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# ELIMINATION OF THE EFFECT OF WATER LOSS FROM CONCRETE – CRACKS WITHIN PLASTIC STATE

***Summary***

This work deals with plastic shrinkage which concrete undergoes when to be exposed to intensive loss of moisture.

In the experimental part of this work we evaluate an efficiency of the concept of reduction of cracks formation in plastic concrete if let it without early curing or we are not technically able to supply curing. The concept is based on addition of extremely fine polymer fibers into the mass of very fresh concrete. We focused the evaluation on determination of efficiency of the concept using standardized boundary conditions and its dependence on fibers´ type and dosage.

***Key words***

plastic shrinkage, moisture, concrete, cracks, curing concrete, fibers

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# 1. INTRODUCTION

Plastic shrinkage is one of the volume changes of fresh concrete. In this (plastic) state, the bonds between hydrating cement particles or rigid bonds between binder and filler are still not formed [1].

Volume changes occur up to the point of initial set of cement paste can not show in horizontal direction because, as mentioned above, there are no bonds between hydrating particles of cement. A collapse of the system develops the volume changes display of which is consolidation of the cement paste. Cement particles, so far without bonds, undergo action of gravity as individual particles and thus the overall volume change in plastic state is only characterized by vertical component of dimension change of original body. There are two (generally) equivalent driving forces standing behind the plastic shrinkage. One is chemical or if you want autogenous shrinkage and the second is related to loss of moisture from concrete to the environment – usually denoted as evaporation [1,2,3].

External, visible to the naked eye, shows of plastic shrinkage occur by the action of different settlement in the form of cracks namely in the areas of somehow restricted settlement of cement paste. The typical example of this are may be concrete above inserted steel rod. Cement paste above the rod disposes of lower potential to settlement because the vertical consolidation is to be restrained by the reinforcement element. By the influence of absolute settlement of nearby cement paste, there in forming structure the horizontal and shear stresses are to be generated what results in creation of a crack just above the reinforcing element [1].

One of the means how to reduce exposes of plastic shrinkage is usage of fine disperse reinforcement – polymer fibers.

The polymer fibers (both monofilament and fibrilated) are fine enough (has got high aspect ratio and specific surface) and dispose with high tensile strength. That predestinate them for reduction of exposes of tensile stresses generated in early hours of concrete age by their own fineness and density of occurrence in concrete whats enable them to carry stresses generated in setting composite and keep it whole without any material discontinuities. Following experimental part evaluate an efficiency of different types of polymer fibers in several length modifications and batch amounts.

# 2. TASKS AND ASSUMPTIONS

The goal of this project was to prove and evaluate efficiency of reduction of occurrence of plastic shrinkage cracks with acceptable rate of risk using different types of polypropylene (PP) fibers with several aspect ratios.

A fundamental assumption was that with larger addition volume of the fibers, plastic shrinkage cracks would diminish as they would be bound with crossing fibers [1,4].

## 3. EXPERIMENTAL PART

### 3.1. INVESTIGATED FIBERS, USED MATERIALS AND MIXTURES

The influence of polymer fibers on reduction of formation of cracks due to plastic shrinkage was evaluated on 6 series of samples (each one consisted of 3 specimens) made out using PP fibers. For evaluation there was used a reference concrete without any fibers (denoted as PLAIN). Individual mixtures were made out according to mixture proportions shown in table 1. Marking M or F means type of fibers "Monofilament" or "Fibrilated". The fibers are also marked according to their length (mm) and dosage (kg/m$^3$).

