EFNARC CREEP TEST PROCEDURE DESCRIPTION FOR SPRAYED CONCRETE AND TEST RESULTS WITH STEEL AND SYNTHETIC FIBRES

EFNARC KRIECHTEST, BESCHREIBUNG DES PRÜFVERFAHRENS FÜR SPRITZBETON MIT TESTERGEBNISSEN FÜR STAHL- UND KUNSTSTOFFFASERN

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Creep is a term used to define the tendency of a material to develop increasing strains through time when under a sustained load, this resulting in increasing deflection or elongation values (depending on the type of loading) with time in relation to the initial, instantaneous strain that the material experiences directly after the load is applied.

A new test procedure concerning long term behaviour of fibre reinforced concrete under constant load has recently been proposed by EFNARC [1]. The test procedure is based on the square panel test and extended for a pre-cracked panel exposed to constant load.

This paper describes the results of an experimental campaign aimed at investigating the long term behaviour of steel and macro synthetic-fibre reinforced concrete plates on continuous support. The tests show the differences in the long term behaviour for shotcrete with different types of fibres.

Kriechen ist als zeitabhängige Formänderung unter dauernd wirkender Belastung definiert. Dieses Phänomen ist daher bei manchen Materialien dafür verantwortlich, dass (je nach Beanspruchung) Durchbiegungen oder Formänderungen zur ursprünglichen elastischen, sofort auftretenden Verformung mit der Zeit mehr oder weniger stark zunehmen.

Durch EFNARC [1] wurde gerade eine neue Prüfvorschrift zum Langzeitverhalten von Faserbeton unter Dauerlast vorgeschlagen, welche auf dem Plattenbiegetest basiert.

In diesem Beitrag werden die Ergebnisse eines Versuchsprogramms zum Langzeitverhalten von allseitig gelagerten Platten aus Stahlfaserbeton und Kunststoffmakrofaserbeton beschrieben. Die Ergebnisse zeigen die Unterschiede im Langzeitverhalten von Betonen mit verschiedenen Fasertypen auf.

1. Introduction

When a concrete specimen is subjected to load, its response is both immediate and time-dependent. Under sustained load, the deformation of a specimen gradually increases with time and eventually may be times greater than its initial value. Since concrete is used so extensively, it is only right that we should learn to know it better, and understanding of creep and of the underlying phenomena is essential in this respect.

Some research has been undertaken into the creep of cracked concrete with either steel or synthetic fibres [2-19]. These tests have been conducted as three point bending tests on notched beams (according to EN 14651), four point bending tests on notched beams (according to UNI standard), four point bending test on beams (according to Austrian guideline on shotcrete, Japanese standard JSCE-SF4) and bending test using centrally loaded round panel (according to ASTM Standard C1550). The tests are performed until a certain deflection of the specimen and after the occurrence of the corresponding cracks or crack mouth opening the specimen is kept under constant load. The test results are deformation versus time curves at constant loads and maximum load levels before creep rupture occurs.

Following remarks can be given:

- There is no standardized methodology to assess creep behaviour of concrete except ÖBV [21]
- Creep deformation has been found to be generally larger for cracked macro-synthetic fibre reinforced concrete (FRC) than for steel fibre reinforced concrete (SFRC)
- the creep investigation should focus on a better understanding of the behaviour of steel and macro-synthetic fibre

The test method described in this paper is based on EN 14488-5 [23]. For testing the FRC panel is placed on a rigid square support and centrally loaded with a rigid steel square block. This test is good for comparison of the behaviour of different fibres, but shows high friction at the support.

This paper will provide first test results for synthetic and steel fibre reinforced concretes under constant loads of up to 80 % of the initial force for achieving a deflection of the panels of 2 mm.

2. General Remarks

The behaviour of fibre reinforced concrete is more than a simple superposition of the characteristics of the concrete matrix and the fibres. In order to analyse the behaviour of this composite material, also the interaction between both has to be taken into account, i.e. the transfer of loads from the concrete matrix to the fibre system.

Therefore, for efficient load transfer, the following three conditions must be satisfied:

- Sufficient <u>exchange surface</u> (number, length, diameter of fibres)
- The <u>nature of the fibre-matrix interface</u> allows for proper load transfer
- The <u>mechanical properties</u> (Young's modulus, anchorage and tensile strength) of the fibre allow the forces to be absorbed without breaking or excessively elongating the fibre.

Different Materials show different creep behavior:
Creep behaviour of steel:
Steel does not exhibit creep behaviour under normal service conditions. "Steel fibres are suitable reinforcement material for concrete because they possess a thermal expansion coefficient equal to that of concrete, their Young's Modulus is at least 5 times higher than of concrete and creep of regular carbon steel fibres can only occur above 370°C" [24].

