ANALYTICAL ANALYSIS OF DRYING SHRINKAGE OF SFRC BASED ON EXPERIMENTAL RESULTS

NAKOV Darko [1], MARKOVSKI Goran [2], MARK Peter [3], ARANGJELOVSKI Toni [4]

Abstract

In order to find out the influence of different fibre dosages on the drying shrinkage of SFRC, an experiment was carried out at the Faculty of Civil Engineering–Skopje. The experiment consists of 9 specimens which were manufactured with concrete class C30/37, and according to the type of material they were divided in three series: Series A, ordinary concrete (C30/37); Series B, SFRC with 30 kg/m^3 steel fibres (C30/37 FL1.5/1.5) and Series C, SFRC with 60 kg/m^3 steel fibres (C30/37 FL2.5/2.0). According to the experimental results at the age of concrete of 400 days, the addition of steel fibres has almost no influence on the free drying shrinkage (decrease up to 2%). Based on the experimental results up to an age of 400 days, the analytical analyses of drying shrinkage were performed by the B3 model and fib Model code 2010 and were prolonged up to the age of service life of structures of 100 years. It was concluded that the fib Model Code 2010 underestimates the drying shrinkage strain for 29%, while the original B3 model for 11.5%. An improvement of the B3 model is proposed by updating the drying shrinkage strain with calculation of a scaling parameter p_6.

Keywords: Steel fibre reinforced concrete, drying shrinkage, experiment, B3 model, fib Model Code 2010

1. Introduction

Knowing the time-dependent properties of any type of concrete is very important if we want to use it as a structural material. Exact prediction of creep and shrinkage strains, as a material properties problem, is a prerequisite for determination of the time-dependent structural response.

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2. Drying shrinkage of SFRC

Shrinkage of concrete is a combination of several types of shrinkage: plastic, autogenous, drying, thermal and carbonic shrinkage.

The most important type of shrinkage for normal strength concretes is the drying shrinkage, Fig. 1, which occurs because of the movement of the water through the hardened concrete, i.e. evaporation of the internal water into the external environment. It starts after curing of concrete is finished. Drying shrinkage is smaller in high-strength concretes due to the smaller quantities of free water after hydration. The magnitude and rate of development of drying shrinkage depends on many factors: type and quantity of cement, type and quantity of any chemical admixtures and mineral additives, water content, water/cement ratio, type of aggregate, fine/course aggregate ratio, size and shape of specimen, curing regime and relative humidity and its change rate. Drying shrinkage increases when:

- the water/cement ratio increases;
- the content of the aggregate decreases;
- less stiffer aggregates are used;
- the relative humidity decreases;
- there is an increase in temperature which accelerates drying;
- fly ash or silica fume are used, and
- the exposed surface area to volume ratio increases.

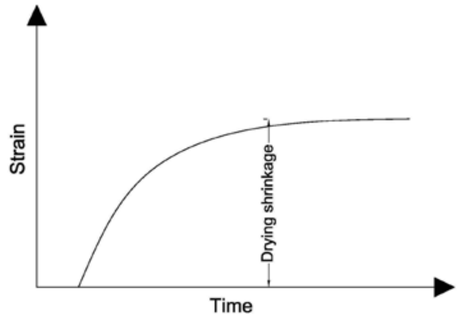

Fig. 1: Drying shrinkage

However, in the case of steel fibre reinforced concrete, the situation is slightly different. The restraint provided by aggregate particles to the shrinkage of concrete is well recognized. The mechanism of restraint is realized through idealized spherical aggregate inclusions which restrain deformations in a radial direction. The addition of fibres in concrete provides additional restraint and the mechanism of this restraint is different since the contact area at the tip of the fibre is too small to allow any restraint to matrix deformation parallel to the fibre. The shrinkage matrix has a tendency to slide past the length of the fibre and restraint is only possible through the fibre-matrix interfacial bond strength [5].

Up to now, there are many experimental results from testing of drying shrinkage of SFRC, mainly with different conclusions.

