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The effects of fibres on the shrinkage of high-strength concrete under various curing temperatures

Farid Bouziadi, Bensaid Boulekbache *, Mostefa Hamrat

Laboratory of Materials Sciences and Environment, University Hassiba Benbouali of Chlef, Chlef, Algeria

HIGHLIGHTS

- The addition of the fibres improves the mechanical properties of high strength concrete.
- The addition of the fibres in the high-strength concrete improves significantly the volume stability.
- The evolution of the total shrinkage is influenced by the dosage and aspect ratio of steel fibres.
- Rising the curing temperature increases the magnitude and rate of the total shrinkage.

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ABSTRACT

In this paper, an experimental investigation is carried out to study the influence of the curing temperature, types of fibres, their dosages and their aspect ratios on the total shrinkage and mechanical properties of the high-strength concrete (HSC) containing steel fibres (SF) considering two aspect ratios (55, 80), polypropylene fibres (PF) and hybrid fibres (HF), exposed to isothermal curing temperatures 20 °C, 35 °C and 50 °C. Two dosages were used, 0.5% and 1% for the steel fibres, 0.1% and 0.2% for polypropylene fibres and hybridization of 0.5% for SF and 0.1% for PF. The obtained results show that the increase of the dosage of fibres reduces the total shrinkage. Hybridizing of fibres induces considerable decrease of the total shrinkage compared to single fibre types. The results of the total shrinkage show that the polypropylene fibres are more efficient than the steel fibres. Furthermore, rising the curing temperature amplifies significantly the rate and the magnitude of the total shrinkage. On the other hand, the addition of fibres improves considerably the flexural tensile strength.

1. Introduction

The use of high strength concretes (HSC) is widely used in the civil engineering field, particularly in the construction of bridges and skyscrapers. These concretes are characterized by a W/C ratio less than 0.4, the combined use of superplasticizers and mineral additives (silica fume, pozzolana, ground blast-furnace slag…) which increase the compressive strength at the same time to improve the workability and the durability [1–7].

The total shrinkage is defined as the shrinkage measured on a test specimen in the exchange with the external environment [8]. The shrinkage starts from the beginning of the setting time of cement. It is a phenomenon known since early 20th century, and saw its practical importance [5,8–10]. With a ratio of W/C less than 0.4 in the HSC, the presence of silica fume and the area ratio of the volume of the specimen used are significant and cause a reduction in the internal humidity of the concrete, which causes tripping of shrinkage [7,9,11,12]. The shrinkage is one of the major problems identified in a long-term sustainability of HSC, as it causes micro-cracks and macro-cracks especially at early age [5,13].

The rise of the curing temperature of the concrete causes the acceleration of hydration and the non-uniform distribution of the hydration products. The hydrates formed do not have time to arrange suitably; causing a high porosity, increasing shrinkage at early age on one hand and decreasing shrinkage at long-term on the other hand: this behaviour is called “Crossover” as stated in [14]. Porosity leads to an increase in the magnitude and rate of shrinkage [5,15]. However, in previous studies it has been shown that the total shrinkage magnitude of concrete is influenced by the curing temperature history. It seems that for a given degree of hydration, concretes with different temperature histories do not develop the same total shrinkage [16,17].

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* Corresponding author.
E-mail address: bboulekbache@yahoo.fr (B. Boulekbache).

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Lura et al. have studied the effect of curing temperature on autogenous shrinkage of high performance concretes. Their results show that the curing temperature has an important effect on the development of shrinkage [18]. For Portland cement, the shrinkage is equivalent to 10 μm/m at 40 °C after six days, but it remains lower than that when measured at 30 °C. The same observation can be made for the cement of slag whose shrinkage at 10, 20 and 40 °C are similar to those at 6 days but still lower than those measured at 30 °C.

Mounanga et al. have studied the volume shrinkage at various isothermal curing temperatures (10–50 °C). They note that shrinkage increases with temperature to a certain limit. Indeed, at a temperature of 50 °C, the shrinkage is lower than that measured at 40 °C (Crossover effect), this phenomenon is explained by structural and physical and chemical change of hydrates which are different from those obtained in the cases of more low temperatures [19]. Other researchers [20,21], have found that autogenous shrinkage increases proportionally with temperature.