*Table 1. Used mixture proportions*

| Mixture | W/C | Cement | Water | Fine Aggregate | Coarse Aggregate | Fibers |
|---|---|---|---|---|---|---|
| | | (kg/m$^3$) | | | | |
| Plain | | | | | | 0,0000 |
| M12,7-0,445 | | | | | | 0,4450 |
| M12,7-0,593 | | | | | | 0,5930 |
| M19,1-0,297 | 0,55 | 461,12 | 253,61 | 780,00 | 780,00 | 0,2970 |
| M19,1-0,890 | | | | | | 0,8900 |
| F25,4-0,593 | | | | | | 0,5930 |
| F25,4-0,890 | | | | | | 0,8900 |

Concrete was mixed with using of ordinary portland cement (OPC) Type I (in accordance with ASTM C150 [5]) with fineness of 370 m$^2$/kg and Bogue phase composition of 50% $C_3S$; 16% $C_2S$; 12% $C_3A$; 7% $C_4AF$ and 0,68% of $Na_2O$. Before mixing, cement was measured and kept sealed in plastic containers at temperature 22±1°C. There was used no water reducer or any other admixtures.

Water to cement ratio was chosen 0,55. High dose of water should ensure standardized progress of loss of moisture through evaporation, cover all water needed for hydration of cement and simultaneously prevent autogenous shrinkage of concrete.

Aggregate consisted of coarse aggregate (fraction 4/8) and fine aggregate (sand) with fineness modulus of 3,13. Both were designed in proportions of 30 % of final batch volume and sum of them represented 60 % of mentioned batch volume. Before mixing the aggregate was oven dried for 24 hours at temperature 143°C and subsequently cooled down by fans onto 22±3°C. When reached desired temperature it was measured and sealed in plastic buckets till mixing.

## 3.2. MIXING

As a first step, the whole batch of coarse aggregate was dumped into the horizontal mixer bowl with forced rotation. After beginning of mixing, in rapid sequence (without interruptions) 1/3 of mixing water was added, the whole batch of fine aggregate was dumped into the bowl followed by 1/3 of mixing water, then cement and rest of mixing water and fibers (when applicable) [6].

Since this moment, concrete was mixed 3 minutes following with 2 minutes of resting time and then by 3 minutes long mixing again.

Ready concrete was then manually cast into the oiled molds, scraped and finished by trowelling. After 25 minutes since water addition, the samples were put into a chamber for plastic shrinkage testing.

## 3.3. TESTING PROCEDURE AND BOUNDARY CONDITIONS

The plastic shrinkage tests were performed according to ASTM C1579 [7] on the specimens of dimensions as illustrates figure 1.


*Figure 1. Geometry of the specimens used for plastic shrinkage investigation [7]*

The specimens were put on the balances into an environmental chamber where they were exposed to following ambient conditions: temperature of 36±3˚C, relative humidity of 30±10% and wind velocity 24±2 km/h. Immediately after they were placed on the balances with resolution of 20 g, data acquisition in 1 minute intervals was started. The specimens were kept for 6 hours under conditions of blowing wind, then the blowers were turned off and thus for additional 18 hours, specimens were exposed to the environment without significant air circulation. The tests were finished after 24±2 hours, when specimens were taken outside to taking pictures of their surfaces. The pictures were always taken from the same heigth of 7.25 in [7]. Subsequently, pictures were adjusted for cracks widths analysis using software "ImagePro" which enables approximately 300 measurements for each specimen, thereby provide statistically valid information about cracks widths and their variability [8].

The result of cracks widths analysis is a distribution function of probability of certain crack widths occurrence (multiple of 1 pixel dimensions) and a cumulative function of the same phenomenon probability as well as crack reducing ratio (CRR) calculated according to equation 1 [7], where $w_{MOD,C}$ is an average width of cracks in concrete with modified composition and $w_{REF,C}$ is an average width of cracks in reference (plain) concrete.

$$CRR = \left(1 - \frac{\overline{w}_{MOD,C}}{\overline{w}_{REF,C}}\right) \cdot 100 \qquad (\%)$$

(1)

### 3.4. RESULTS AND DISCUSSION

Within evaluation of efficiency of plastic shrinkage cracks reduction using fine PP fibers we gathered a database of probability of certain crack widths occurrance as shown on figure 3 and data on reduction of plastic shrinkage cracks (table 2) and many other interesting parameters.

