EFFECT OF THE USE OF DISPERSIVE FIBRES ON THE SIZE OF CRACKS IN THE EARLY STAGE OF SETTING AND HARDENING OF CONCRETE

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Abstract

Origin and development of the cracks in the early stage of setting and hardening of concrete unfavourably influence its durability. This contribution presents the results of experimental works describing the influence of fine dispersive fibres admixed into concrete on the cracks widths in early stage of setting and hardening.

Keywords: cracking, early age of concrete, cracks, shrinkage, fine dispersive fibres, setting and hardening of concrete

1. Introduction

The cracking in concrete is a relevant problem for the designers and the suppliers of concrete structures. One of the factors that may significantly affect the service life of concrete structures is cracking, namely the formation and development of cracks during the using of the structure. The cracks occur not only because of external loads, which must be transferred by concrete, but they also arise because of rheological changes, which affect concrete since its origin.

Currently, in many laboratory workplaces around the world people pay attention to cracking in the early age of concrete - this is the stage of a setting and hardening. The concrete in early age obtains its strength and deformation parametres. In this period there are very significant tensile stresses that are caused by volume changes of concrete by temperature during hydration and by change of moisture. These stresses exceed the immediate tensile strength of concrete and it results in cracking. Movement of the water and the aggregates in the liquid mixture also contributs to the cracking in this period.

There is the list of periods in service life of concrete structure in terms of concrete cracks by prof. Šmerda [1]:

1) 1st period – to 12 - 24 hours after casting
    a) Fresh concrete - it is a very ductile concrete after the compaction. Cracks at this stage most often arise from plastic shrinkage and plastic settlement, which is caused by the movement of heavier aggregates, which may fall to the bottom of the formwork.

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b) Stiffening concrete - at this stage concrete is setting and cracks are often caused by chemical shrinkage. At this moment hydration takes place stormly, new minerals grows up and the volume of concrete part decreases.

2) 2nd period - from 12 to 24 hours to full maturity of concrete.

a) Hardening concrete - there is an increase of strength and deformation parametres of concrete, the chemical shrinkage and shrinkage from drying take place.

b) Mature concrete – concrete at this stage reaches its full strength and deformation parametres, cracks occur mostly due to loads of concrete. The shrinkage of drying continues at this stage and during whole service life of concrete.

It seems very advantageous to limit the rise and development of cracks at an early age by using dispersive fibres, which in this period help concrete to cope with a relatively low tensile strength and significantly reduces the rise and development of cracks.

2. Experimental work

Experimental works were focused on observing the rise and development of cracks during setting and hardening of concrete. The main aim of the experiments was to determine the cracks width and theirs opening for each mixture.

To get complete information about concrete the specimens were manufactured for determination of compressive strength and modules of elasticity of concrete. In addition, the specimens were manufactured for setting shrinkage of each mixture.

2.1 Production of fresh concrete

For the production of reference mixture there were used: fine aggregate 0-4 mm from Bratčice, coarse aggregate 8-16 mm from Olbramovice, cement CEM I - 42.5 R from Mokrá and water. The composition of fresh concrete mixtures clearly shows Tab. 1. Because the fibers can also affect the consistency of concrete, the recipe was modified for fibers containing mixture. The consistency index S4 was always achieved due to the test of cone slump.

Tab. 1 Recipe of reference mixture

CEM I 42,5 R	Agg. 0-4 mm	Agg. 8-16 mm	water	w/c
[kg]	[kg]	[kg]	[l]	-
370	850	940	207	0.559

Each mixture was mixed in the mixing device with forced circulation. Production was carried out by dosing coarse and fine aggregate and a half dose of water into the mixing device. After a short mixing cement and remaining dose of water was added. The dose of water was adjusted due to the required consistency index. If the fibers were in the recipe, their dosage was carried out with the aggregate, i.e. right in the beginning of mixing. After three minutes mixing of fresh concrete the consistency index was always tested.

The reference mixture without fibers was made and then four mixtures with different types of fibres. For further clarity there will be given a list of of fibers:

- AntiCrak - this is a very strong and high modulus microfibers, which are made of special glass with a high content of zirconium. Fiber diameter is 14 microns, fiber length is 12 mm.
- Fibruco –fibers are made of polypropylene, their length is 12 mm.
- STAVON – these are polymerous monofilament microfibers with length of 12 mm.
- FORTA Econo-Net – are polypropylene fibers manufactured in the fibrillated form with length 19 mm.