The Report on FRC published by ACI [6] shows that, according to limited test data on shrinkage of SFRC, if fibres are used to the amount of less than 1% of the volume, there is no signifacant improvement in shrinkage strain. Edgington et al. have reported that shrinkage of concrete over a period of three months is unaffected by the presence of steel fibres [3]. Balaguru and Ramakrishnan found that 0.5% of steel fibres lead to less shrinkage strains [1]. Swamy and Stavrides have reported that drying shrinkage is reduced by about 15-20% due to the addition of 1% fibres [7]. Hannant have reported that steel fibres have no significant effects on shrinkage properties of concrete [8]. Malmberg and Skarendahl, have reported that Steel fiber concrete with a fiber content of up to 2% undergoes less shrinkage than plain concrete [9]. Similar conclusion was reported by Young and Chern. They found out that the optimal volume fraction of steel fibres to reduce shrinkage is not more than 2%.

Mangat and Azari proposed a theoretical expression to predict shrinkage of SFRC, based on the knowledge of shrinkage of ordinary concrete ε_{os}, coefficient of friction μ, fibre volume ν_f and aspect ratio of the fibres l/d:

$$\varepsilon_{fs} = \varepsilon_{os}\left(1 - 2.45\mu\nu_f\frac{l}{d}\right) \tag{1}$$

According to this expression, the decreasing of shrinkage of SFRC, compared to plain concrete, ranges from 0 to 40 % [5].

3. Experimental program

In order to find out the influence of different fibre dosages on the drying shrinkage of SFRC, an experiment was carried out at the University “Ss. Cyril and Methodius”, Faculty of Civil Engineering–Skopje, Republic of Macedonia, in the period from October 2011 to December 2012. The experiment consists of 9 specimens which were manufactured with concrete class C30/37, and according to the type of material they were divided in three series: Series A, ordinary concrete (C30/37); Series B, SFRC with 30 kg/m^3 steel fibres (C30/37 FL1.5/1.5) and Series C, SFRC with 60 kg/m^3 steel fibres (C30/37 FL2.5/2.0). The used steel fibres were hooked-end HE1/50, manufactured from Arcelor Mittal with diameter 1mm, length of 50mm and tensile strength of 1100 N/mm^2. The fibres were produced of cold-drawn wire and are presented in Fig. 2.

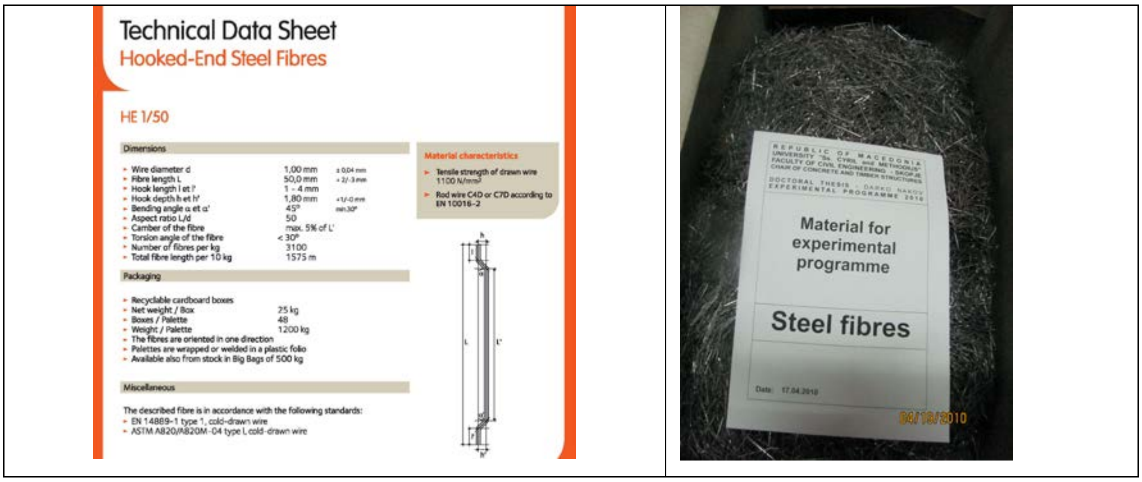

Fig. 2: Technical data sheet of the used fibres

The mixture proportioning was done so that it is the same for the three types of concrete and it is presented in Tab.1.

