Construction and Building Materials 173 (2018) 101–110

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental and finite element analysis of creep behaviour of steel fibre reinforced high strength concrete beams

Farid Bouziadi [a,b], Bensaid Boulekbache [a,*], Abdelkader Haddi [b], Chafika Djelal [b]

[a] Hassiba Benbouali University of Chlef, Laboratory of Materials Sciences and Environment, Chlef, Algeria
[b] Univ. Artois, EA 4515, Laboratoire de Génie Civil et géo-Environnement, Béthune, France

HIGHLIGHTS

- Experimental long-term creep behaviour of FRC beams under flexure is investigated.
- Steel fibres have an influence on both tensile and compressive total creep.
- The magnitude of tensile creep is more important than the compressive one.
- A good agreement between the experimental and numerical results was found.

ARTICLE INFO

Article history:
Received 22 June 2017
Received in revised form 31 December 2017
Accepted 2 April 2018

Keywords:
Concrete
Beam
Creep
Steel fibre
Numerical analyses
Sustained load in bending
Time hardening model

ABSTRACT

The present study is focused on experimental investigations and numerical analyses of compressive and tensile total creep at long-term of high-strength concrete (HSC) beams. Reinforced concrete (RC) beams with and without steel fibres were investigated for their long-term creep behaviour. These beams are under sustained uniformly distributed load (SUDL) in bending containing steel fibres (SF) with two aspect ratios (55 and 80) and two steel fibre dosages (0.5% and 1%). The objective of this work is to evaluate the influence of steel fibres, their dosage and their aspect ratio on compressive and tensile total creep. Experimental results show that the long-term total creep is influenced by the volume fractions of steel fibres. Moreover, steel fibres decrease the tensile total creep more than the compressive one. A non-linear finite element method (FEM) is performed to simulate the long-term total creep strain rate included thanks to the time hardening model called generalized Garofalo creep which is based on Bailey-Norton law called power law creep. It was found a good agreement between the experimental and numerical results.

1. Introduction

The high strength concrete is widely used in the civil engineering field, particularly in the construction of bridges and skyscrapers. These concretes are characterized by a water/cement ratio less than 0.4, the combined use of superplasticizers and mineral additives as silica fume, which increase the compressive strength at the same time to improve the workability and the durability [1–7]. The mastery of these materials in the future requires a good knowledge of their mechanical behaviours as creep phenomenon in prestressed concrete structures [8]. The first person who noticed this phenomenon was Eugène Freyssinet during the construction of the Veurdre bridge (Allier) in 1911 [9]. The total creep of concrete refers to the deformation of hardened concrete caused by a long-lasting constant load applied on it [10,11].

Several studies have focused on creep under bending in the literature. Tensile, compressive and flexure basic creep tests were carried out by Ranaivomanana et al. [12], where 100 × 100 × 500 mm beams are tested 28 days after manufacture. Tests have shown that the extreme tension fibre stress is equal to 50% of the direct concrete tensile strength.

Similar tests have been performed by Tailhan et al. [13] on specimens with dimensions of 150 × 200 × 700 mm out 64 days after manufacture. The specimens subjected to bending are loaded at 70% of its maximum moment strength. Al Chami et al. [14] have studied the creep behaviour of reinforced concrete beams with dimensions 100 × 150 × 1800 mm. The applied sustained loads varied from 59% to 78% of the ultimate static capacities of the beams. For these two studies; the authors observe that the normal section remains plane during testing and deformation.

* Corresponding author.
E-mail address: b.boulekbache@univ-chlef.dz (B. Boulekbache).

https://doi.org/10.1016/j.conbuildmat.2018.04.013
0950-0618/

Creep is one of the major problems identified in sustainability of HSC, as it causes micro-cracks and macro-cracks especially at an early age and stress redistribution in long-term [15,16]. Even such cracks are developed in the long-term as a result of longer drying time for the loading age [8,12,17–20].

Two methods are proposed to mitigate the creep. The first one using fibres is effective in improving the stabilization of HSC volume and the second one using an admixture (shrinkage-reducing-admixture) that reduces the creep by creating an expansion [21,22].

In addition, the use of fibres as a secondary strengthening mechanism can also help reducing stresses developed during drying. The steel fibres tend to provide the required tensile strength for the concrete to control creep cracking. In addition, the steel fibres reduce the crack widths of concrete in the long-term [23–25].

The finite elements method (FEM) calculations need a stiffness matrix, an applied load and boundary conditions that will influence the response of the model [26,27]. In the case of reinforced concrete structures, there are three major problems: first the behaviour of the bond between the concrete and the rebar, second the modelling of existing cracks and third the heterogeneity of concrete [28,29].

