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LASER SYSTEM FOR TESTING EARLY SHRINKAGE OF CONCRETE ELEMENTS IN CONJUCTION WITH THE DETERIORATION OF THE SETTING TIME

Abstract

The paper presents a method for testing the shrinkage of concrete beams with dimensions of 10x10x50cm. Measurements followed from setting into the form until 24 hours after setting. It was used modified TLS system, which originally was meant for the determination of changes in the length of thin-mortar. Simultanously measured were the changes of speed propagation of sound waves by Vikasonic, what allows to specify the setting time of binders. It could be a base for determining the scratch resistance of the concrete in the first 24 hours after casting.

Keywords

Early shrinkage, setting time.

1 INTRODUCTION

Shrinkage of composite materials in which cement paste is the matrix is connected to several processes which are often simultaneous. From the moment of combining the consituents of the cement paste, autogenous shrinkage occurs, due to the fact that the volume of the paste constituents is smaller than the volume of the hydration products of the reaction. Chemical shrinkage lasts more or less until the end of the setting time of the cement. Progressing hydration causes the process of self-drying; the solution which fills the capillaries is "consumed" by the ongoing hydration, causing tensile stress and, as a result, shrinkage. Capillary action is also responsible for shrinkage occurring during drying. The water in the capillary pores, while migrating to the surface of the element, produces negative pressure which causes stress. If the resulting stress is higher than the tensile strength of concrete, cracks and micro-fractures of concrete will appear. Cracks may propagate further because of the loads, thereby the properties of concrete can be further degraded. Cracks caused by shrinkage reduce the value of mechanical properties, in particular tensile strength. In cracked concrete lagging ceases to be a barrier protecting the reinforcement, which in turn becomes susceptible to corrosion. Cracked concrete is also a cause for impaired water tightness and frost resistance. In pre-stressed constructions great drying shrinkage causes a significant loss of pre-stressing force.

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The mechanism of shrinkage is well known, but is still the subject of research [1, 2, 3, 4, 5]. These works include both the phenomenon of shrinkage, the impact of technological factors [6], research methodology [7] as well as computer modeling using eg. FEM [8]. Topic of early shrinkage has grown in significance due to the development of a new branch of concrete technology – technology of high performance self-compacting or traditionally thickened concretes. Low w/c ratio and a significant amount of binder, specific for these technologies, are responsible for a significant change in volume in the first 24 hours of setting. Measuring these changes is more complicated than the measurement of drying shrinkage, as it requires specialized equipment. Very often for this type of measurement are used systems based on laser length measurement. One of them is TLS system used to measure changes in linear dimensions of the 210 x 180 x 5 mm samples of mortars [9].

The TLS system (thin layer shrinkage) (Fig. 1, 2) exhibits good ability to measure changes in linear composites with cement matrix in a set of changing technological factors such as the composition of concrete mix or climatic conditions. In [10] presented are the results of research into the influence of viscosity enhancing admixtures on the early shrinkage of mortars. The use of hydroxypropylmethylcellulose and admixtures based on synthetic co-polymers enables to reduce shrinkage in the early stages of setting and hardening of the binder, that is, in the phase in which the composite does not have sufficient strength to resist the appearing tensile stress. Changes of length of the mortar samples (composition of mortars are shown in the Table 1) are shown in Fig. 3. The obtained results are consistent with the results presented in paper [2]. The use of viscosity-enhancing admixtures allowed to reduce the shrinkage and therefore had a positive effect on the crack-resistance of the composite.