Creep behaviour of polymeric materials:
Most synthetic fibres are thermoplastic, which exhibit considerable creep due to sliding of the long chained molecules under external load.

The European standard EN 14487-1 mentions the different ways of specifying the ductility of fibre reinforced sprayed concrete in terms of residual strength and energy absorption capacity. It also mentions that both ways are not exactly comparable.

- **The energy absorption** value measured on a panel can be prescribed when - in case of rock bolting - emphasis is put on energy, which has to be absorbed during the deformation of the rock: especially useful for primary sprayed concrete linings [23].
  This flexural – punching square slab test simulates very effectively the behaviour of a tunnel lining under rock pressure around an anchor bolt. This test procedure was part of the AFTES recommendation [25].
  No material properties, such as post-crack strength values, can be determined from the square panel test on continuous support due to an irregular crack pattern. However this has never been the intention of this structural test method; this method serves to quantify and illustrate the ductile behaviour of a fibre reinforced sprayed concrete tunnel lining.

- **The residual strength** can be prescribed when the concrete characteristic is used in a structural design model. For the residual strength the new test method proposed by EFNARC is a three point bending test on square panel with notch [20] instead of the EN 14488-3 [22]. It would therefore seem interesting to study also in the future the behaviour of pre-cracked structures on square panel with notch in order to provide designers with additional data considering creep. Consideration of creep is part of the rational approach to satisfy some design criteria.

3. Test description

3.1 Purpose of the test procedure

The test method described here for the evaluation of creep behaviour is realized on a square panel specimen (figure 1). This test method has the following advantages for sprayed concrete:

- This test method on continuous support is simulating at a laboratory scale the structural behaviour of the system anchor bolt – sprayed concrete under flexural and shear load
- The geometry and dimensions of the specimen, as well as the spray method are as close as possible to that encountered in the real structure
- The dimensions of the test specimen will be acceptable for handling within a laboratory (no excessive weights or dimensions)
- The test will be compatible, as far as the experimental means permit, with use in a large number of normal equipped laboratories (no unnecessary sophistication)
- The panel could be sprayed on the job site

3.2 Test procedure description

The test procedure contains 3 major steps:

Step 1

A fibre reinforced slab specimen is subjected to a load, under deflection control, through a rigid steel block positioned at the centre of the slab. The load-deflection curve is recorded and the test is continued until a specified deflection is achieved at the centre point of the slab.

- Square panels (600 mm x 600 mm x 100 mm) are either sprayed (according to EN 14488-1) or casted
- Static test is performed according to EN 14488-5 until a centre deflection of 2 mm (just after development of the cracks). This set-up and a typical crack pattern of the FRC after 2 mm deflection is shown in figure 2.

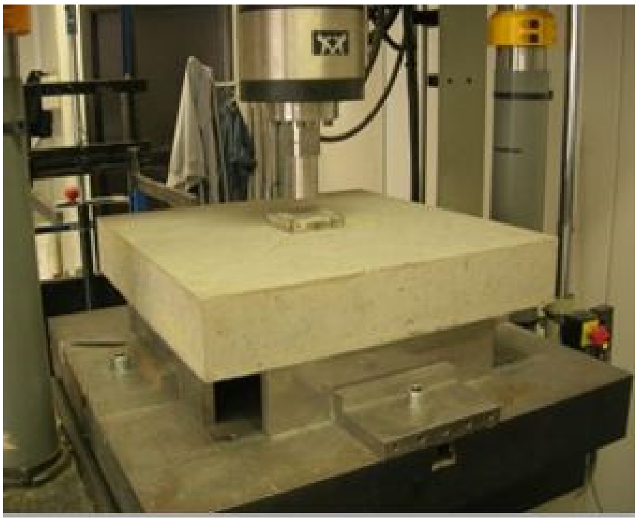

Figure 1 & 2: Square panel test according to EN 14488-5 (left) and crack pattern after 2 mm deflection (right)

Step 2

The square panel is exposed to a constant load, which corresponds to a percentage of the load achieved at the end of the initial test phase. The deflection of the slab will be continuously monitored for determination of the creep speed (figure 3).

- The first load equals 40 % of the load at deflection of 2 mm
- The deflection due to creep should be measured during application of the load initially every second, afterwards every hour up to 1 day and finally every week

Figure 3: Test set-up

Step 3
In order to determine the FRC behaviour at higher loads and especially for investigating maximum load levels before creep rupture the following load levels are applied:

- increase to 60 % of the residual load at deflection of 2 mm
- further increase to 80 % of the residual load at deflection of 2 mm

4. Fibre concrete composition

For this study FRC specimen were casted using macro synthetic (embossed, E=10 GPa, length 65 mm, modified olefin) and steel (Dramix® 3D 65/35BG) fibres. The mixture composition and the fibre dosages for the concrete specimen are given in table 1.