Tab.1: Mixture proportions for C30/37, C30/37 FL1.5/1.5 and C30/37 FL2.5/2.0

Mixture proportions	(kg/m^3)
Cement CEM II/A-M 42.5N	410
Water	215
Water/Cement ratio, w/c	0.524
Aggregate: 0-4 mm (river sand), 50% 4-8 mm (limestone), 20% 8-16 mm (limestone), 30%	 875 350 525
Fibres: C30/37 C30/37 FL 1.5/1.5 C30/37 FL 2.5/2.0	 0 30 60

The control specimens were cured for 8 days and then they were transported to the Laboratory at the Faculty of Civil Engineering – Skopje, where they were kept under almost constant temperature with an average of 19.5°C and constant relative ambient humidity with an average of 60.2%, which was regulated with special humidifiers and dehumidifiers. The temperature and humidity through the period of 400 days are presented in Fig. 3.

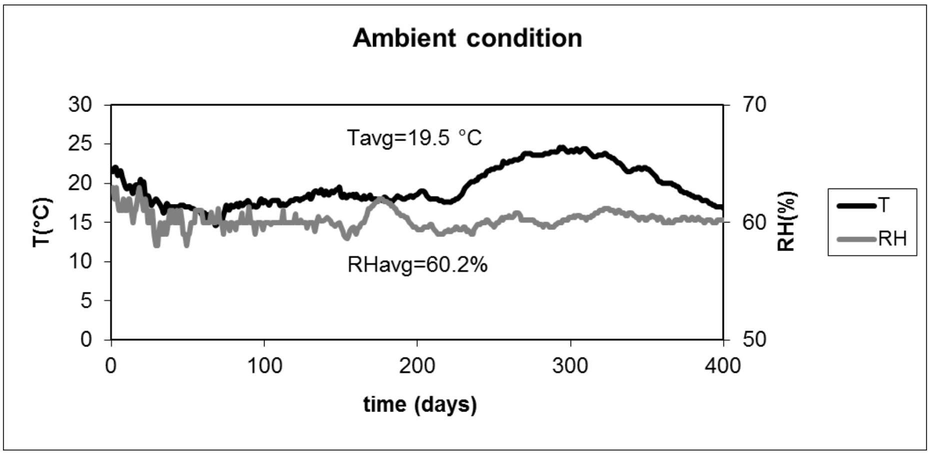

Fig. 3: Ambient condition in the Laboratory at the Faculty of Civil Engineering

The drying shrinkage was measured on three control prism specimens with dimensions 12x12x36cm for each type of concrete. The strains were measured on four sides of each prism, which means that for each type of concrete, the presented results in the following tables and figures are mean value of 12 measurement points.

Drying shrinkage was measured since the opening of the moulds of the control specimens to the age of concrete of 400 days (Fig. 4).

