XV International Conference on Durability of Building Materials and Components
DBMC 2020, Barcelona
C. Serrat, J.R. Casas and V. Gibert (Eds)

Influence of Surface Treatment of Fresh Concrete on its Resistance to Drying Shrinkage

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Abstract. *The volume changes of cement-based composites are significantly exhibited during the hardening process. Initial phases of the hardening are complemented by the expansion due to the heat evolution that is subsequently alternated by the shrinkage. Both could cause the crack initiation causing significant loss of the durability and service-life shortage. The present paper focuses on the experimental investigation of the surface treatment of fresh concrete, which is applied to prevent sudden loss of the moisture during a hardening process, especially during the concrete highway construction. The technology of concrete highway production is extremely costs demanding, but its efficiency is determined by the longer lifespan in comparison with the asphalt pavement. However, negative impacts of the drying shrinkage could significantly reduce the durability. The efficiency of used treatment was investigated in terms of restrained shrinkage tests, water adsorption and mechanical testing. In addition, there were studied two types of conventional Portland cement. Performed program confirmed great sense of the curing on the concrete durability; in addition, there was well illustrated the efficiency of the utilization of blended binder systems in the paper.*

Keywords: *Concrete Permeability, Drying Shrinkage, Surface Treatment.*

1 Introduction

The concrete is the most used material for the construction of civil infrastructure worldwide. The fundamental part of the structural concrete is Portland cement, which exhibits hydraulic properties and sufficient mechanical and also durability performance. There is a number of various types of cements, that are based on Portland clinker, however these cement types were primarily developed for the specific applications (Aitcin, 2000). For example, blended systems are preferably used for massive structures for the reduction of total hydration heat and also volume changes (Lotenbach *et al.* 2011; Vinkler and Vítek, 2019). On the other hand, due to rapidly increasing price of human work there are currently preferred technologies limiting number of craftsmen on the construction site and approaches significantly accelerating the process of construction.

These technologies often lead to the supressing of specific technological steps, such as curing. Portland cement based concrete is hydraulic material, which is sensitive for a sudden loss of moisture during hydration. Surface treatments in form of thin films are applied to prevent the drying of concrete after its casting, because hardened mass of concrete significantly reduces its diffusivity. The quality of surface layer of concrete is crucial in relation to the durability, because this thin part of structure determine final resistance to the impact of external environment. The deterioration of the concrete “skin” during hardening is the most frequent reason of the damage during structure operation. Traditional exhibition of the problem in concrete surface layer is the presence of micro cracks or tendency to release dust particles. These failures of concrete surface subsequently lead to the increased transport of water, which significantly contributes to the gradual degradation of the structure (Reiterman *et al.,* 2019; Holcapek *et al.,* 2014). The ingress of deicers and freezing-thawing are the main mechanisms causing the degradation of concrete infrastructure (Glinicki *et al.,* 2016). The effect of frost causes propagation of cracks and their depth, and deicers, mostly on the basis of chlorides, lead to the chemical corrosion of concrete, surface scaling and corrosion of the embedded steel rebars. Hence, the permeability of concrete surface has crucial sense in relation to the lifespan of concrete structures.

2 Experimental Program

Conducted experimental program was focused on the evaluation of the quality of concrete surface layer, of which properties were modified by the application of surface treatment to prevent sudden evaporation of the moisture. This technology is used during the production of concrete pavement by the roller, and also after production of continues concrete guardrails. This effect was studied on standard cement mortars with the fraction of sand to cement 3:1, water to cement ration was set to 0.45. There were used two types of Portland clinker-based cements – CEM I 42.5 (SC) and CEM II 32.2 B-S, of which properties are introduced in Table 1.

Table 1. Properties of used cements.

Properties	CEM I 42.5 R (SC)	CEM II 32.5 B-S
CaO	63.80 %	50.51 %
SiO_2	20.60 %	27.24 %
Al_2O_3	4.80 %	7.85 %
Fe_2O_3	3.40 %	2.72 %
MgO	1.40 %	3.75 %
SO_3	3.20 %	2.85 %
K_2O	0.74 %	0.77 %
NaO	0.20 %	0.36 %
LOI	1.40 %	1.1 %
Blaine	311 m^2/kg	345 m^2/kg

CEM I 42.5 (SC) is a specific type of Portland cement, produced in Czech Republic, which is intended for the utilization during the construction of road pavement and transport structures. Its significant feature is low content of C_3A and lower value of specific surface by Blaine. CEM II 32.2 B-S performs cement with the content of blast furnace slag, which stands out from low hydration heat, low shrinkage and long-term evolution of mechanical properties.

Fresh mortars were prepared in laboratory mixer and sets of specimens were casted. Standard prismatic specimens 40×40×160 mm were used for the determination of mechanical properties in terms of EN 196-1.

Transport properties of cement mortars were studied using cylindrical specimens of height 50 mm and diameter 150 mm. A half of these samples were approximately 5 minutes after casting sprayed by surface agent to prevent evaporation. A commercial product Novapor HV, on the basis of ethoxylated alcohol was used in the program. Recommended amount of the treatment is 200 – 250 g/m^2. A second half of samples served as a reference set. These cylindrical specimens were subsequently weighed to monitor the loss of the moisture in time. After 28 days were cylinders extracted from plastic molds, sealed on the lateral sides and they were subjected to the determination of water adsorption test to assess the surface quality. Samples were partially wetted into the water basin with downward orientation and the gradual ingress of water mass was gravimetrically determined.

