau)} = \varepsilon_{cr(t,\tau)} / \varepsilon_{e(\tau)} \tag{2}$$

where: $\varphi_{(t,\tau)}$ - the creep coefficient; $\varepsilon_{cr(t,\tau)}$ - the creep strain; $\varepsilon_{e(\tau)}$ - the instantaneous strain (Gilbert *et al.* 2011).

Compact tension (CT) tests with notched specimens

The testing procedure developed for the present work consisted of applying a tensile load to a single-edge notched specimen (see Fig. 4). The selected specimen shape resembles the one used for the evaluation of crack propagation behavior in metals (ASTM-E647 2005), the so-called Compact Tension specimen.

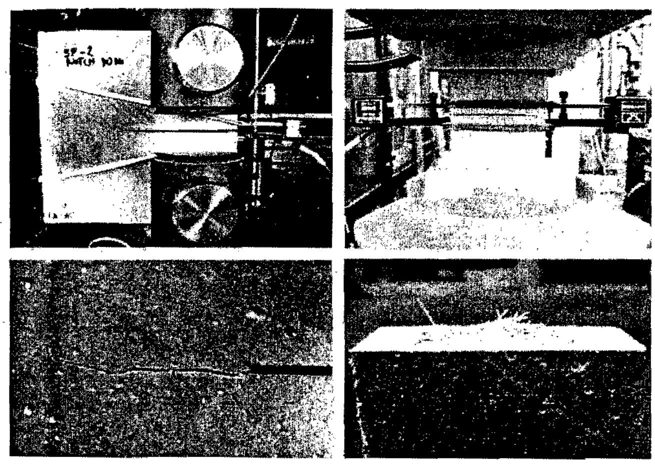

Fig. 4. Test setup and specimens after CT and coupon testing (DTU laboratory)

Clear access to the surface where the crack progression becomes visible was important. At the same time, the stress intensity achieved at the tip of the notch limited the area where the crack initiates. With the purpose of maximizing the stress intensity at the tip of the notch, the notch thickness was reduced to 0.5 mm using a small diamond cutting disc. (see Fig.1). The depth of the specimen was also reduced, promoting the plain stress state. Summarizing, the dimensions adopted for the specimens were 150 mm by 150 mm (perpendicular and parallel to the notch) and 12 mm (thickness). The available path for progress of the initiated crack parallel to the notch was 30 mm. The distance between the loading axis and the tip of the notch was also 50 mm. The testing sequence consisted of subjecting the specimens to a tensile load at a constant displacement rate, transmitted by two rods with a diameter of 20 mm (see Fig.4). The use of the two rods allowed the transmission of the displacement while keeping free the rotation of the specimen with respect to the rods. The adopted displacement rate was 1µm/s (Pereira *et al.* 2012). Before testing, to measure crack mouth opening displacement (CMOD), the extensometer with precision +/- 2.5 mm was centrally and symmetrically positioned at the edge of the test plate's notch.

3. Results and discussion

The tests to determine compression and tensile strength, modulus of elasticity, creep, creep coefficient, shrinkage and crack propagation were done on concrete samples with PVA fibres in which micro and nano silica was used as an active additive.

High cement content and low water/cement ratio provides rapid concrete hardening process with high strength gain. High compressive strength had developed in the cubes after the first 7 days of hardening, and continuous compressive strength growth was observed (Sprince *et al.* 2012). Compressive strength of the cubes after 28 days had reached 110 MPa for both concrete batches. Compression strength tests were done after the creep test (123 days later). The compressive strength of the cubes was obtained as approximately 150 MPa for both concrete batches. Tensile strength after 127 days was approximately 3 MPa.

During creep tests modulus of elasticity was obtained. It was observed that the modulus of elasticity in all conditions is similar for both mixes, and it was 47 GPa.

The total creep strains are given in Fig. 5. The creep tests results of the FRC indicate that the highest creep strain was observed for both concrete batches in dry. The biggest difference between the specimens hardened in moist and dry conditions was for specimens with nano silica - approximately 23%.

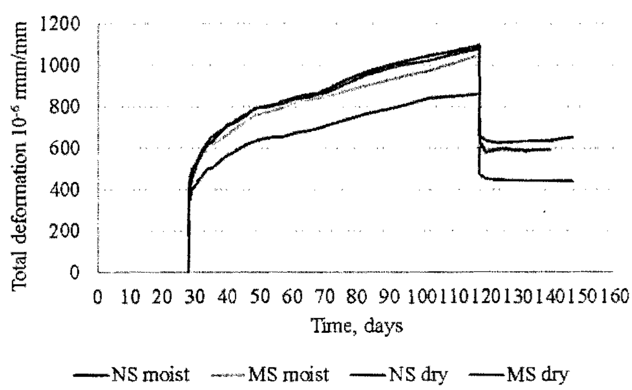

Fig. 5. Total deformation of FRCC at air-drying and moist conditions (RTU laboratory)

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 largest difference of irrecoverable creep strain was exhibited by dry-hardened specimens. The highest residual creep strains were observed for specimens with micro silica.

