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Original Research Article

Influence of steel fibres addition on mechanical and selected rheological properties of steel fibre high-strength reinforced concrete

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ABSTRACT

The paper discusses the mechanical and selected rheological properties of steel fibre high-strength reinforced concrete (SFHSRC). The creep deformation in compression, total shrinkage strain, compression strength, longitudinal modulus of elasticity and tensile strength of steel fibre high-strength reinforced concrete have been presented in the research. Steel reinforcements with a length of 13 mm and a diameter of 0.2 mm have been used. The content of fibres in 1 m^3 of the concrete mix was 0, 78.5, 157 and 235.5 kg. Four batches of composite materials with different mixture compositions have been tested. The average compressive strength ranged from 128.2 to 147.7 MPa. The functional relations describing the increase of shrinkage and creep deformation in time have been discussed. The summary contains conclusions related to the rheological deformation of steel fibre high-strength reinforced concrete and the effects of steel fibre content on the mechanical properties of such composite materials.

1. Introduction

New engineering challenges accepted by architects and designers require finding durable materials with high parameters, which will allow for economic design of structures. An example of such material is the steel fibre high-strength reinforced concrete (SFHSC). It can be used in road and railway infrastructure, bridges, tall buildings [26], and also as an effective material for the repair of reinforced concrete elements [7,17]. The specialist literature contains numerous publications on the mechanical features of high strength fibre reinforced concrete [23]. In case of rheological features (creep and shrinkage) the researchers obtain diverging experiment results, which do not allow for providing general conclusions [5].

This paper contains the results of our tests regarding creep deformation on compression and total shrinkage strain. They serve to supplement the results presented in other specialist publications. Also, the influence of the fibre components on mechanical properties and the improvement on plastic properties of such components are presented.

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2. Literature review

The minimum value of 28-day compressive strength, which allows qualifying the given concrete to the high-strength group is different in different parts of the world. Usually this value is 60 MPa [2,21]. However, in North America this value is 41 MPa [1]. Concrete of this type is characterised by high brittleness, which increases as the compressive strength increases. Therefore, in order to improve the plastic properties of such composite materials, their composition includes reinforcement in the form of e.g. steel fibres [16,24]. The addition of steel fibres also has a positive impact on limiting the development and propagation of cracks [19].

The mechanical properties of steel fibre high-strength reinforced concretes have already been thoroughly analysed [23]. In case of rheological features (creep and shrinkage) some controversy exists – the researchers obtain diverging experiment results, which do not allow for providing general conclusions [4].

The total deformation of high-strength concretes in time (t) are a sum of instantaneous deformation ε_{el}, creep $\varepsilon_c(t)$ and shrinkage $\varepsilon_{sh}(t)$, as expressed in the formula (1):

$$\varepsilon(t) = \varepsilon_{el} + \varepsilon_c(t) + \varepsilon_{sh}(t) \quad (1)$$

The creep and shrinkage deformation of concrete are described using various rheological models, whose authors define the limitations of their applications [4]. For example CEB-FIP Model Code 1990 [10] applies only to structural concretes, whose 28 days cylinder compressive strength ranges from 12 to 80 MPa and the concrete is in the environment with an average relative humidity between 40 and 100% and a temperature between 5 and 30 °C. Another model in use is the B3 model [6], which applies only to concretes with compressive strength of 17–70 MPa, with w/c ration of 0.30–0.85, a/c ratio of 2.5–13.5 and the cement content of 160–720 kg/m^3. The model contained in the Eurocode 2 [11] describes the behaviour of high-strength concrete classes from C50/60 to C90/105 and the one contained in the Australian standard [3] includes the strength of 100 MPa. Based on experimental research Chowdhury [9] has shown that the best one among the listed rheological models is the one contained in the Australian standard. However, the listed models do not include an addition of steel fibres and therefore require further development.

The phenomenon of high-strength concrete and steel fibre high-strength reinforced concrete shrinkage may be divided into four categories: plastic, carbonation, autogenous and drying [15], however only the two former categories are included in the analysis of concrete structure deformation. Autogenous shrinkage is caused by the loss of water from the capillary pores related to the hydration of cement. The shrinkage during drying results from the diffusion of water from the hardening concrete mixture, and later – concrete, to the surrounding environment. Any flow and loss of water from capillary pores causes the change in volume and the creation of additional tensile stresses. Sakata and Shimomura [22] note that for high-strength concrete (Fig. 1b) as compared to normal strength concrete (Fig. 1a) the autogenous shrinkage is becoming more important than drying shrinkage. Their influence on the total deformation changes depending on the age of the curing concrete and the drying time.

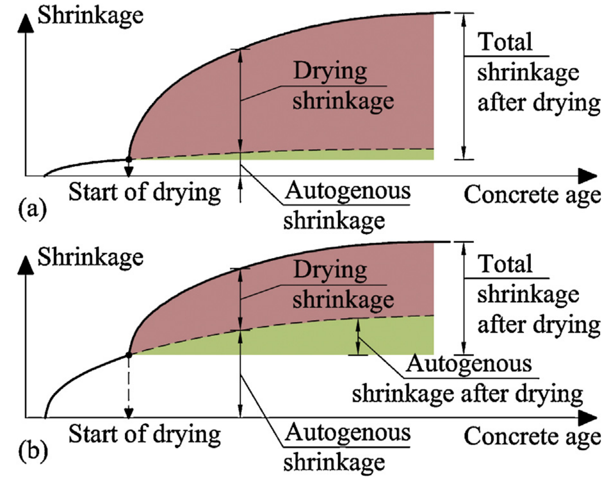

Fig. 1 – Shrinkage strain components in normal (a) and high-strength (b) concrete [15,21].

In case of fibre reinforced concrete the addition of fibres causes the increase in the number of microcracks, while the cracks in concrete without fibres appear with greater intervals between each other [12]. Experiments show a considerable decrease of shrinkage deformation in fibre reinforced concrete as compared to concrete without fibres [25]. Additionally, also the autogenous and, as a result, total shrinkage is decreased. The decrease of different types of deformation depends on the volume content of fibres and their length. The best results for autogenous and total shrinkage are obtained by using long fibres (l = 30 mm) constituting up to 1% of mixture content. The shorter fibres (l = 16 mm) constituting up to 0.75% of the mixture were more effective for drying shrinkage [5].

Less information may be found in literature about the creep deformation of fibre reinforced high-strength concrete. The analysed phenomena include e.g. values of ultimate creep strains and ultimate specific creep [20]. The collected results were used to establish the theoretical relation between the maximum/peak specific creep of fibre reinforced concrete and time and load intensity. The knowledge of creep strain is particularly important in estimating long-time deflection of fibre reinforced concrete beams [8].

The paper [12] contains information that the steel fibres have little impact on creep deformation of the composite material due to the stiffening effect of fibres and the distribution structure of the pores, which are, to a large extent, balanced. Another reference presents almost the opposite situation [13]. Namely, the addition of short fibres, which constitute 2% of the composite volume decreases the tensile creep coefficient by about 10% and the specific creep by about 42%.

In the following part of the paper results of our own experiments related to creep and total shrinkage deformation of high-strength composites with an average compression strength of 128.2–147.67 MPa and content of steel fibres from 0 to 78.5, 157 and 235.5 kg per 1 m^3 of concrete mixture.