DETERMINATION OF SHRINKAGE OF FIBRE REINFORCED CONCRETE

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ABSTRACT

During hardening of concrete, different chemical and physical processes occur. As a result, shrinkage of concrete develops causing cracking of construction elements. In order to reduce shrinkage, a variety of methods are used beginning from curing of concrete to using different shrinkage reducing admixtures. One possibility to reduce shrinkage is to add different types of fibres to concrete. The aim of this study was to explore the shrinkage of fibre reinforced concrete depending on the added types of fibre with different volume fractures. Altogether five series of experiments were carried out. Two series were carried out with steel fibre reinforced concrete with volume fractures of 0.32% (25 kg/m) and 0.51% (40 kg/m^3), and two series with concrete reinforced by synthetic fibres with volume fractures of 0.44% (4 kg/m^3) and 0.77% *(7 kg/m^3). One series of tests was performed with normal concrete. The shrinkage of the specimens was determined according to the standard ASTM C490. Steel fibre reinforced concrete with a volume fracture of 0.51% and concrete with synthetic fibres with a volume fracture of 0.77% displayed the smallest shrinkage. For concrete consisting less fibres, differences in shrinking were smaller. However, concrete without fibres showed the largest shrinkage.*

Key words: concrete shrinkage, fibre reinforced concrete, steel fibres, synthetic fibres

INTRODUCTION

Drying shrinkage is probably the most deleterious property of portland cement concrete (Yazici, 2007). Shrinkage generally leads to cracking in concrete structures and further influences the service life of structures.

Shrinkage of concrete can be divided into two distinct stages: early and late age shrinkage. The early stage is commonly defined as the first 24 hours when the concrete is setting and starting to harden. Later ages, or long term, refers to concrete at an age of 24 hours and beyond (Holt, 2001).

Long term shrinkage can be divided into four types: drying, autogenous, thermal and carbonation. In case of drying shrinkage concrete loses water to the environment and undergoes a volumetric change. Early age drying shrinkage can be eliminated by proper handling and curing techniques to prevent moisture loss and to provide time for the material to strengthen.

Autogenous shrinkage is defined as a concrete volume change occurring without moisture transfer to the environment. It is merely the result of the internal chemical and structural reactions of concrete components. Thermal shrinkage refers to volume changes that occur when concrete undergoes temperature fluctuations. It is often referred to as thermal expansion, which is the portion resulting when the temperature of concrete is rising. Carbonation occurs when cement paste in hardened concrete reacts with moisture and carbon dioxide in the air.

Hardened cement paste undergoes high drying shrinkage, whereas concrete shows significantly less shrinkage due to the restraint provided by more rigid aggregate particles. The restraint provided by aggregate particles to the shrinkage of concrete is well understood, and corresponding theoretical models have been successfully developed (Neville, 2003).

Introduction of different types of fibres also leads to reduction in the shrinkage of the cementations matrix (Illston, 2001). Fibre-reinforced concrete is currently used in a wide range of applications, including bridges, industrial floors, walls and structural slabs (Banthia, 1999). Fibres suited to reinforcing composites have been produced from steel, glass and organic polymers. Different fibres affect the properties of concrete differently. Adding of synthetic fibres prevents cracking caused by plastic shrinkage and plastic setting, and gives tensile strength in the initial phase of hardening. Adding of steel fibres gives to concrete higher flexural tensile strength, higher cracking resistance, higher impact resistance and higher resistance to volume shrinkage. Adding of fibres sufficiently improves the post-cracking process of the concrete (Banthia, 1999). In this study the shrinkage of fibre reinforced concrete, depending on the added types of fibre with different volume fractures, was investigated. Two types of fibres were used: steel crimped fibres and synthetic textured fibres. Later age shrinkage was investigated as well.

EXPERIMENTAL PROCEDURE AND METHOD

Measurements of the shrinkage of specimens were carried out according to the standard ASTM C490. According to the recommendation of the standard, the measurements of specimens were (75×75×285) mm. The cross-section of the specimens was related to the length of fibres, allowing them to take a random position in the mortar.
A special mold was designed and manufactured from plastic for casting specimens. Gauge studs were fixed to each end of a specimen for measurement of length change. Each mold was equipped by the end plate to hold the gauge studs properly in place during the setting period. The gauge length of the specimens was 250 mm, which was measured between the bottoms of the gauge studs.
The measuring equipment (Figure 1) was designed and manufactured for determining the length change of the specimens.

