Creep and Shrinkage of Ultra High Strength Steel Fibre Concrete

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Summary

Developments in concrete mixture design and the introduction of new admixtures have resulted in a still ongoing increase of concrete strengths reached. Very high strength concrete, i.e. strength classes B 150 - B 200, has an improved packing density by addition of extreme fine fractions, improvement of workability by new superplasticizers and a high steel fibre content. These concretes have a position between steel and "traditional" concrete with regard to their properties. Some material properties, however, have to be studied more thoroughly before design rules can be derived. The creep and shrinkage behaviour of a special type of ultra high strength steel fibre reinforced concrete, namely BSI (Béton Spécial Industriel), were amongst the properties that were investigated. These properties were regarded as being highly relevant because in the Netherlands, it was intended to use BSI as a concrete without traditional steel bar reinforcement, using only prestressing strands if required. Design rules should provide the information to estimate time-dependent prestress losses.

Keywords: very high strength concrete; steel fibre; prestressing; creep; shrinkage.

1. Introduction

In a design study for a drawbridge to be constructed in BSI, it appeared that there was a lack of insight into the material's time-dependent behaviour [1]. Preliminary calculations were based on material parameters obtained by extrapolation of rules presented in design codes, suited for concrete strength classes up to C100/115 [2]. Calculations for precast pretensioned T-shaped beams were based on a shrinkage of $-0.15 \cdot 10^{-3}$ and maximum creep factor 1.4. It was found that elastic and time-dependent losses (creep and shrinkage of the concrete and relaxation of the prestressing steel) were about 40% of the initial prestressing force.

The aim of the research was to gain insight into the time-dependent behaviour of BSI in both the loaded and non-loaded state. Comparison between theory and experiments should indicate whether design rules describe this behaviour sufficiently accurate.

2. Materials and methods

General

The BSI mixture contained Portland cement and 3% (by volume) steel fibres. Maximum aggregate size was 7 mm. Use was made of 1074 kg/m^3 cement, 163 kg/m^3 silica fume and 197 l/m^3 water. This resulted in a water-binder ratio of 0.16 [m/m]. Two different ages at loading were foreseen, namely 30 h and 91 d after casting. The first was regarded as being representative for the behaviour under loading by releasing the pretensioned prestressing strands; the second for the behaviour under normal design loading conditions, e.g. traffic loads.

Special attention was given to the components of shrinkage, namely drying and autogenous shrinkage. Therefore, some of the specimens were sealed, thus preventing exchange of moisture with the environment.

Nine prisms ($100 \cdot 100 \cdot 400$ mm^3) and nine cubes (rib length 150 mm) were cast per testing age. Directly after casting, the moulds were covered with a plastic foil. The specimens were demoulded after 24 h and stored in a fog room (20$\pm$2ºC; 99% RH). As the planned testing age was reached, the following actions were taken:

- testing in compression up to failure of three prisms and three cubes, including the determination of the E-modulus of the prisms;
- tensile splitting testing of two cubes;
- two unsealed prisms for one year subjected to longterm loading at a level of 50% of the short-term prism compressive strength in a climate room at 20$\pm$2ºC and 50% RH;
- two non-sealed and two sealed non-loaded prisms and four non-sealed cubes stored for one year in a climate room at 20$\pm$2ºC and 50% RH;
- at an age of one year, compressive and tensile splitting strength of two cubes was determined.

The deformations of the prisms were measured over 200 mm measuring length by means of LVDT's on two opposite sides, being the side faces during casting. Figure 1 presents sealed and not sealed not loaded prisms as well as a not sealed prism, loaded at an age of 30 h.

Fig. 1 Shrinkage testing of sealed and not sealed specimens and creep testing equipment for high loads.

3. Materials and methods

3.1. Short-term loading

The short-term strengths and E-moduli of the cubes and prisms tested at an age of 30 h and 91 d are presented in table 1 and 2, respectively. The mean 30 h prism compressive strength was 53.3 MPa, which implied that the two prisms to be subjected to a creep test were loaded to a stress of 26.65 MPa (compressive force 266.5 kN). Mean strength was 166.2 MPa for the prisms tested at an age of 91 d. The creep load was 831 kN, corresponding to a stress of 83.1 MPa.

Table 1 Cube and prism compressive strength, cube tensile splitting strength and E-modulus at an age of 30 h.

Type	Strength [MPa]	E-modulus [GPa]
cube		
compression	52.0 – 65.8 – 66.2	
splitting	12.2 – 14.4	
prism		
compression	52.5 – 55.4 – 52.0	34.4 – 31.8 – 31.5

Table 2 Cube and prism compressive strength, cube tensile splitting strength and E-modulus at an age of 91 d.

