SCC DELAYED EFFECTS DEVELOPMENT WITHIN A NEW TYPE OF STEEL-VHPC PREBENDED BEAM

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Abstract
An extensive experimental research has been carried out to extend the technique of prebended composite beams to VHPC. The main advantage of using VHPC instead of C55 concrete is to decrease the prestressing losses of the system thanks to a significant decrease of the creep deformations. As one-step was the casting of two 13m-span beams, it was necessary to use a SCC. Since a risk of cracking at early age due to the transversally restrained shrinkage in the beam was probable and due to the influence of partly restrained longitudinal shrinkage on the composite behavior, the autogenous shrinkage development was examined both under standard isothermal and realistic temperature (same as the beam) conditions. Numerous complementary measurements such as mechanical characterization, creep and shrinkage tests in standard (20°C, 50% RH) and variable ambient conditions were performed. The effects of a realistic temperature history on the VHPC autogenous shrinkage are quantified. With the efforts of mix-design optimization, it could be demonstrated that the creep deformations of this VHPC were reduced by about a factor 2 in comparison with currently used C55 concrete, which made the use of prebending significantly more efficient.

1. INTRODUCTION
The aim of the research program that has been carried out at LCPC in the framework of the French National Project MIKTI was to extend the system of the Preflex beam [1] to Very High Performance Concrete (VHPC). In comparison to the present realizations coming from the Belgian industry, the main advantage of using VHPC with silica fume instead of C55 concrete is to decrease the prestressing losses of the system thanks to a significant decrease of the creep deformations, and save material and dead weight. It was searched to optimize the Preflex system, taking into account the maximum material capabilities available (high quality steel and VHPC) [2]. As one research step was the casting of concrete around the bottom flange of two 13m-span steel girders, it was necessary to use a SCC due to the presence of passive reinforcements, ribbed stirrups and steel square ribs along the beams. In addition to the rheological requirements [3], the VHPC had to develop a very high compressive strength
at early age to remove the prebending loads applied on the steel girders only 48 hours after casting. Since a risk of cracking at early age due to the transversally restrained shrinkage in the beam was probable and due to the influence of partly restrained longitudinal shrinkage on the composite behavior, the autogenous shrinkage development was examined both under standard isothermal and realistic temperature (same as the beam) conditions. Numerous complementary measurements such as mechanical characterization, creep and shrinkage tests in standard and variable ambient conditions were performed, so that a correct analysis of the structural behaviour of the beams could be done taking advantage of low delayed deformations of VHPC. Moreover, stress [4] and strain measurements in steel and concrete were recorded on the two beams in order to access directly to the creep evolution of the structure.

2. AUTOGENOUS SHRINKAGE

A new test rig was designed to measure the autogenous shrinkage of concrete [5]. It consists of a stainless steel base supporting three columns located at 120° around the rig (see Fig.1) made of invar alloy. An upper platen follows the movements of the top end of the specimen. The concrete is cast inside a corrugated PVC mould of about 125 mm in diameter and 250 mm in length. The ends of the mould are fixed to the base and to the upper platen with stainless steel hose clamps. After casting, a cover, equipped with an O-ring, is placed with bolts on top of the upper platen so that the specimen is completely sealed. Then, the test rig is placed in a bath. A displacement transducer, fixed on a support above the upper platen and fixed to the columns, measures the vertical displacement of the top end of the specimen. A thermocouple measures the temperature in the middle of the specimen. Two other temperature transducers measure the temperature of the water bath and the ambient temperature.

![Diagram of the test rig](image)

Figure 1: Diagram of the test rig. The base length (250 mm) gives the scale.
The mix proportions of the SCC are: 920 kg/m³ calcareous gravel (4 to 12.5 mm), 379 kg/m³ calcareous sand (0 to 4 mm), 369 kg/m³ silico-calcareous sand (0 to 4 mm), 500 kg/m³ CEMI 52.5N cement, 50 kg/m³ silica fume, 10 kg/m³ polyphosphonate superplasticizer and 165 l/m³ added water. The average slump flow is 70 cm and the average compressive strength at 28 days obtained on cylinders 32 cm in height, 16 cm in dia. stored at 20°C and 50% RH is 106 MPa (design characteristic strength would be 90 MPa).

For the isothermal autogenous shrinkage test, the temperature of the bath was set to a constant value 20 ± 0.05 °C while the ambient temperature was fluctuating. The test with a realistic temperature history was also carried out on two specimens. For this test, both the ambient and the bath temperatures were recorded. The temperature in the bath followed the set points (from 22°C up to 36°C, 20 hours after casting and then down to 22°C, 44 hours after casting) but the temperature evolution in the core of the specimen was smooth due to the specimen thermal inertia. It was not possible to follow the evolution of the coefficient of linear thermal expansion during the realistic temperature history.

The figure 3 shows the evolution of the autogenous shrinkage with equivalent age in isothermal and realistic conditions for an Ea/R ratio value of 3980 K and for an equivalent τ₀ time of 14 hours corresponding to the time when the temperature curve starts to increase quite linearly. The τ₀ represents the zero-time corresponding to the test in isothermal conditions at 20°C and expressed in real age whereas τ₀ represents the zero-time corresponding to the test in realistic conditions expressed in real age. The scatter of the four curves is limited to only 15µm/m. The magnitude and the kinetics of the autogenous shrinkage strain in both temperature histories are very similar. For this temperature evolution and for this VHPC, these results confirm that a correct estimation of the autogenous shrinkage can be derived from an isothermal test or under a realistic temperature history using the Equivalent Age Method, provided the τ₀ time is chosen at the beginning of the linear part of the temperature curve.