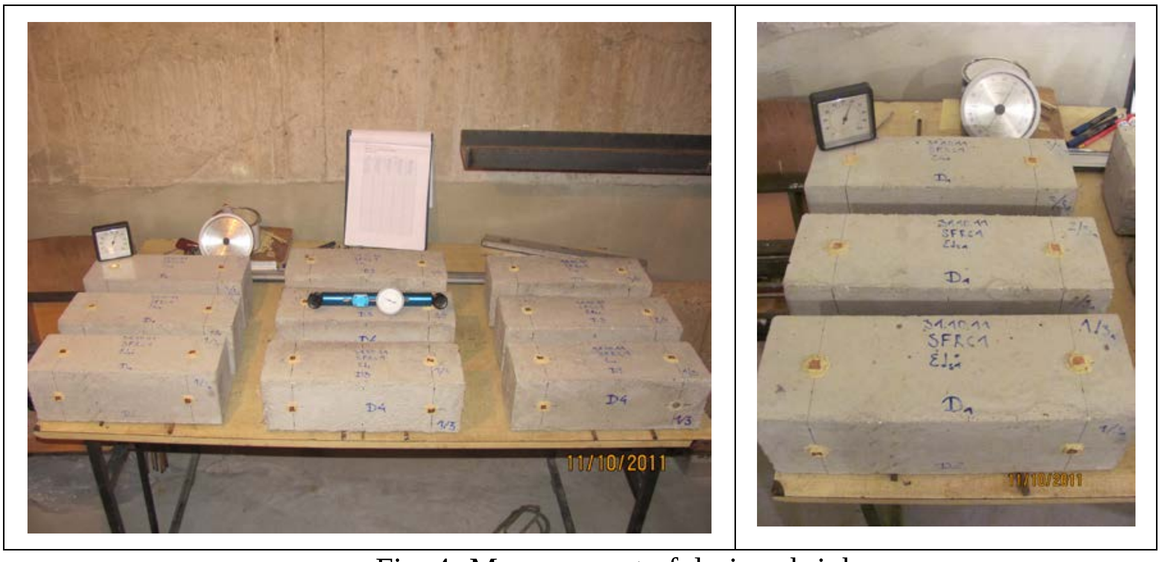

Fig. 4: Measurement of drying shrinkage

4. Results

In Tab. 2 and Fig. 5 results from the measurement of the drying shrinkage are presented. As it can be noticed from the figure, the fibers did not have big influence on the drying shrinkage strain. In concrete types C30/37 FL 1.5/1.5 and C30/37 FL 2.5/2.0, drying shrinkage strain decreased for 0.4 and 1.6%.

Tab.2: Drying shrinkage strain for the three concrete types

Time-dependent properties	Age t(days)	C30/37	C30/37 FL1.5/1.5	decr. % ↓	C30/37 FL2.5/2.0	decr. % ↓
Drying shrinkage ε_{ds} $[10^{-6}]$μs	400	808.0	805.0	0.4	794.9	1.6