Type	Strength [MPa]	E-modulus [GPa]
cube		
compression	228.0 – 236.0 – 237.6	
splitting	31.7 – 31.3	
prism		
compression	168.7 – 159.1 – 170.9	69.9 – 70.0 – 70.5

3.2. Strength at an age of one year

Cube compressive and tensile splitting strength are presented in table 3. It should be noted that the cubes related to the 30 h tests were exposed to 20±2ºC and 50% RH directly after being demoulded. The cubes related to the 91 d tests were, until they reached that age, first stored in a fog room at 20ºC and 99% RH.

Table 3 Compressive and tensile splitting strength at an age of one year for cubes related to the tests started at an age of 30 hrs and 91 days.

Type	Strength after 1 year (30 h tests) [MPa]	Strength after 1 year (91 d tests) [MPa]
cube		
compression	216.3 – 222.6	257.4 – 247.8
splitting	29.9 – 27.4	32.1 – 30.0

3.3. Shrinkage and creep

Figure 2 presents the results of the shrinkage measurements for both the sealed and not sealed prisms. The creep results are shown in Figure 3. These results refer to specimens that were not sealed during their exposure to external loading.

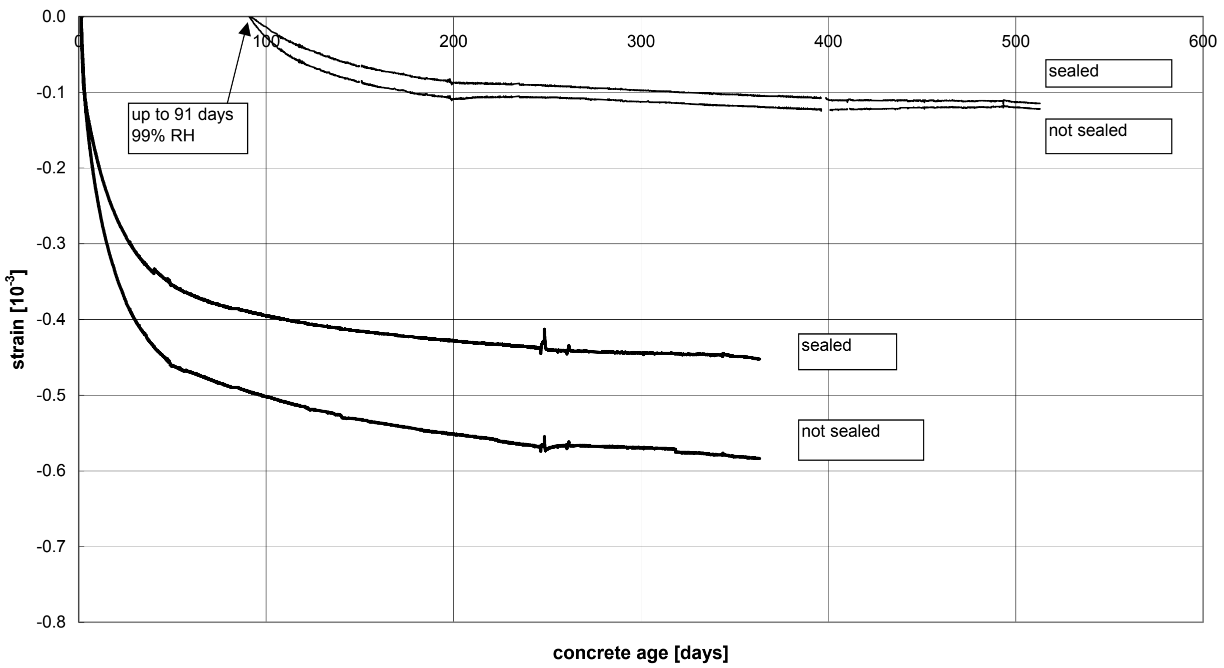

Fig. 2 Shrinkage of sealed and not sealed specimens

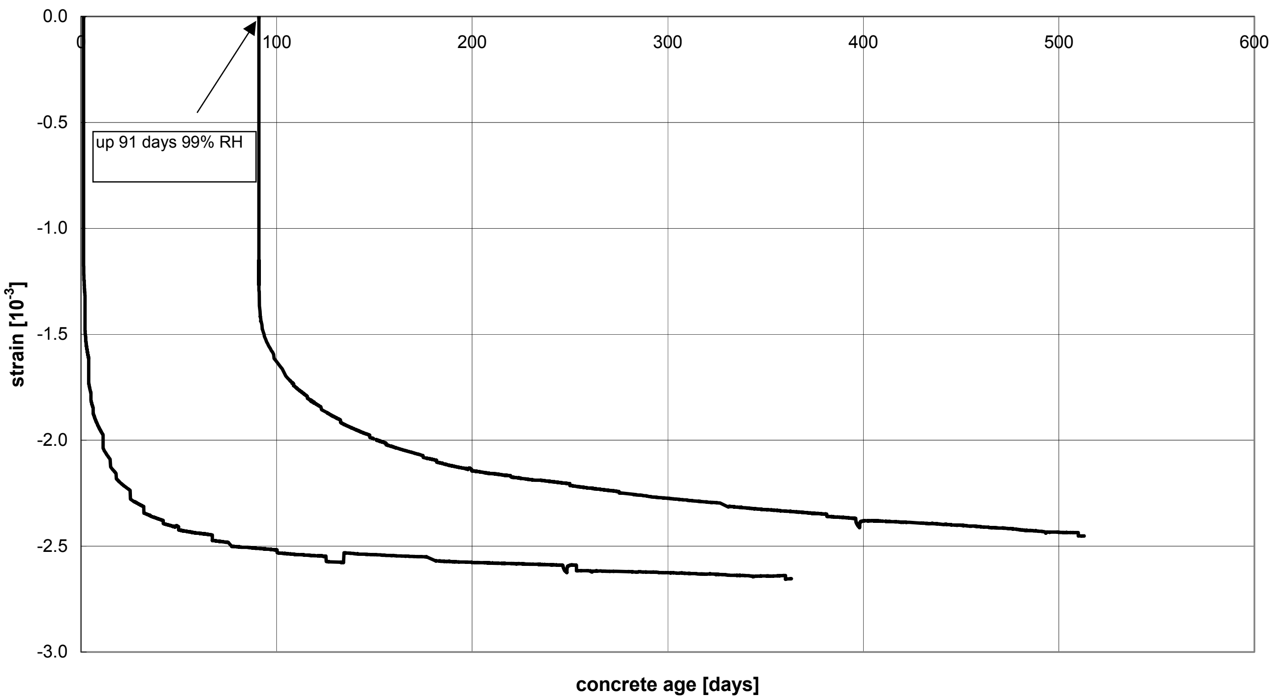

Fig.3 Creep of not sealed specimens loaded at an age of 30 h and 91 d

4. Discussion and Conclusions

4.1. Shrinkage

Autogenous shrinkage is best represented by the not-loaded prisms demoulded and sealed after 30 h. These specimens were from that moment on not subjected to moisture exchange with the environment. From figure 2 it can be seen that autogenous shrinkage of these sealed specimens was $-0.450 \cdot 10^{-3}$ in the time interval 30 h – 350 d. It was already $-0.390 \cdot 10^{-3}$ at 91 d which is almost 90% of total autogenous shrinkage after one year. It should, however, be noted that measurements started after 30 h. Autogenous shrinkage then has already started to develop [3].

When registrating started at an age of 91 d, hardly any drying shrinkage (difference in shrinkage of the not sealed and sealed specimens presented in figure 2) was observed. Then also, as stated before, the major part of autogenous shrinkage has developed. Total shrinkage of these specimens was only $-0.11 \cdot 10^{-3}$ after one year.