![Figure 3: Autogenous shrinkage evolution with equivalent age in isothermal and realistic conditions with an equivalent τ₀ time of 14 h and a ratio Ea/R of 3980K.](image-url)
3. CREEP AND SHRINKAGE DEFORMATIONS

In order to take full advantage of using a VHPC, shrinkage and creep tests as well as a complete mechanical characterization have been carried out in standard and variable ambient conditions (see Fig.4 and 5), so that a correct analysis of the structural long-term behaviour of the beams could be done. The conditions of these tests are in direct link with the phases of construction and the history of loading of the two beams. Firstly, the two beams were exposed to variable ambient conditions (average temperature: 20 °C and average relative humidity: 40% with fluctuations from 16 to 25 °C and from 30 to 70% RH) at one day of concrete age and the prebending forces applied on the beams before the casting phase were released at two days of concrete age, so that the concrete was prestressed at a theoretical level of 23 MPa in compression. After that, permanent loads (4 t made of lead masses, representing the load of the upper concrete deck, superstructures and ballast) were applied on the beams at 56 days. The deflection of the beams was monitored for more than 8 months as well as numerous complementary strain and stress [4] measurements (ex: strain gauges bonded on concrete and steel surfaces). Therefore, it could be possible to validate at the structural scale the creep and shrinkage results obtained on cylinders. The Table 1 summarizes the creep and shrinkage tests carried out on the VHPC of this project.

Table 1. Creep and shrinkage tests description on VHPC

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Ages of concrete (in days) at the beginning and the end of the test</th>
<th>Conditions of storage</th>
<th>Dimensions (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autogenous shrinkage</td>
<td>0 to 20</td>
<td>Isothermal (20°C)</td>
<td>Dia. 12.5 - h 25</td>
</tr>
<tr>
<td></td>
<td>0 to 40</td>
<td>Realistic temperature</td>
<td>Dia. 12.5 - h 25</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>1 to 330</td>
<td>Sealed – 20°C</td>
<td>Dia. 16 - h 100</td>
</tr>
<tr>
<td></td>
<td>1 to 330</td>
<td>Controlled drying 50%</td>
<td>Dia. 16 - h 100</td>
</tr>
<tr>
<td></td>
<td>1 to 270</td>
<td>Variable ambient cond.</td>
<td>Dia. 16 - h 100</td>
</tr>
<tr>
<td>Creep</td>
<td>2 to 330</td>
<td>Sealed – 20°C</td>
<td>Dia. 16 - h 100</td>
</tr>
<tr>
<td></td>
<td>2 to 330</td>
<td>Controlled drying 50%</td>
<td>Dia. 16 - h 100</td>
</tr>
<tr>
<td></td>
<td>2 to 270</td>
<td>Variable ambient cond.</td>
<td>Dia. 16 - h 100</td>
</tr>
<tr>
<td></td>
<td>2 to 56 and then total unloading</td>
<td>Variable ambient cond.</td>
<td>Dia. 16 - h 100</td>
</tr>
<tr>
<td></td>
<td>28 to 330</td>
<td>Sealed – 20°C</td>
<td>Dia. 16 - h 100</td>
</tr>
<tr>
<td></td>
<td>28 to 330</td>
<td>Controlled drying 50%</td>
<td>Dia. 16 - h 100</td>
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<tr>
<td></td>
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<td>Variable ambient cond.</td>
<td>Dia. 16 - h 100</td>
</tr>
</tbody>
</table>

In this paper, we focus on the comparison between the experimental creep and shrinkage results obtained for the HPC currently used in the Preflex beams in Belgium [1] and for the VHPC used in this project. The HPC mix proportions are 680 kg/m³ of calcareous sand (0 to 5mm), 1200 kg/m³ of calcareous gravel (7 to 14mm), 400 kg/m³ of cement CEMI 52.5 RLA, 8 kg/m³ of water reducing admixture and 132 l/m³ of added water. The HPC average compressive strength at 28 days obtained on cylinders 30 cm in height; 15 cm in dia. is 64 MPa (design characteristic strength of 55 MPa). The VHPC total shrinkage deformation about 100 days after exposure to drying (20 °C, 50 % RH) at one day of concrete age is lower than the one of HPC (see Fig.6). The magnitude of the basic creep function (see Fig.7) as well as the total creep function (20 °C; 50 % RH) (see Fig.8) 100 days after loading is significantly lower for the VHPC than the corresponding HPC values.
Figure 4: Shrinkage tests.

Figure 5: Creep tests in ambient conditions.

Figure 6: Total shrinkage of HPC (C55) and VHPC (C90) cylindrical samples (dia. 15 cm; height 60 cm for HPC and 16 cm; 100 cm for VHPC) exposed to drying (50% RH) at 1 day.

Figure 7: Evolution of the basic creep function of HPC (C55) and VHPC (C90) cylindrical samples (dia. 15 cm; height 60 cm for HPC and 16 cm; 100 cm for VHPC) loaded at 2 days.
4. CONCLUSIONS

The autogenous shrinkage deformation of a SCC has been investigated under isothermal conditions and under realistic temperature conditions. The magnitude of the autogenous shrinkage at 28 days is lower than 200 µm/m. Since a significant part (more than 50%) of the autogenous shrinkage occurs during the first 48 hours after casting, a new test rig has been used to start the measurements just after casting. Results have shown that for this VHPC, a very small scatter is obtained between the different autogenous shrinkage curves (isothermal and realistic) when the \( t_0 \) time is chosen at the beginning of the linear part of the temperature curve. Due to the efforts of mix-design optimization, it could be demonstrated also that the creep deformations of this VHPC were reduced by about a factor 2 by comparison with currently used C55 concrete, which made the use of prebending significantly more efficient.

REFERENCES