It was used the dosage of fibers recommended by manufacturers, which is 600 grams per 1 m^3 of fresh concrete. The dosage was the same for every mixture, because of results comparison.

2.2 Production of test specimens and measurement methodology

For the purposes of experimental work the specimens have been manufactured to determine the control compressive strength and TPT tests (cubes with edge 150 mm), the values of modulus of elasticity (prisms with dimensions 100 mm x 100 mm x 400 mm), the shrinkage (beams with cross-section 100 x 100 mm and length 1000 mm) and specimens for determining the rise and development of cracks (forms with notches). Test specimens were stored in the laboratory at 20 ± 2 ° C and relative humidity 35 ± 5%.

Tests methodology for compressive strength and modulus of elasticity is according to ČSN 73 1330 and ČSN 73 6174. The attention was paid to the methodology of measuring shrinkage, rise and development of cracks and TPT tests.

The shrinkage was in the first 72 hours measured in non-contact way in special moulds (see Fig. 1). The principle of non-contact measurement of shrinkage is in recording changes of distance. The moulds are equipped by two faces with anchors, one side is fixed, the other side is able to move in the direction of the axis of the beam. The side is equipped by the guide bar Ø 8 mm, which is supported by two leading elements perpendicular to each other. At the end of the guide bar there is located inductive sensor, which records the movements in the axis of the beam from the casting and compaction of concrete. The precision of measuring of the shrinkage is 10^{-3} mm. At the same time the temperature and relative humidity were measured in the laboratory. The changes of distance are saved to a measuring unit in the selected time sequence and then they are transported to the computer. After 24 hours, the specimen surface is provided by three measuring discs at distances of 200 mm and specimen length change is measured by a mechanical charging device at the base of 2 x 200 mm. This manual measurement was processed until the shrinkage was fixated.

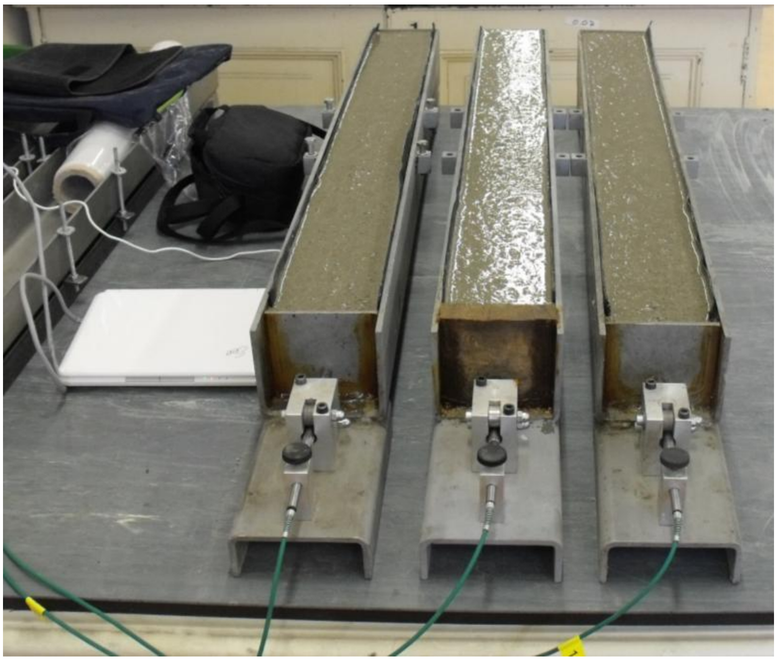

Fig. 1 Special moulds for measurement of shrinkage

Measurement of crack rise and development was realized in the forms with three notches, one big notch is 78 mm high and two smaller ones are high 38 mm. The form is 100 mm high and is clearly shown in Fig. 2.