If, however, shrinkage measurements start directly after demoulding at an age of 30 h, autogenous shrinkage is dominant over drying shrinkage (see both curves in figure 2 referring to the 30 h measurements). Total shrinkage of the not sealed specimens is about $-0.6.10^{-3}$ after one year of which about 80% is autogenous shrinkage. The design rules underestimate the deformation of the not sealed specimens by 27%.

4.2. Creep

Directly after the load was applied, the strain was $-0.97 \cdot 10^{-3}$ and $-1.30 \cdot 10^{-3}$ for the specimen with an age of 30 h and 91 d, respectively. After 362 and 422 d of registration, the deformation had increased to $-2.65 \cdot 10^{-3}$ and $-2.45 \cdot 10^{-3}$ for both types of specimens, respectively. After taking into account the contribution of shrinkage, estimated on the basis of the deformations measured on the not loaded not sealed prisms, the corresponding creep factor was 1.13 and 0.79, respectively.

The curves from figure 3 tend to develop towards the same end value for total deformation. It should be noted that the increase of concrete strength in time results in a reduction of the load level relative to the compressive strength. This effect is more pronounced for specimens loaded at an early age.

4.3. Total deformation

The experimental results were compared with calculations using recommendations especially designed for very high strength concretes [4]. It appeared that for the specimens loaded at an age of 91 d, the calculated elastic plus creep deformation was only slightly higher (7%) than experimentally observed. No calculations were done for the specimens loaded after 30 h since the design rules have an age of 2.65 d as minimum value.

4.4. Conclusions

The results from design rules are in close agreement with the measurements for specimens loaded at an age of 91 d. For the specimens loaded after 30 h, the interim rules don't apply since a minimum age of 2.65 d is assumed. Further research is required to extend the application of these rules, especially the behaviour at early ages which is an important aspect in the production cycle of the precast concrete industry. With regard to shrinkage, the results presented indicate that shrinkage is underestimated. The reason for this might be the dominancy of autogenous shrinkage, a material property of which recording should start as soon as possible after casting.

Acknowledgement

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5. References

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