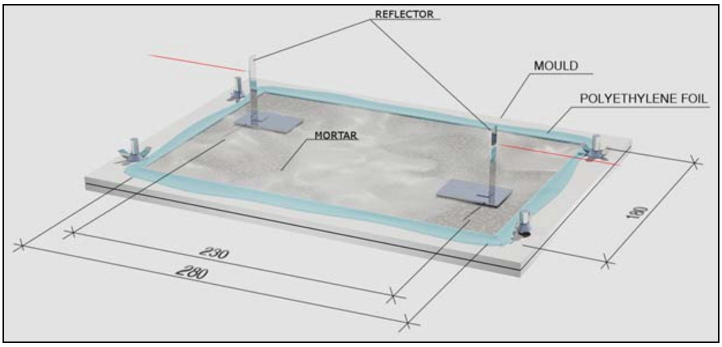

Fig. 1: The mortar sample with reflectors placed on its surface

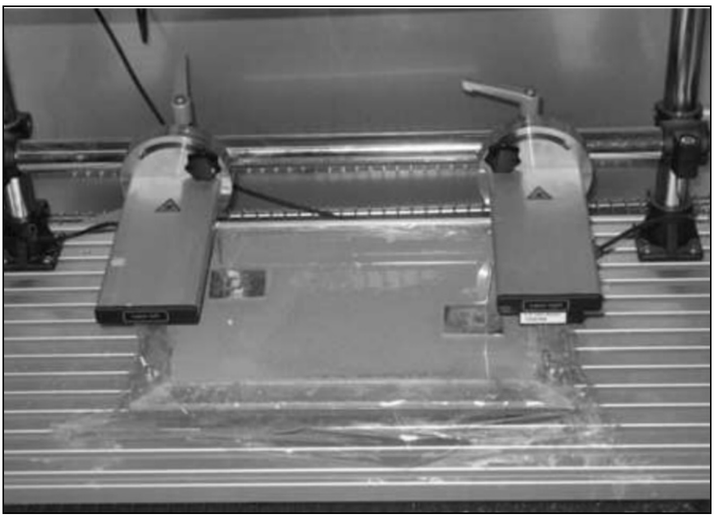

Fig. 2: Thin layer Shrinkage System in climatic chamber

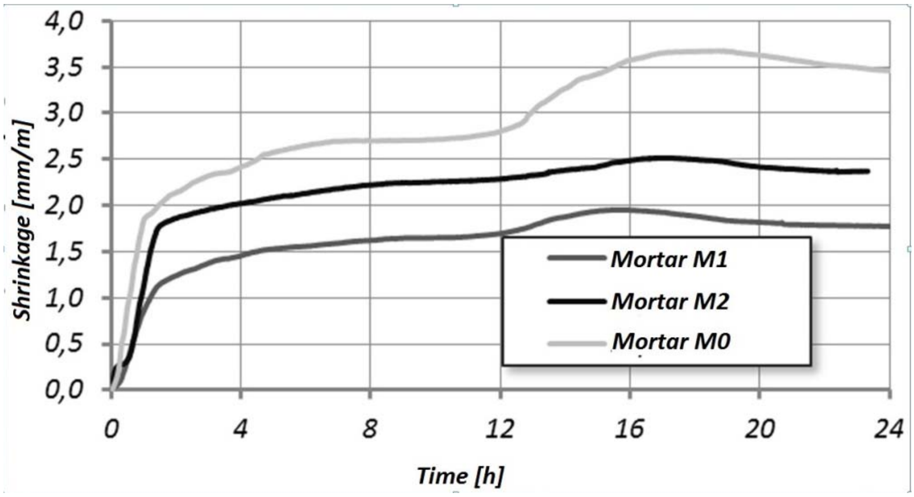

Fig. 3. Change of the length of the mortars with viscosity-enhancing admixtures during first 24 hours

Tab. 1: Composition of mortars for 1 dm^3 [1]

Constituent [g/batch]	Mortar		
	M0	M1	M2
CEM I 42,5 R	525		
Water	236		
Standard sand	1516		
Superplasticizer	2.6	5.2	4.6
VMA 1	-	0.139	
VMA 2			5.37

2 CHARACTERISTICS OF THR SYSTEM AND ITS MODIFICATIONS

In its basic version, TLS has the capabilities that require only a small alteration to be significantly broadened. Using a measuring system enables to test the shrinkage of concrete elements with dimensions of 10 x 10 x 50 cm in the first 24 hours after their casting. After 24 hours, hardened beam can be used for testing the drying shrinkage by the Amsler's method. The fundamental problem in the measurement of early shrinkage is ensuring the freedom of deformation of the element. This freedom is limited by the friction between the element and the walls of the form. There are various proposals as to how to reduce this effect, eg. through the use of Teflon spacers. In the solution suggested by the authors, a form made of formwork plywood is lined inside with polypropylene foam and polyethylene foil (Fig. 4). Compressible polypropylene foam allows the potential expansion, while the foil reduces friction, thus limiting the volume changes the least. Changing dimensions of the element are relayed to the reflectors of laser beams through the anchored in the concrete mix screws M8 x 40 mm, which are screwed to the metal fittings on each end pf the beam (Fig. 5). After the shrinkage test, metal fittings and reflectors can be removed, however anchored screws remain in the beam. The protruding fragments of a screws are used as benchmarks for measuring the drying shrinkage by Amsler's method.