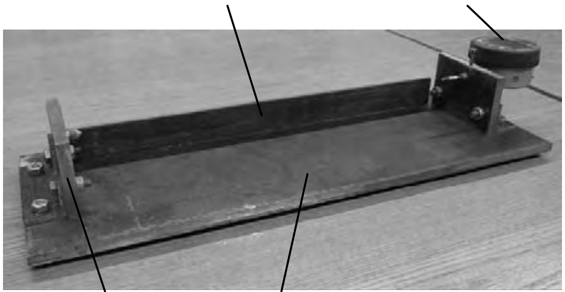


Figure 1. Equipment for measuring the length change of the specimens.

The length change was measured by the digital dial gauge Mitutoyo ID-C112B with an accuracy of 0.001 mm.
All test specimens were manufactured from industrial concrete class C25/30. The water/cement ratio was 0.65. The mix details of concrete are presented in Table 1. The unit weight of concrete was 2330 kg/m^3.

Table 1

Mix details

Material	Quantity
Cement CEM II A-T 42.5 R	344.5 kg/m^3
Sand	1124.0 kg/m^3
Gravel, 4-12 mm	482.7 kg/m^3
Gravel, 8-16 mm	394.0 kg/m^3
Water	172.1 *l*

Two types of fibres were used for preparing the test specimens: steel crimped fibres TABIX 1/50 (length 50 mm, diameter of cross-section 1 mm) and synthetic textured fibers BARCHIP (length 50 mm, cross-section 0.65×1.3 mm).
The volume fractions of the fibers were chosen to correspond to fractures used in industrial floors. Specimens were prepared for five series of experiments. One series contained 12 specimens. The first and the second series were cast with steel fibres with a volume fraction of 0.32% and 0.51%, respectively. The third and the fourth series of specimens were cast with synthetic fibres with a volume fraction of 0.44% and 0.77%, respectively. The fifth series was prepared from plain concrete as the reference.

RESULTS AND DISCUSSION

As this study was carried out within a Master's course, the duration of the shrinkage measurements was limited to 60 days. During this time the ultimate shrinkage of concrete is 80% (Holt, 2001). The well-known equation (1) (Neville, 2003) can not be used for prediction of short term shrinkage of concrete, as is the case also in this study.

$$s(t) = \frac{t}{t+35} \cdot s_{\mathrm{ult}}, \qquad (1)$$

where $s(t)$ is shrinkage after t days from the end of 7-day moist curing;
s_{ult} is ultimate shrinkage;
t is time in days from the end of moist curing.

Although the prediction of development of shrinkage by the above equation is subject to considerable variability, the equation can be used to estimate the ultimate shrinkage of a wide range of the moist-cured concretes. It can be seen that one half of ultimate shrinkage is expected to occur after 35-day drying. For steam-cured concrete, the value of 35 in the denominator is replaced by 55, and the time t is calculated at 1-3 days from the end of steam curing.
In the case of short term measurement the experimental data can be approximated by the following analytical equation

$$s(t) = \ln\left(1 + t^{c}\right), \qquad (2)$$

were t is the number of days,
c is the dimensionless parameter.

The purpose was to find the unknown constants so that the measured displacements $s(t)$ are approximated in the best way. This problem was solved using the mathematical program *Mathcad 2001i Professional* regression function *genfit* (vx, vy, F) (Kir'yanov, 2001).
Test specimens from plain concrete were prepared for reference as the etalon. The results of the measurements and the approximation curve are presented in Figure 2.

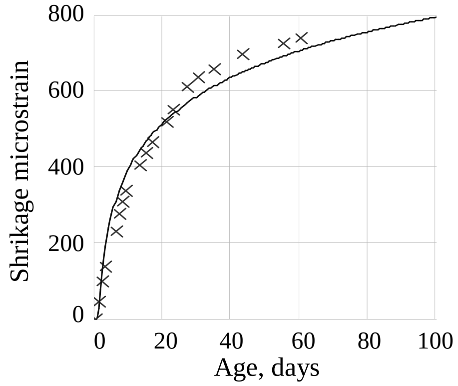


Figure 2. Experimental data and the curve of approximation of specimens cast from plain concrete.