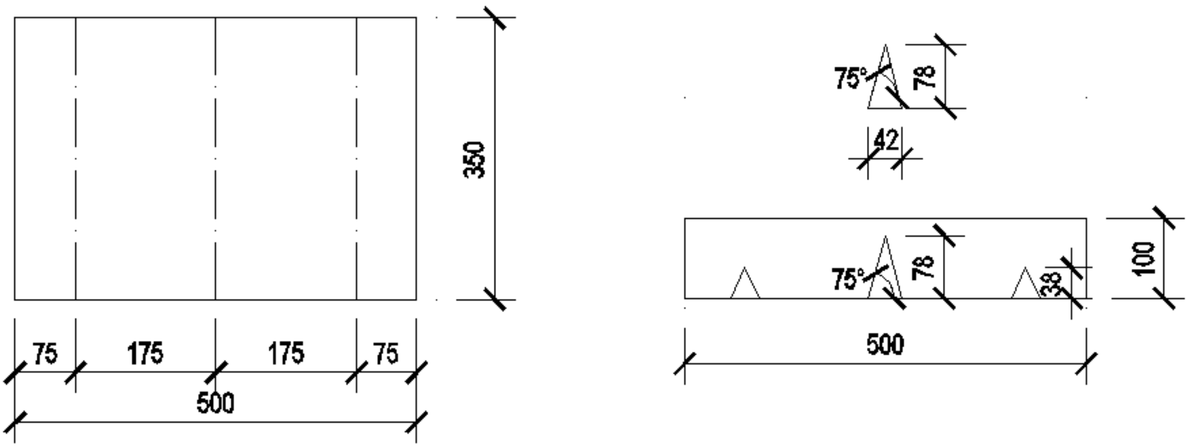

Fig. 2 Form with three notches

The cracks width measurements were realized along the length form of 350 mm at measured distances of 50 mm. In the first stage measurements were realized by a measuring device with precision of 0.05 mm, in the second stage when the concrete surface was able to carry the microscope, the microscope was used for measurements with precision of 0.01 mm.

Fig. 3 Photo of forms with notches

The air permeability of concrete is determined by the device Torrent Permeability Tester (TPT), which is produced by Swiss company Proceq. The test is realized by measuring air flow into the inner chamber of the device. The basic elements of the device are dual vacuum cell and the pressure regulator, which procure the air flow into the inner chamber oriented perpendicular to the surface of tested structure. The device works in conjunction with a vacuum pump.

Fig. 4 Torrent Permeability Tester

From Tab. 2 is evident relationship between values of air permeability coefficient k_T and the estimated value of the current durability of concrete.

Tab. 2 Grade of quality of concrete coatings

Quality of cover of concrete	Index	k_T (10^{-16} m^2)
very bad	5	> 10
bad	4	1,0 - 10
middle	3	0,1 - 1,0
good	2	0,01 - 0,1
very good	1	< 0,01

3. Measured values and results

3.1 Origin and development of cracks

The measurement of formation and development of cracks started immediately after compaction of concrete and it has continued for 10 days. After this time the cracks width doesn't extend a lot, so this measurement is satisfactory. In Fig. 5 you can see the expansion of cracks for each mixture.