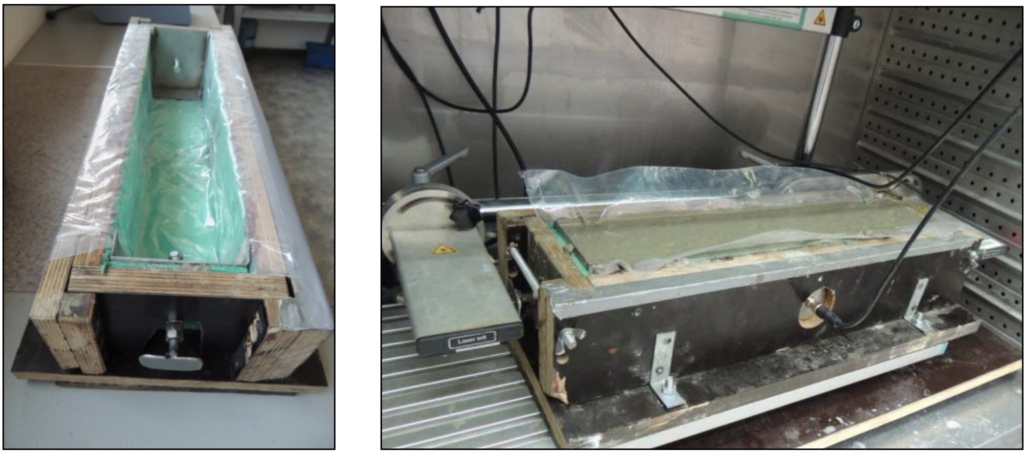

Fig. 4: Mould for measuring the early shrinkage (left), mould in the climatic chamber (right)

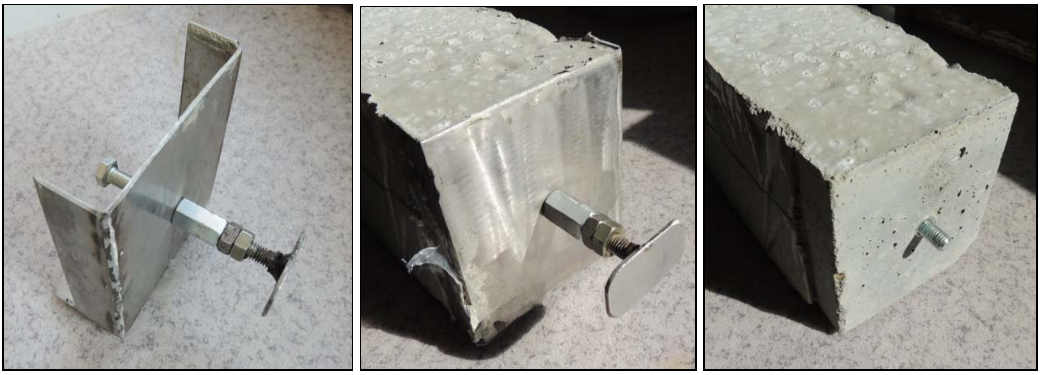

Fig. 5: Reflector of the laser beam and its anchoring

The study of the changes of the length of samples in the first 24 hours, although interesting in itself, takes on a particular importance only after relating it to the initial setting time of the binder. It can be used as an indicator of the level of damaging effects of the determined shrinkage on concrete durability. It is reasonable to say that the shrinkage observed before the determined initial setting time of the binder will not cause cracks, however after this time a part of the shrinkage can be dangerous for the hardening concrete, especially due to the fact that its tensile strength is relatively small. Knowing the size and dynamics of development of shrinkage-induced changes in concrete following the initial setting of the binder allows to assess the subscrebility of concrete to cracking caused by the shrinkage deformation. The initial setting time can be determined by a standard Vicat test, however it is much better to define it for cement paste which is a part of the concrete mix. The setting time is significantly affected by the w/c ratio and chemical admixtures, without which it is difficult to imagine the technology of HPC and SCC. Therefore, the measuring system is equipped with ultrasonic device for determination of initial setting time - Vikasonic. The device is designed for determining the initial setting time of the binder contained in the cement paste or cement mortar placed in a standard Vicat ring. To be able to determine the "actual" setting time of the binder in the concrete mix, a transmitter and a receiver were placed one the sides of the 10 x 10 x 50 cm beam (Fig. 7) so that the pulse had to travel 10 cm. The time impulse requires to travel through setting fresh concrete is recorded in real time. Of course, the authors are aware of the limitations of such measurement method, mainly caused by the presence of coarse aggregate and phenomena occurring at the layer of contact between phases. However, setting time determined in this way has a more practical value than the setting time determined in the traditional way.