Several methods are proposed to mitigate the shrinkage. The traditional method of wet concrete by spraying proves its ineffectiveness in reducing the shrinkage of the HSC of low permeability. The second method which uses fibres is effective in improving the stabilization of volume (shrinkage or expansion) of HSC and the third method which uses an admixture (shrinkage-reducing-admixture); and reduces the shrinkage by creating an expansion [22,23]. In addition, the use of fibres as a secondary strengthening mechanism can also help to reduce the stresses developed during drying. The steel fibres tend to provide the tensile strength required for the concrete to control shrinkage cracking. The addition of synthetic fibres such as polypropylene is stated to reduce the width of the concrete cracks at long-term [12,24]. Research has shown that there is linear relationship between the cracks and shrinkage. The percentage of shrinkage reduction and cracking differs depending on the characteristics of the employed fibres, climatic conditions and the material used.

Table 1
Properties of Ordinary Portland cement and silica fume.

	CEM II/A	Silica fume
Chemical compositions		
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
Free lime	2.17	0.8
Mineralogical compositions		
C_3S	57.79	–
C_2S	20.47	–
C_3A	7.20	–
C_4AF	11.49	–

The most available fibres are steel fibres, organic fibres (polypropylene, polymer, nylon, palm and straw) and inorganic fibres (glass, carbon). The most utilized are organic fibres such as synthetic fibres (lower cost), because they increase the hardness and ductility, reduce shrinkage and resist to micro-cracks [25]. The incorporation of hybrid fibres in the high strength concrete improves these characteristics at early age as well as for the case of long-term. Research shows that hybrid fibre in percentage lower than 0.2% for polypropylene fibres and 0.5% for steel fibres are effective than are single fibres [26–28].

Research on the influence of curing temperature and fibres on the total shrinkage of HSC are limited and the tests are carried out only on mortars or cement pastes. Current influence of aspect ratio and geometry of the fibres on total shrinkage remains unknown.

The aim of this work is the study of the effect of fibres properties on the workability, the mechanical characteristics and the total shrinkage of the fibre reinforced high-strength concrete in three curing temperatures.

2. Experimental program

2.1. Materials used

The cement used is of type CEM II/A of class 42.5, of density 3.1 and of specific surface 3298 cm^2/g. The Silica fume "CONDENSIL S95 DS" used by replacing cement (8% mass of cement), according to EN 13263-1, of density 2.4 and a specific surface 220,000 cm^2/g. The chemical and mineralogical characteristics of the cement and silica fume are shown in Table 1. The Superplasticizer (SP) used to ensure good workability, is a polycarboxylate-based acrylic copolymer in accordance with the EN 934-2. The fine aggregate used is rolled sand of specific gravity 2.60, of fineness modulus 2.67. The coarse aggregate used is a crushed gravel of specific gravity 2.70.

Two types of fibres have been used, the hooked-end steel fibres of the aspect ratios 55 and 80 and polypropylene fibres. Table 2 shows the characteristics of the utilized fibres. Two dosages were used, 0.5% and 1% for the steel fibres, 0.1% and 0.2% for polypropylene fibres and hybridization of 0.5% for SF and 0.1% for PF. The steel fibres are available in bundles, which were fibrillated with water-soluble glue to ensure immediate dispersal in the concrete during mixing.

2.2. Mix proportioning and mixing method

The mixing was performed in an inclined axis mixer with a capacity of 50 l. The water/binder ratio selected to formulate concrete is 0.4. The following steps were conducted to mix the concrete ingredients:

(1) Mix dry components (cement, silica fume, fine aggregate and coarse aggregate) for 2 min.
(2) The required superplasticizer was poured into the total water outside of the mixer and then the solution was added to the mix gradually for 2 min.

Table 2
Characteristics of the different fibres used.

Characteristics	Steel fibre		Polypropylene fibre
Length L_f (mm)	50	30	12
Diameter d_f (mm)	0.62	0.55	0.034
Aspect ratio (L_f/d_f)	80	55	353
Density	7.8	7.8	0.91
Tensile strength (MPa)	1100	1100	450
Elastic modulus (GPa)	200	200	5
Failure strain (‰)	3.5	3.5	18
Number of fibres per kg	8168	16,750	11.3 million
Morphology