The creep coefficient increases with time at an ever-decreasing rate. The final creep coefficient is a useful measure of the creeping capacity of concrete. The creep coefficient reduces significantly with the growth of the concrete strength. The highest creep coefficients from experimental tests were established for concrete specimens with nano silica in the dry conditions and it was approximately 2.0. (see Fig.6). The lowest creep coefficient was exhibited by the specimens with micro silica in the moist conditions and it average value was 1.5.

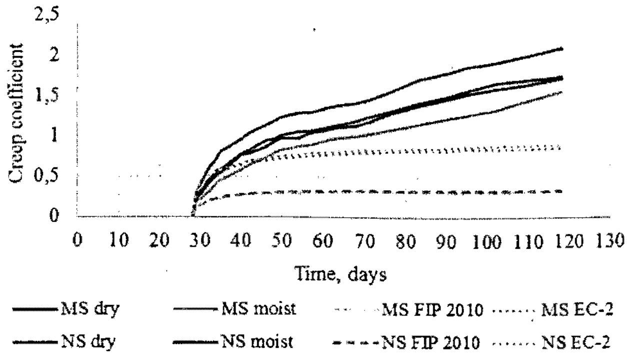

Fig. 6. Creep coefficient of FRCC at air-drying and moist conditions (RTU laboratory)

The CEB-FIP 2010 and the EN 1992-1-1:2004 models produce significantly different creep coeffiecient development. The values of creep coefficient are 2-5 times smaller than from experimental tests. This could be explained by the fact that the models are evaluated only the part of the creep impact parameters, such as compressive strength, moisture, sample cross-sectional dimension, but are not to evaluate the size and amount of grading, w/c ratio, etc. which are essential for the development of creep phenomena.

Shrinkage results were obtained from the same shape and concrete mix specimens as the creep specimens, and the strains were measured during creep tests. The shrinkage deformations are decreasing with time. The lowest shrinkage deformations were observed for specimens in moist conditions. The average value for specimens in moist conditions for both concrete mixes is approximately 80 micro strains and in dry conditions - approximately 65 micro strains.

According to Brandt (2008) the "cocktail" of two types of PVA fibers exhibited different behavior of tension curve. The main role of short dispersed fibers was to control the opening and propagation of small cracks, whereas long fibers control the large cracks and serve as a bridge between the two sides of the crack.

Figure 7 shows the behavior of short and long fibers, the experimental load – crack mouth opening displacement (CMOD) curves are presented. The results are presented for CMOD values of up to 0.5 mm. The experimental results are quite similar and they indicate that nanosilica does not have significant influence on the tensile load and CMOD properties of FRHSC. The average tensile load for NN specimens was 570 N and CMOD was 0.57 mm respectively. The average tensile load for SF specimens was 613 N and CMOD was 0.59 mm.

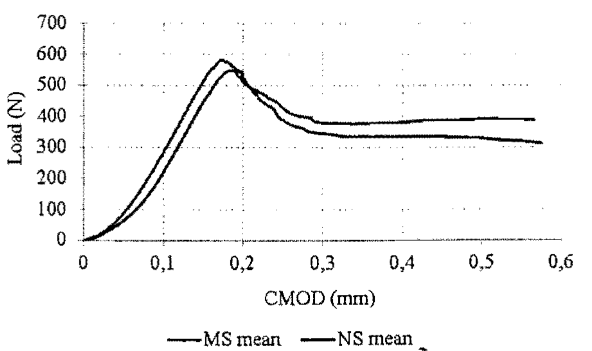

Fig. 7. Tension load and CMOD of two kind of FRCC (DTU laboratory)

4. Conclusions

Two FRHSC with micro and nano silica as active additive were prepared for a laboratory examination. The compressive and tensile strength, modulus of elasticity, creep, shrinkage, crack propagation were determined.

During creep tests, the modulus of elasticity was obtained. It was observed that the modulus of elasticity of specimens hardened in moist and dry conditions are similar for both mixes.

The results of the experiments permitted the prediction of long-term deformations of the concrete. Concrete specimens were tested for creep and shrinkage. All creep specimens were loaded with an equal stress level 0.25. The load was applied for 90 days and the long-term deformation responses were measured. The highest creep strain was observed for both mixes specimens in dry 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 largest difference of irrecoverable creep strain was exhibited in dry condition specimens.

The creep coefficient reduces significantly with the growth of the concrete strength. The highest creep coefficients were established for concrete specimens with nano silica in dry conditions. The CEB-FIP 2010 and the EN 1992-1-1:2004 models produce significantly different creep coeffiecient development and final values.

The shrinkage results were obtained from the same shape and concrete mix specimens as the creep specimens, and the strains were measured during creep tests. The shrinkage deformations are decreasing with time. The lowest shrinkage deformations were observed for specimens in moist conditions.

The experimental results of tensile strength and CMOD are quite similar for both mixes.

The experimental study indicates that nano silica does not have significant influence on the FRHSC mechanical and deformative properties.

In the future, the physical and mechanical properties of new FRHSC containing PVA fibers with micro and nano silica should be investigated in a more detailed way.

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