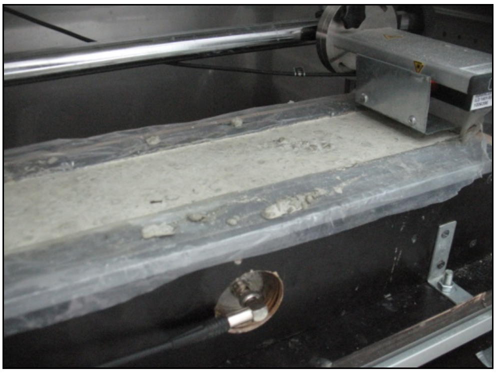

Fig.7: Location of the transmitter of ultrasonic pulse

3 RESULTS

For the time being, the authors' aim is not to discuss the mechanisms of shrinkage or the factors that can affect it. Following test results are brought up to establish credibility of the methodology of research, since it allows to obtain results which are consistent with recognized as legitimate mechanisms that cause shrinkage.

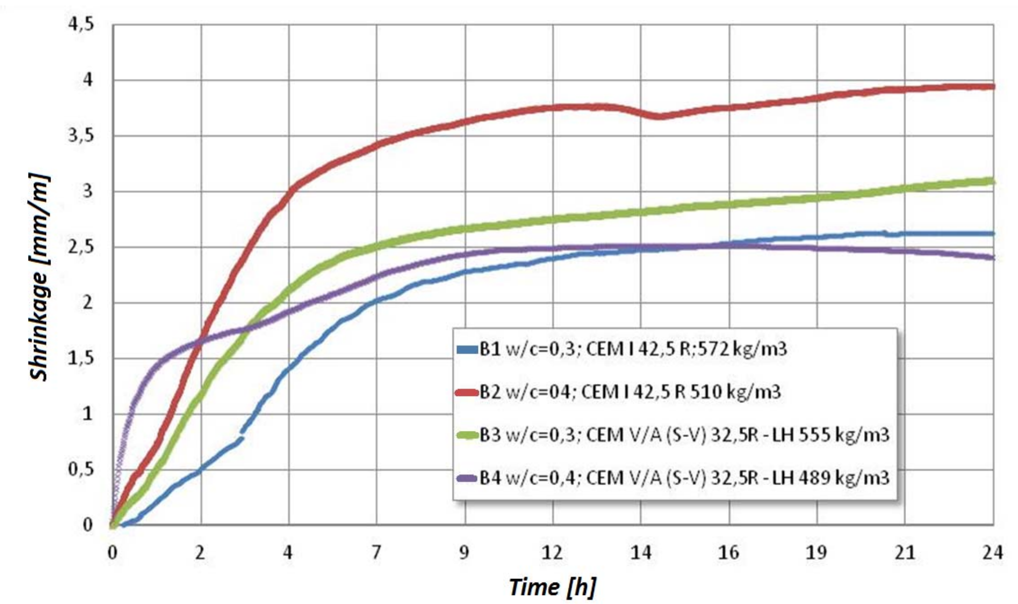

Fig. 8: Change the length of the beams, as measured in the first 24 hours of maturation