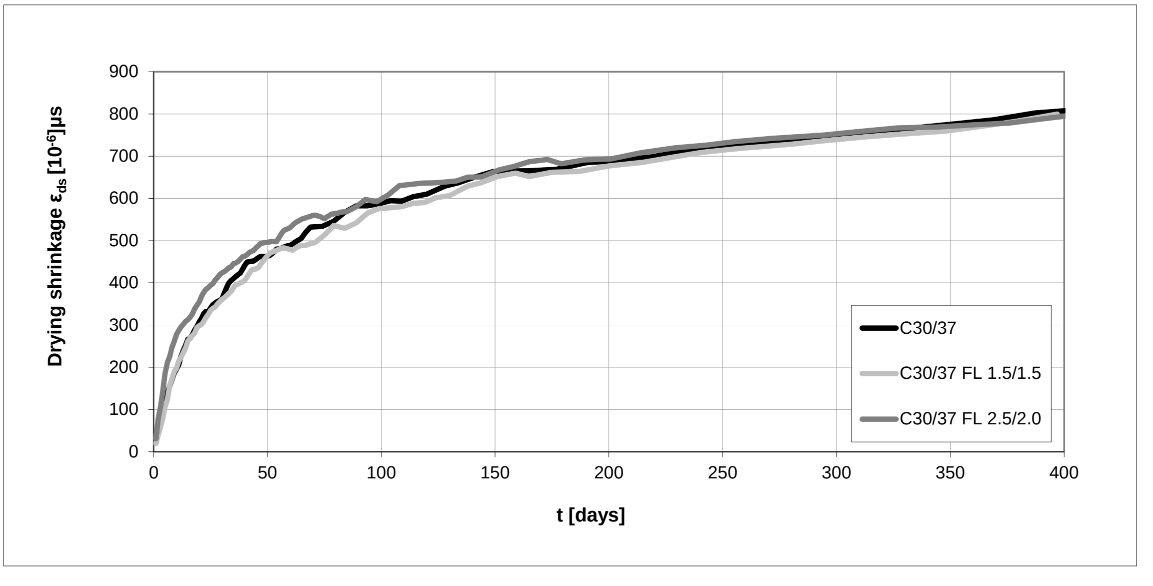

Fig. 5: Drying shrinkage strain for the three concrete types

5. Analytical analysis of drying shrinkage

The analytical analysis of drying shrinkage was performed by the B3 model [2] and fib Model code 2010 [4]. At the beginning, the analysis was done only for the time period considered in this research, which is 400 days.

The B3 model offers possibility of improving the model by its users, updating its predictions based on short-time measurements [2]. The updating of the drying shrinkage strain was done very efficiently by using the scaling parameter p_6.

The experimental and analytical results for the drying shrinkage up to age of 400 days are presented in Fig. 6 and only the final values of the drying shrinkage strain at 400 days are presented in Tab. 3. It can be noticed that the fib Model Code 2010 underestimates the drying shrinkage strain for 29%, while the original B3 model for 11.5%. The obtained scaling parameter in the improved B3 model is p_6=1.123. It can be noticed that there is very good agreement between the experimental results and the improved B3 model.

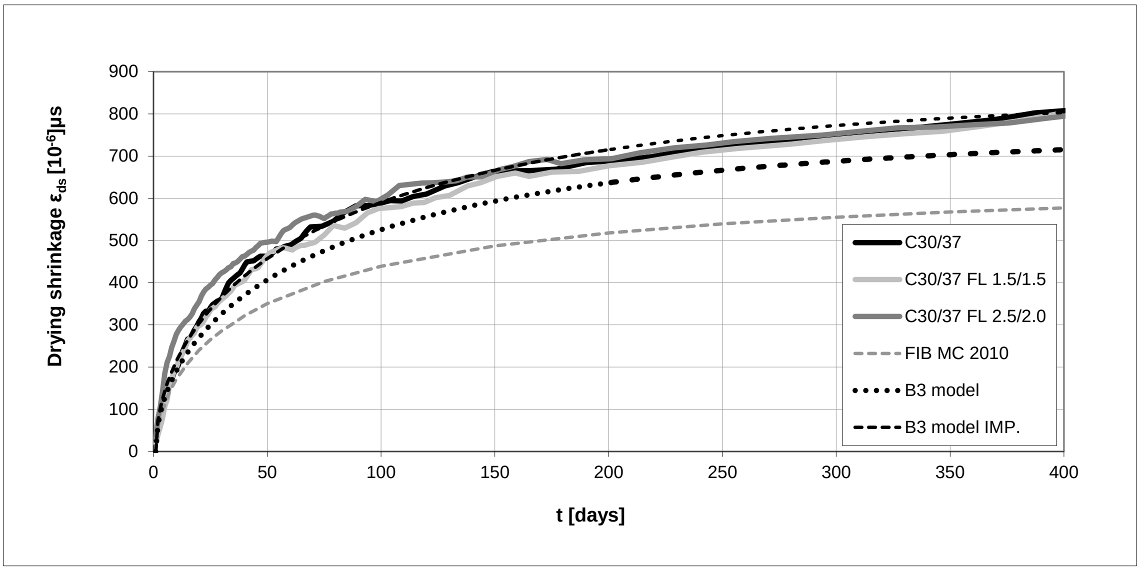

Fig. 6: Experimental and analytical results for drying shrinkage up to age of 400 days

Tab.3: Results from the analytical analysis of drying shrinkage at the age of 400 days

Drying shrinkage ε_{ds} [10^{-6}]µs	Age t(days)	C30/37	C30/37 FL 1.5/1.5	C30/37 FL 2.5/2.0
Experiment	400	808.0	805.0	794.9
FIB Model Code 2010	400	577.1		
B3 model	400	715.1		
B3 model improved	400	803.2		

Due to the very small differences between the different types of concrete, the analytical analysis of the drying shrinkage was not performed for each type.