From figure 2, it´s easily traceable in what percentage ration cracks of width less than e.g. 1 mm occured what might be an interesting input within mixture proportion design as to ensure required durability of the structure. All the samples bahaved according to our expectations, however, what is intereted – the effect of fibers at 5% fractile showed to be very strong. In this case, the difference in crack widths between samples "Plain" and "M12,7" is circa 1 mm. It may further be seen from figure 3 low efficiency of fibrilated fibers as to reach the same curve of distribution of crack occurance probability as sample M19,1-0,297 performed, roughly three times bigger dose of fibrilated fibers has to be used.

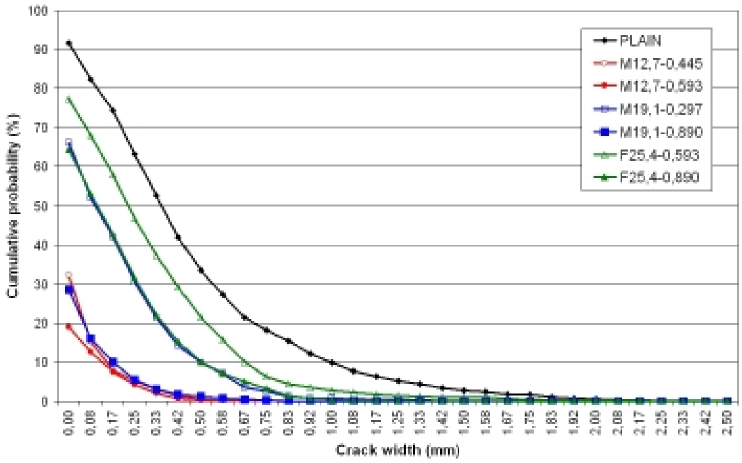


*Figure 2. Curve of cumulative probability of occurance of certain widths of crack*

Table 2, through "CRR", clearly proves that the efficiency of fibers rises inversly proportional to their length – e.g. M12,7 at dose 0,445 kg/$m^3$ are just as effective as fibers M19,1 at double dose. According to "CRR" it´s evident that lower efficiency of fibrilated fibers relates with it´s lower specific surface and tendency to clumping and thus do not disperse uniformly. Second very important parameter is probability of occurance of tight cracks (less than 0,25 mm in width) which are generally considered to have a chance to close themselves up after penetration of additional (external) moisture and hydration of unhydrated coarse cement particles. Moreover, it´s important to notice that sufficient CRR were achieved even at 2/3 of dosages recommended by fibers´ producers.

*Table 2. CRR, average crack widths and probability of occurance of certain cracks*

| Mixture | CRR (%) | Fibers (kg/m$^3$) | Crack width (mm) | | Probab. of crack width ≤ 0,25 mm |
|---|---|---|---|---|---|
| | | | Average | Maximum | |
| Plain | 0,00 | 0,0000 | 0,5958 | 2,9996 | 25,56 |
| M12,7-0,445 | 90,70 | 0,4450 | 0,0554 | 0,8332 | 92,06 |
| M12,7-0,593 | 93,38 | 0,5930 | 0,0394 | 0,8332 | 92,40 |
| M19,1-0,297 | 64,20 | 0,2970 | 0,2133 | 1,9164 | 57,86 |
| M19,1-0,890 | 90,46 | 0,8900 | 0,0568 | 0,8332 | 89,98 |
| F25,4-0,593 | 44,66 | 0,5930 | 0,3297 | 2,7496 | 42,14 |
| F25,4-0,890 | 63,83 | 0,8900 | 0,2153 | 1,3331 | 57,34 |

## 4. CONCLUSIONS

From the results of the experiments flows undoubted efficiency of fine polymer fibers in reduction of plastic shrinkage cracking. More precise correlations between fibers´ characteristics, dosages and efficiency lack an extensive research. At this moment, it may be stated that default minimum dosage 0,9 kg fibers per 1 m$^3$ of fresh concrete (recommended by their producers) safely eliminates plastic shrinkage cracking. Actually even dosage 0,6-0,7 kg/m$^3$ of fibers might by sufficient for cocnreting structures at hot weather. This range flows from laboratory tests of monofilament fibers 12,7 (1/2 inch) in length.

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