A few works has been done regarding the long-term creep responses of reinforced concrete beams under bending. The aim of this work is to study the effect of fibre properties on the long-term compressive and tensile total creep of HSC beams under bending and the prediction of the long-term creep behaviour of the beams using experimental and numerical approaches.

2. Characterisation of concrete

2.1. Used materials

The cement used is CEM II/A type of 42.5class, 3.1density and 3298 cm^2/g specific surface. Silica fume is used replacing cement (8% mass of cement), according to EN 13263-1, of 2.4 density and 220000 cm^2/g specific surface. The chemical and mineralogical characteristics of the cement and silica fume are shown in Table 1. The superplasticizer used to ensure good workability is a polycarboxylate-based acrylic copolymer in accordance with the EN 934-2. The fine aggregate used is a rolled sand of 2.60 specific gravity and 2.67 fineness modulus. The coarse aggregate used is a crushed gravel of 2.70 specific gravity.

Two steel fibre types have been used, the hooked-end of the aspect ratios 55 and 80. Table 2 shows the characteristics of the steel fibres utilized. Dosages of 0.5 and 1% were used for the steel fibres. The steel fibres are available in bundles, which were fibrillated with water-soluble glue to ensure immediate dispersal in the concrete during mixing.

Table 1
Ordinary Portland cement and silica fume properties.

Chemical compositions	CEM II/A	Silica fume
SiO_2	20.58	93
Al_2O_3	4.90	0.47
Fe_2O_3	4.70	0.91
CaO	62.8	0.8
SO_3	2.28	0.35
MgO	0.53	0.93
K_2O	0.42	1.20
Na_2O	0.12	0.40
CaO free	2.17	0.8
Mineralogical compositions		
C_3S	57.79	–
C_2S	20.47	–
C_3A	7.20	–
C_4AF	11.49	–

Table 2
Characteristics of steel fibres.

Characteristics	Steel fibre	
Length L_f (mm)	50	30
Diameter d_f (mm)	0.62	0.55
Aspect ratio (L_f/d_f)	80	55
Density (kg/m^{-3})	7800	7800
Tensile strength (MPa)	1100	1100
Elastic modulus (GPa)	200	200
Poisson's ratio	0.3	0.3
Failure strain (%)	3.5	3.5
Number of fibres per kg	8168	16750

2.2. Mechanical properties of concrete

The mixing is performed in an inclined axis mixer. The water/binder selected ratio is 0.4. The following steps are conducted to mix the concrete ingredients [23]:

1. Mix dry components (cement, silica fume, fine aggregate and coarse aggregate) for 2 min.
2. Required superplasticizer is poured into the total water outside the mixer and then the solution is gradually added to the mix for 2 min.
3. The steel fibres are added manually by slowly sprinkling them into the mixer, to avoid balling and to produce a concrete with uniform material consistency and good workability, then the fresh concrete with steel fibres is mixed for 1 min.

Table 3 provides the concrete mix portions used in the testing program in details.

For each mix, three 100 mm cubes were tested to measure the compressive strength according to EN 12390-4 and three prismatic specimens 70 × 70 × 280 mm were also prepared to determine the flexural tensile strength in accordance with EN 12390-5. For each test, fifteen specimens are tested.

To prevent evaporation at a very early age, the specimens were covered with wet burlap. After 24 h, test specimens are removed from the mould and stored at 20 ± 2 °C temperature and 50% ±5 humidity. The mechanical properties at 28 days for all concretes are presented in Table 4.

3. Long-term creep tests

3.1. Reinforced concrete beams

An experimental program is carried out to evaluate the long-term creep behaviour of five designed reinforced concrete beams of 150 × 150 × 2800 mm dimensions. First, the preparation of the beams involved cutting, fabricating and installing the steel reinforcement according to the same steel reinforcement cage. Then, the beams are reinforced with three longitudinal bars of 10 mm diameter at the bottom and top zones, and stirrups of 6 mm diameter and 100 mm spacing (Fig. 1). The mechanical properties of the steel reinforcement used are fixed according to experimental tests as follows: 200 GPa steel modulus of elasticity, 0.3 Poisson's ratio and 215 MPa tensile strength.

Reinforcement will be accurately placed and adequately supported before concrete is placed, and be secured against displacement. The spacing between longitudinal bars is equal to 30 mm according to ASTM specification requirements. The beams are cast with different concrete batches (Table 3), removed from moulds 24 h after casting and then stored at 20 ± 2 °C temperature and