Figure 8 shows the changes of the length of the beams measured in the first 24 hours after placing in the form. Tested beams were made of self-compacting concrete mixes, which composition and basic characteristics are summarized in Table 2. All presented research into early shrinkage was carried out at 20° C and relative humidity of 60 %. It can be seen that in the first 4-6 hours, the growth rate of shrinkage is significant especially in the case of a sample from concrete mix B4, wherein the shrinkage in 2nd hour reached 65 % of the maximum shrinkage observed after 15 hours. This high rate of growth of shrinkage effects can be explained by the phenomenon of leakage of water from the cement paste to the surface of the sample, what was particularly evident in the case of the concrete mix B4. Migrating water causes a vacuum in the gel pores and capillaries, causing stress, which in turn causes shrinkage. In the case of sample concrete mix B4, course of changes of the sample length after 15 hours is interesting – it can be noticed that instead of the shrinkage, expansion occurs. It lasts for 30 hours, thus it reduces the maximum value observed after 15 hours by 11 %. After 30 hours, the test sample exhibited shrinkage again. In the case of concrete mixes made with Portland cement CEM I 42.5 R, beneficial effect of lower w/c ratio on the magnitude of shrinkage can be observed.

Tab. 2: Mixture composition of SCC

Concrete mix	CEM I 42,5 R	CEM V/A (S-V) 32,5R - LH	Water	w/c	SP Glenium Sky 115 [% m.c]	Sand 0-2	Aggregate 2-8	Slump flow [cm]	Time T_{500}, [s]
B1	572		172	0.30	3.0%	884	780	62	5.7
B2	510		204	0.40	1.0%			72	2.2
B3		555	167	0.30	2.5%			74	6.9
B4		489	195	0.40	1.5%			68	2.5

Below are presented the results of the research into early shrinkage of beams from regular concrete, compacted by vibration. Composition and basic properties are summarized in Table 3. Shrinkage of the elements made of those concretes after 24 hours is on average two times lower than of the elements made of self compacting concrete. It is connected with smaller amount of cement paste in the concrete compacted by vibrating and different aggregate composition. In concrete, the phase which undergoes shrinkage is the cement paste, while the aggregate limits it. Self-compacting concrete, which to reach appropriate rheological properties of the concrete mix requires a relatively large amount of cement paste, will be also exhibiting greater shrinkage than regular concrete.

Tab. 3: Composition and constituents of the regular concrete mixes

Constituent	B0	B0M	B2	B2M	B3	B3M
Cement	330	330	292	292	311	311
Fly-ash	0	0	96	96	47	47
Water	160	160	160	160	160	160
W/C	0.48	0.48	0.55	0.55	0.51	0.51
W/B	0.48	0.48	0.48	0.48	0.48	0.48
Sand 0-2	706	706	673	673	690	690
Aggregate 2-8.	446	446	425	425	436	436
Aggregate 8-16.	706	706	673	673	690	690
Plasticizer SX32	4.62	4.62	5.43	5.43	5.01	5.01
Plasticizer BV34	1.65	1.65	1.94	1.94	1.79	1.79
Methylcellulose		0.066		0.078		0.072