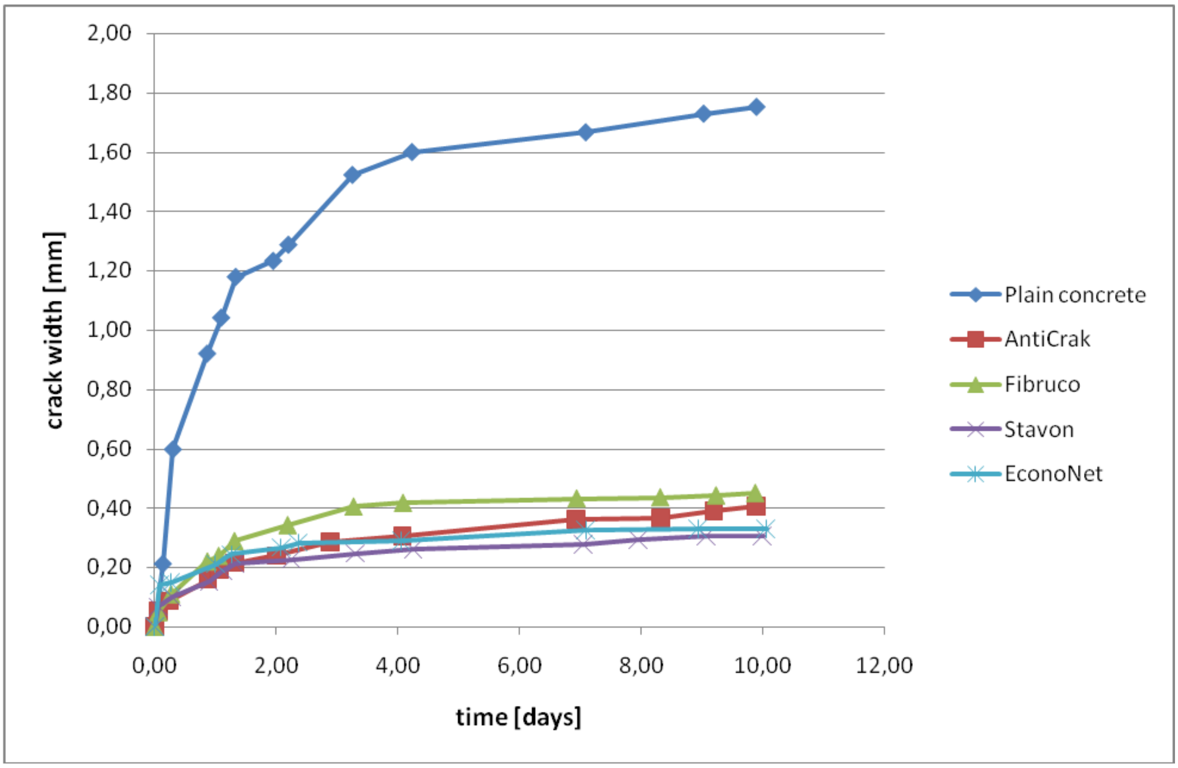

Fig. 5 Developing of cracks depending on time

3.2 Shrinkage

Shrinkage was measured in the first 72 hours after the placing of concrete by non-contact way in special moulds. After 24 hours the concrete surface was equipped by measuring discs and measurements were carried out for 48 hours by non-contact way and by mechanical device simultaneously. In the age of three days concrete speciment was removed from the mould and measurement continued with manual measuring discs. Measurement has continued until the values of shrinkage have stabilized. This is diverse for different concrete, generally the values of shrinkage are stabilized in one year of concrete age. The following figure clearly shows the shrinkage values for each mixture. Measurement has not been finished yet, the values of shrinkage are displayed only to the concrete age about 200 days.