Tab. 1: Mix design and fibre dosages

		synthetic FRC	steel FRC
Cement: CEM I 42,5 R HES	kg/m³	427	
River sand 0/4	kg/m³	854	
Crushed limestone 4/8	kg/m³	854	
Water	kg/m³	214	
w/c		0,50	
Macro synthetic fibres	kg/m³	7	-
Dramix® 3D 65/35BG	kg/m³	-	25

The FRC samples were demoulded 24 hours after mixing and further stored for 24 hours under water. The static test started 2 days after casting. Immediately after the static test, the creep test started.

5. Test results

At an FRC age of 2 days the panels were loaded up to a center deflection of 2 mm. The resulting load-deflection curves are shown in figure 4.

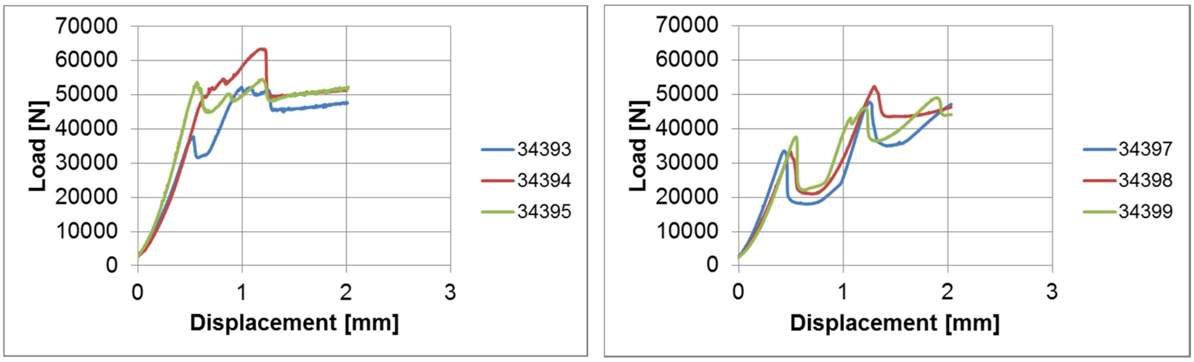

Figure 4: Initial test results for steel (left) and synthetic (right) FRC

As can be seen the steel fibres exhibit higher loads over the deflection path. The first crack for the three SFRC panels occur between 37 to 52 kN (medium value 44.5 kN), whereas for the synthetic FRC panels this load lies between 33 to 38 kN (medium value 35.5 kN). At 2 mm deflection the two different FRCs show similar loads, which lie between 47.5 to 51.8 kN (medium value 50.3 kN) for SFRC and between 44.3 to 47.5 kN (medium value 46.0 kN) for synthetic FRC.

After the first loading procedure the panels were transferred to the creep test set-up and further loaded according to the test procedure. In table 2 the loads and duration of the applied loads for the FRC panels are given in detail.
Following loads were applied in the creep phase:

Tab. 2: Applied loads and duration of the loads

	Panel	Load level					
	Identification	40 %		60 %		80 %	
		Load kN	Duration days	Load kN	Duration days	Load kN	Duration days
steel FRC	34393	19.0	255	28.5	42	38.0	546
	34394	20.6	255	30.9	42	41.2	546
	34395	20.7	255	31.1	42	41.4	546
synthetic FRC	34397	19.0	255	28.5	42	38.0	546
	34398	18.5	255	27.8	42	37.0	546
	34399	17.7	255	26.6	42	35.4	546

In figure 5 the creep behaviour of the SFRC and synthetic FRC panels under the different load levels is shown as increase in center deflection of the concrete panels.