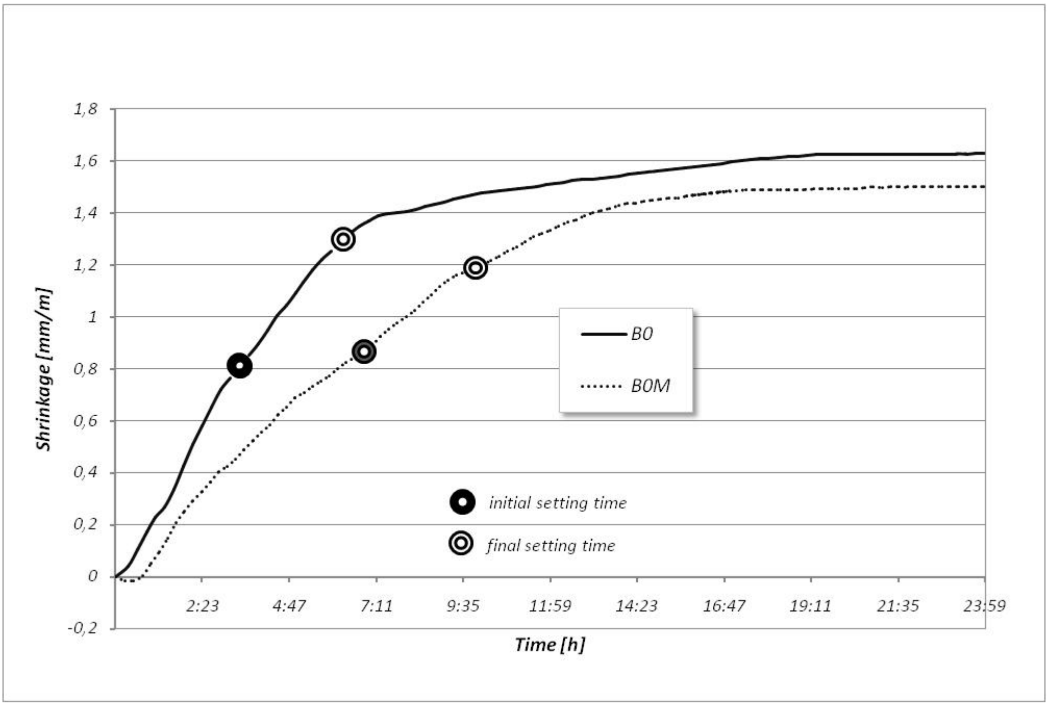

Fig. 4: Shrinkage of 10 x 10 x 50 cm beams of concrete without fly-ash (B0 and B0M) during first 24 hours

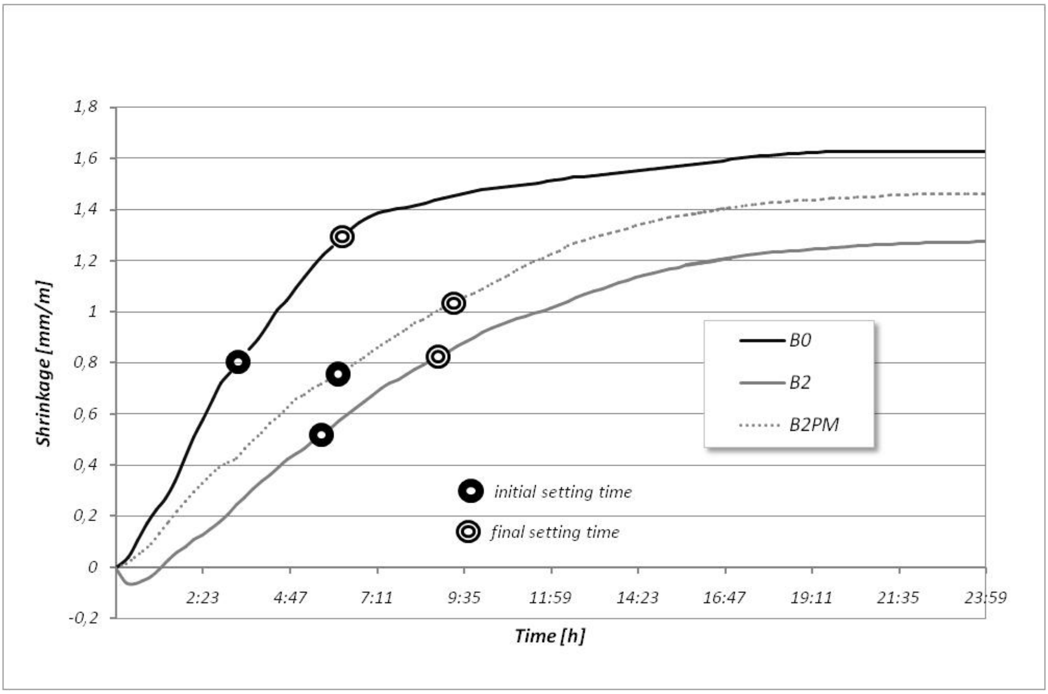

Fig. 5. Shrinkage of 10 x 10 x 50 cm beams made of concrete with 47 kg/m^3 fly-ash during first 24 hours