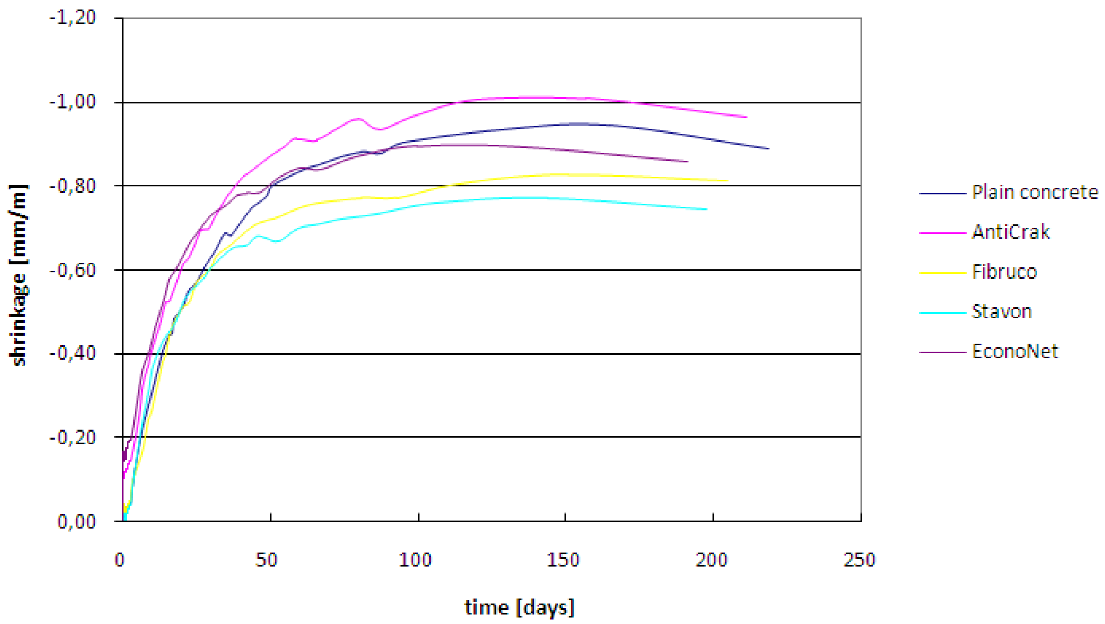

Fig. 6 – Shrinkage depending on time

3.3 Air permeability by method TPT

In the Tab. 3 there is the list of the average values measured air permeability coefficients k_T, the depth of penetration of vaccua in concrete L and pressure Δp at the end of tests for all five concrete mixtures.

Tab. 3 – Values of air permeability for each mixture

Fibers type	k_T [m^2]	L [mm]	Δp [mbar]	Moisture weight
Plain concrete	0.318E-16	37.9	80.0	2.45
AntiCrak	0.217E-16	40.5	63.7	2.23
Fibruco	0.177E-16	22.9	49.3	1.68
Stavon	0.180E-16	15.9	46.0	1.69
Econo-Net	0.141E-16	14.6	71.8	1.47

3.4 Material parametres of concrete

Determination of material parametres of concrete was carried out according to the current standards. There were determined compressive strength at the age of 7, 28 and 90 days (see Tab. 4), then the dynamic modules of elasticity at the age of 28 and 90 days (see Tab. 5), then static modules of elasticity in compression (see Tab. 6) and static modules of elasticity in bending strenght at the age of 28 and 90 days (see Tab. 7).

Tab. 4 Compressive strenght of concrete

Mixture	Strenght [MPa]	Strenght [MPa]	Strenght [MPa]
	7 days	28 days	90 days
Plain concrete	32.05	40.35	42.93
AntiCrak	32.63	39.33	41.12
Fibruco	40.92	48.69	51.47
Stavon	37.69	46.66	52.83
Econo Net	36.40	45.63	48.79

Tab. 5 Dynamic modules of elasticity

Mixture	E_{dyn} [GPa]	E_{dyn} [GPa]
	28 days	90 days
Plain concrete	32.74	34.39
AntiCrak	31.79	32.93
Fibruco	32.99	33.37
Stavon	32.62	33.67
Econo Net	33.55	35.28

Tab. 6 Static modules of elasticity in compression

Mixture	$E_{st,c}$ [GPa]	$E_{st,c}$ [GPa]
	28 days	90 days
Plain concrete	24.57	25.73
AntiCrak	24.90	25.10
Fibruco	24.97	25.47
Stavon	26.17	27.57
Econo Net	27.43	28.77

Tab. 7 Static modules of elasticity in bending strength

Mixture	$E_{st,b}$ [GPa]	$E_{st,b}$ [GPa]
	28 days	90 days
Plain concrete	30.06	31.22
AntiCrak	29.44	30.69
Fibruco	30.52	32.28
Stavon	29.00	31.05
Econo Net	30.86	31.65

4. Conclusions

The results of experimental work clearly demonstrate following:

- Disperse fibers in concrete significantly reduce the width of the main crack in the test speciment. If the width of cracks in plain concrete without fibers is 1.76 mm in average, then cracks in the concrete with fibers range from 0.30 to 0.44 mm, and it represents a reduction of 17 to 25%. This result strongly suggests the possibility of substantial reduction of cracks in the initial stage of concrete hardening.
- Long-term shrinkage (up to 200 days) of concrete caused mainly by drying of concrete is not significantly affected by using dispersive fibers.
- The values of air permeability coefficients for concrete with fine fibers compared with plain concrete are lower so that is why we could expect higher durability of concrete with fibers.
- The effect of fibers on compressive strength is positive, the compressive strength increases by using some sort of fibers.
- The effect of using fibers in concrete on the values of dynamic and static modules of elasticity in principle is insignificant.

A major conclusion from the experiments is the finding that the use of dispersed fibers in concrete significantly reduces susceptibility to cracking in the initial stage of setting and hardening of concrete.

Acknowledgements

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5. References

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