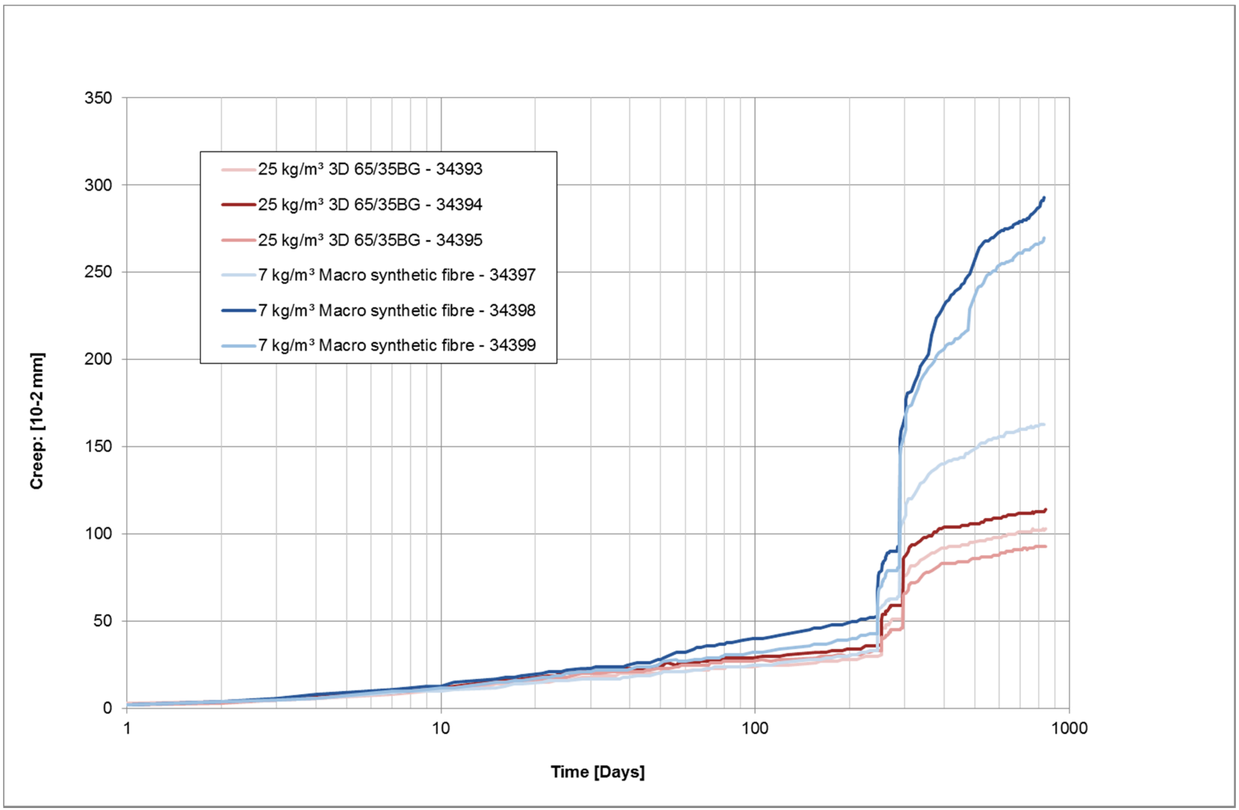

Figure 5: Creep behaviour of macro-synthetic and steel FRC

For the first 40 days at load level of 40 % of residual load at 2 mm deflection the synthetic and steel FRC show very similar creep behaviour. After this period for one of the synthetic FRC panels (panel 34398) a higher increase in deflection is obeserved. A similar behaviour is seen for another synthetic FRC panel after a load time of about 100 days. At the end of the 40 % load level the three SFRC panels exhibit very similar increase in deflection due to creep of about 0.35 mm. However, the three synthetic FRC panels exhibit already a noticeable variation in deflection lying between 0.35 and 0.51 mm.

The increase of the load to 60 % of residual load at 2 mm deflection results after 42 days in an increase of panel deflections for the SFRC to 0.45, 0.50 and 0.60 mm. The synthetic FRC panels exhibit higher increase in deflection reaching 0.65, 0.80 and 0.90 mm.

Very strong differences between the creep behaviour of the SFRC and synthetic FRC panels can be seen after increasing the load to 80 % of residual load at 2 mm deflection. The SFRC panels show very moderate deviations for the deflection lying between 0.90 and 1.15 mm. Also the deflection curves tend to flatten out and no further significant increase in deflection can be expected. Much higher deflections and deviations within the three panels occur for the synthetic FRC. For one panel (nr. 34397) the increase in deflection is up to 1.6 mm and also a slight flattening of the creep curve is seen. The deflection of the other two panels exhibit a strong increase at this load level reaching values of 2.65 and 2.9 mm. As can also be seen the creep curve of these panels is still rising after 546 days of loading and flattening of the curves is not yet reached.

6. Conclusion

The test program described provides additional information considering creep behaviour of fibre reinforced concrete. The test method is based on the square panel test with rigid square support. After loading the FRC panel up to a central deflection of 2 mm the concrete sample is kept under constant loads of 40%, 60% and 80% of the residual load at 2 mm deflection.

The test method can be used for investigating either casted or sprayed FRC panels and comparing the creep behaviour of synthetic or steel FRC. Even the influence of temperature variations could be investigated.

For the present investigations it can be seen that already at a load level of 40% of the residual load at 2 mm deflection the macro synthetic FRC panels exhibit slightly higher creep after 255 days. Increasing to load levels of 60% and especially 80% show that there is a great difference in creep behaviour between the synthetic and steel FRC. The tested macro synthetic FRC has much higher creep deformations.

Additional test results of programs on sprayed panels, using a similar test procedure, will be launched under ASQUAPRO [26] in order to complete informations about creep.

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