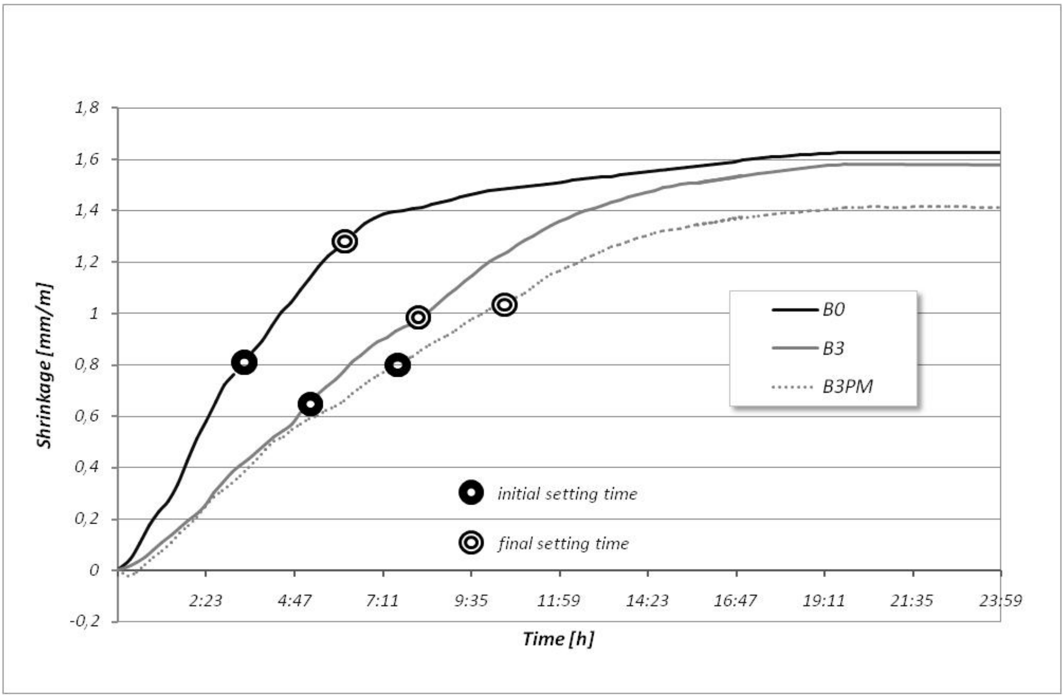

Fig. 6: Shrinkage of 10 x 10 x 50 cm beams made of concrete with 96 kg/m^3 fly-ash during first 24 hours

Up to certain moment, shrinkage is transferred plastically, and when the concrete becomes an elastic body, shrinkage will cause the tensile stress that increases with shrinkage's growth. The point at which the concrete is no longer plastic, and becomes elastic body can be associated with the initial setting time of the binder. Final setting time may correspond to the moment where the concrete is no longer able to undergo the plastic deformation caused by shrinkage. In order to assess the susceptibility to cracking, the growth rate of shrinkage during the setting of the binder was determined (Tab. 4).

Tab. 4: Setting time and growth rate of shrinkage during the setting of the binder

Mixture	Setting time [h:min]			Shrinkage at the moment of		The growth rate of shrinkage during the setting time of binder [mm/h]	Shrinkage at the 24h [mm/m]
	initial	final	initial-final [min]	initial setting time [mm/m]	final setting time [mm/m]		
B0	3:24	6:08	164	0.76	1.29	0.47	1.62
B0M	6:50	9:58	188	0.87	1.18	0.38	1.50
B3	5:11	8:12	181	0.65	0.99	0.33	1.52
B3PM	7:24	10:35	185	0.8	1.04	0.34	1.41
B2	5:44	8:58	194	0.52	0.83	0.26	1.27
B2PM	6:07	8:40	212	0.75	1.04	0.29	1.46

In the case concrete mix without fly-ash an addition of methylcellulose decreased the growth rate of shrinkage during setting from 0.47 mm/h to 0.38 mm/h. In the case of concrete mixes containing 15 % fly ash (CEM 311 kg/m^3 and fly ash 47 kg/m^3) the growth rate of shrinkage is similar with or without methylcellulose. For concrete mixes with 33 % of fly-ash (CEM 292 kg/m^3 and fly ash 96 kg/m^3) methylcellulose slightly increased the growth rate of shrinkage.