Having in mind the service life of designed structures, it is very important to be able to predict the time – dependent deformation properties for their life time period. Therefore, based on the results up to an age of 400 days, the analyses according to the previously mentioned models were prolonged up to age of service life of structures of 100 years. The results are presented in logarithmic scale in Fig. 7. In the Tab. 4 the results are summarized for an age of 2, 10, 20, 50 and 100 years.

It can be noticed that 93% of the drying shrinkage develops in the first year, 98% in the second year and afterwards reaches a final value.

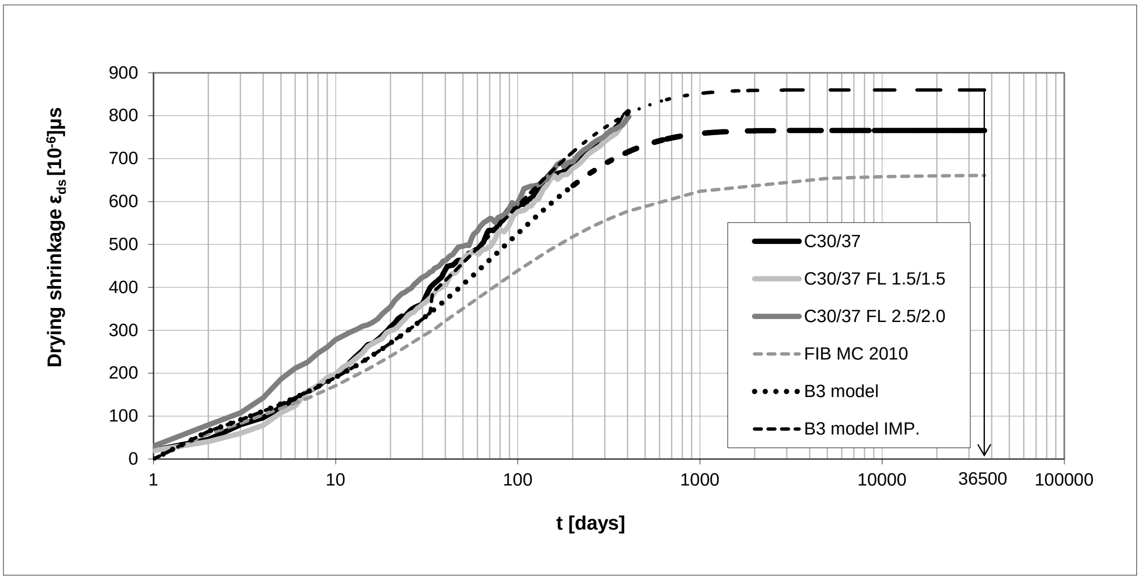

Fig. 7: Experimental and analytical results for drying shrinkage up to age of 100 years in logarithmic scale

Tab.4: Results from the analytical analysis of drying shrinkage up to age of 100 years

	Age t(years)	FIB MC 2010	B3 model	B3 model imp.
Drying shrinkage ε_{ds} [10^{-6}]µs	2	611	749.9	842.4
	10	651	765.6	859.9
	20	656	765.7	860.0
	50	660	765.7	860.0
	100	661	765.7	860.0

6. Conclusions

According to the experimental results at the age of concrete of 400 days, the addition of steel fibres has almost no influence on the free drying shrinkage (up to 2%).

The analytical analysis of the drying shrinkage performed by use of the B3 model and Fib Model Code 2010, demonstrated agreement with the experimental results. However, for concrete C30/37, an improvement of the B3 model was done by calculating of a scaling parameter for the drying shrinkage, p_6=1.123.

Further research is recommended to include steel fibers with bigger aspect ratio and with more different types of fibres (hybrid fibre reinforcement) and fibre volumes.

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