Two series of experiments were carried out with specimens with a steel fibre content of 0.32% and 0.51% per volume, respectively. The experimental data and the curve of approximation for these series are shown in Figure 3.

The graphs presented in Figure 3 allow concluding that increasing the amount of fibres reduces the shrinkage of concrete.

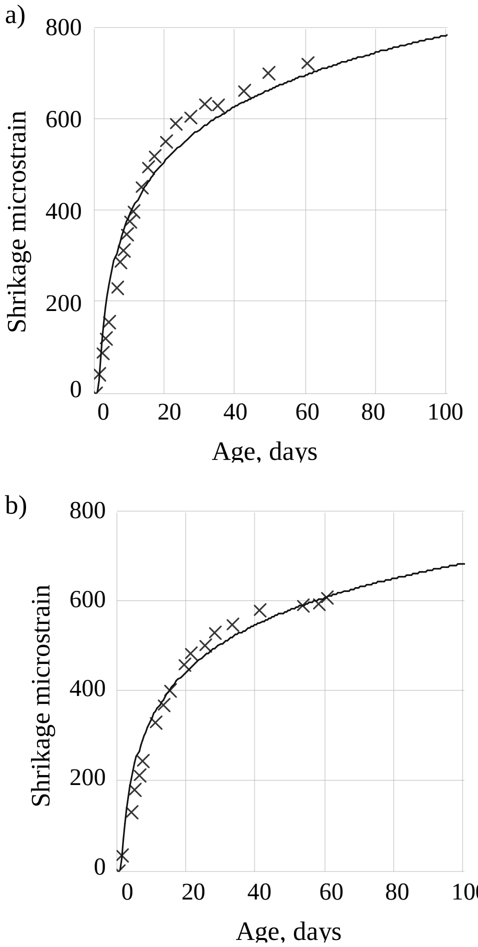


Figure 3. Experimental data and the curve of approximation of specimens containing steel crimped fibres 0.32% (a) and 0.51% (b).

The specimens with a fibre content of 0.32% did not practically reveal changes in shrinkage compared to the shrinkage of plain concrete (the difference is 1.3% at 60 days); however, the shrinkage of specimens with a fibre content of 0.51% was 13.8% lower at the same age. Higher fibre content weakens the mix and hence results in lower shrinkage (Neville, 2003).

Two series of experiments were carried out with specimens containing synthetic textured fibres with a volume fraction of 0.44% and 0.77%, respectively. The experimental data and the curve of approximation are shown in Figure 4. It is evident from the graphs, that the shrinkage of specimens with a fibre content of 0.77% was 7.8% lower at 60 days compared to the shrinkage of plain concrete. However, the shrinkage of specimens with a fibre content of 0.44% was 11% higher.

To verify the use of the proposed equation (2) for approximation of the experimental data, the data presented in (Bolander, 2004) were approximated using this equation. The data of two series of experiments were approximated: the data of the shrinkage of plane concrete and the data of the shrinkage of concrete with 2% steel crimped fibres per volume.