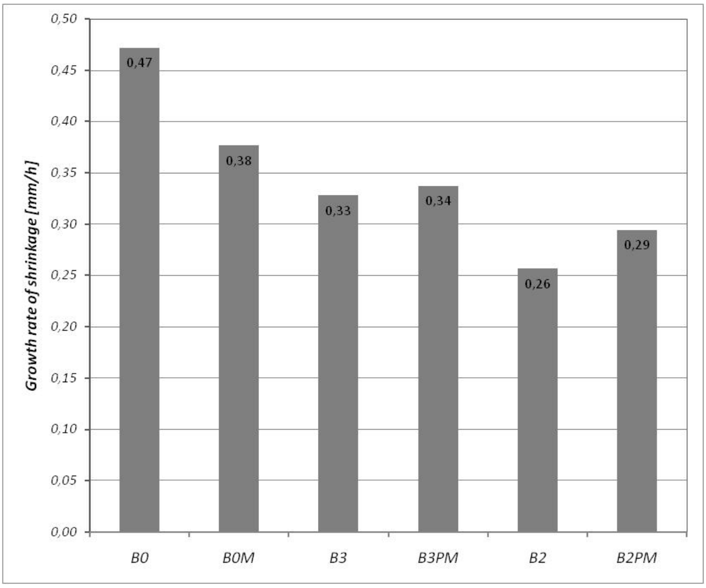

Fig. 4: Growth rate of shrinkage between initial and final setting time of the binder, determined ultrasonically

The use of methylcellulose in the case of concrete without fly-ash or with addition of 15 % of fly-ash as a replacement for the part of cement enabled to reduce the shrinkage at 24 hours after casting. In the case of concrete with 33 % fly-ash as a replacement for the part of cement exhibited the opposite effect (Fig. 5).

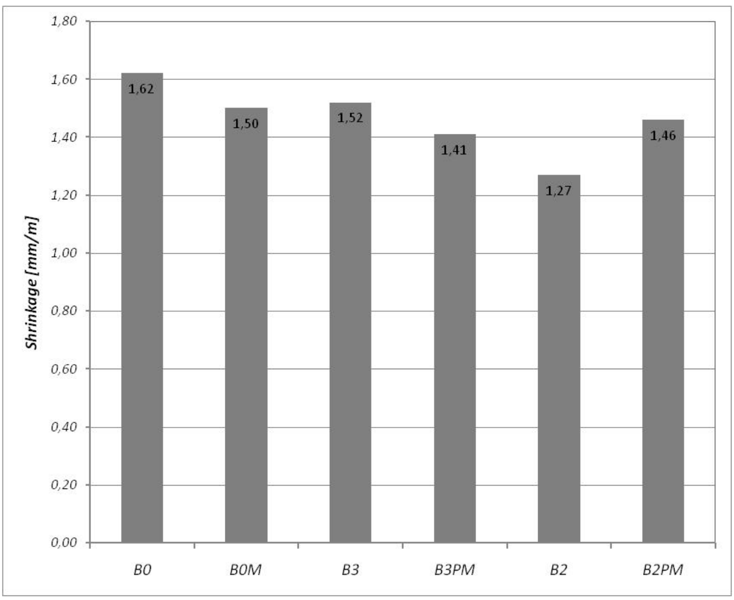

Fig. 5: Shrinkage 24 hours after casting of 10x10x50cm beam

Methylcellulose reduces the shrinkage growth rate during the setting of the binder; during this time the concrete becomes subscrebtible to cracking induced by shrinkage. The susceptibility is higher the greater is the growth rate of shrinkage and consequently, the greater is the tensile stress caused by shrinkage. Reducing the rate of growth can protect "young concrete" from cracking. In this case the use of methylcellulose appears to be beneficial. The beneficial effect of the use of methylcellulose is also evident at 24 hours, while in the case of concrete without or with 47 kg/m^3 fly-ash, shrinkage decreased by approx. 7 %. This effect should be associated primarily with methylcellulose's ability to bind water, which impedes migration of water from capillary pores. This leads to smaller capillary force and, consequently, shrinkage.

4 CONCLUSIONS

The developed procedure of sample preparation allows to measure the changes in length of concrete beams from the moment of their casting. On the basis of the setting time determined by ultrasonic method, or rather a moment in which the stiffness of the composite begins to increase, we can estimate the susceptibility of concrete to cracking during the first 24 hours. During this period, the strength of concrete is only starting to form, and shrinkage-induced stress can exceed its tensile strength. Changes in the length of the elements during the first 24 hours are characterized by a high growth rate, what is typical of the next generation concrete. The developed methodology of research allows to determine the effect of technological factors on the early shrinkage. Due to that, it is possible to obtain sufficiently reliable information which can be used to validate numerical models for estimating the size of shrinkage deformation.

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