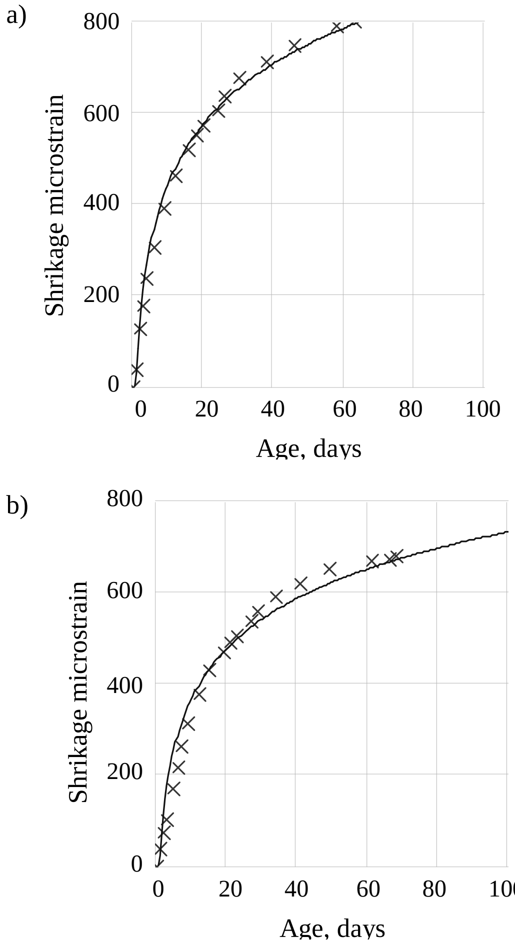


Figure 4. Experimental data and the curve of approximation of specimens containing synthetic textured fibres 0.44% (a) and 0.77% (b).

Measurement of shrinkage was carried out during up to 500 days. The results of approximation are presented in Figure 5 and in Table 2.

Table 2

Data of shrinkage

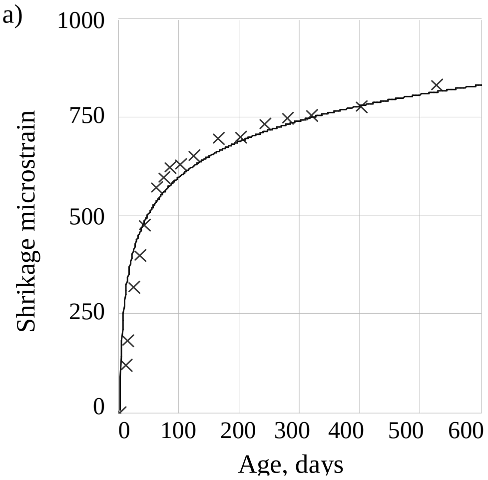
Test specimens	Shrikage, microstrain		
	20 days	40 days	60 days
Plain concrete	518	638	708
Steel fibers 0.32%	511	630	699
Steel fibers 0.51%	446	549	610
Synth. fibers 0.44%	576	709	786
Synth. fibers 0.77%	477	588	653
Plain concrete (Bolander, 2004)	390	481	533
Steel fibers 2% (Bolander, 2004)	314	387	429

It is evident that the analytical equation approximated the experimental data satisfactorily also for long term measurements beginning from the 200th day. The highest mismatch occurred approximately between 50 and 160 days. There is no confirmation for the statement (Holt, 2001) that 80% of ultimate concrete shrinkage occurs during the first 60 days. According to the measurement results (Bolander, 2004), only 65% of ultimate shrinkage occurred during the first 60 days.

CONCLUSIONS

The experimental study showed that fibres with a small volume fracture did not affect significantly the shrinkage of concrete.
In the case of synthetic fibres shrinkage was slightly larger. Specimens with a higher volume fracture displayed smaller shrinkage compared to plain concrete in all cases.
The presented analytical expression proposed for short term experiments approximated the measured data satisfactorily, and can be used, with certain reliability, for prediction of shrinkage in long term experiments. According to the results of this study and basing on literature data, it can be supposed that at least half of ultimate shrinkage occurs during the first 35-40 days, and ultimate shrinkage can be measured 18 months after the preparation of specimens.

a)



b)

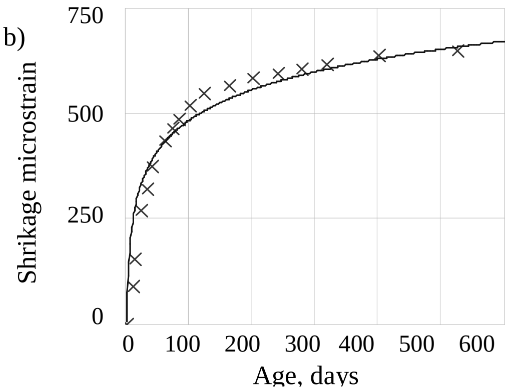


Figure 5. Experimental data and the curve of approximation of specimens of plane concrete (a) and with a steel fibre content of 2% (b).

This analysis was limited to the data obtained from the literature and from the experiments described above.

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