The loss of the moisture has direct influence on the values of the shrinkage, respectively to drying shrinkage, because ultimate level of shrinkage is affected also by the mineralogy and properties of used cements (Davidova and Reiterman, 2020; Deboucha *et al.*, 2017; Nili and Ehsani, 2015). The dimensions of the ring are rather small, which enables quicker testing of mortar susceptibility to cracking. The method consists of casting a ring of mortar around a polished ring of steel and its following spontaneous hardening and drying under normal laboratory conditions. As the mortar attempts to contract against the restraint of steel ring, tensile stress develops in the mortar ring and it might crack. The crack initiation is usually monitored visually in selected time intervals. The mortar rings had cross-section 25 mm in radial thickness and 38 mm deep. With respect to nature of testing, fresh surface of a half of samples was treated by surface agent as well. Subsequent drying was conducted only through upper part of the ring, because the rings were kept in the mold during to test to prevent drying of the part, which cannot be treated.

3 Results and Discussion

The conducted experimental program was focused on the properties of concrete surface in terms of the restrained shrinkage and transport properties, which determine final durability of the concrete and life-span of the structure. Part of the samples was treated by surface agent, which protect fresh concrete surface from the sudden loss of the moisture. Also two types of cement with different properties and hydration kinetics were studied in the paper.

Obtained results of the loss of the moisture of all sets of samples are introduced in Figure 1. It is evident, that reference and treated samples are very sensitive for the evaporation of the water during initial hours of the hardening, where the effect of the treatment is very low. However, after the setting, when solid structure occurs, the studied process is controlled by the diffusion, what well declare obtained curves. There is evident contribution of used treatment from the long-term point of view. There is also visible difference in the efficiency for single cement types. In case of blended system was the improvement over 20 %, however in case of pure Portland cement is the improvement only just about 5 %. It is caused by the different hydration kinetics; rapid setting is more suitable.

Determination of mechanical properties confirmed expected slower development of mechanical performance in case of blended cement. Detailed values are introduced in Table 2. On the other hand, values of compressive strength after 28 days of curing are relatively high. Nevertheless, high kinetics of the setting usually lead to the cracking. Conducted tests of restrained shrinkage did not confirmed this hypothesis, what is well visible on Figure 2.

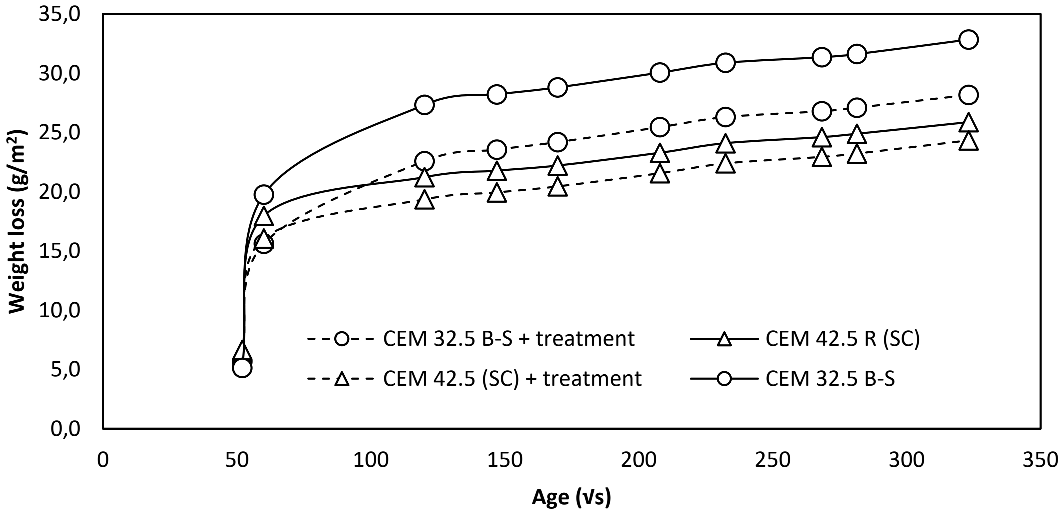

Figure 1. Monitored loss of the moisture in time.

Sudden change of the strain signalizes the moment of the rupture of mortar ring. The measurement of shrinkage declared, that mortar made of CEM I 42.5, which is specially prepared for transport structures, treated by surface agent is well resistant to the cracking. The remaining set of samples cracked approximately after 30 days of drying. However, it is necessary to note, that the time of rupture is dependent on the organization of the test. Only upper surface was exposed to the drying, what significantly extended the rupture time. Previous experiment declared, that in case of three-side drying, the rupture time could achieve a few days.

Table 2. Mechanical properties of used cement mortars.

Flexural strength [MPa]	CEM I 42.5 R (SC)	CEM II 32.5 B-S
1 day	2.9	1.8
3 days	8.1	2.7
7 days	9.7	5.7
28 days	9.8	9.5
Compressive strength [MPa]		
1 day	27.4	4.6
3 days	49.4	12.7
7 days	57.0	24.2
28 days	68.1	52.7

Results of water adsorption test are shown in Figure 3, there is well visible an improvement of the impermeability due to applied surface treatment, used type of cement respectively. On the other hand, obtained differences in non-treated samples are very low, especially up to 15 minutes. Just this short-term water adsorption has significant sense in case of the durability. For both set of samples was the achieved level of improvement about 20 %.

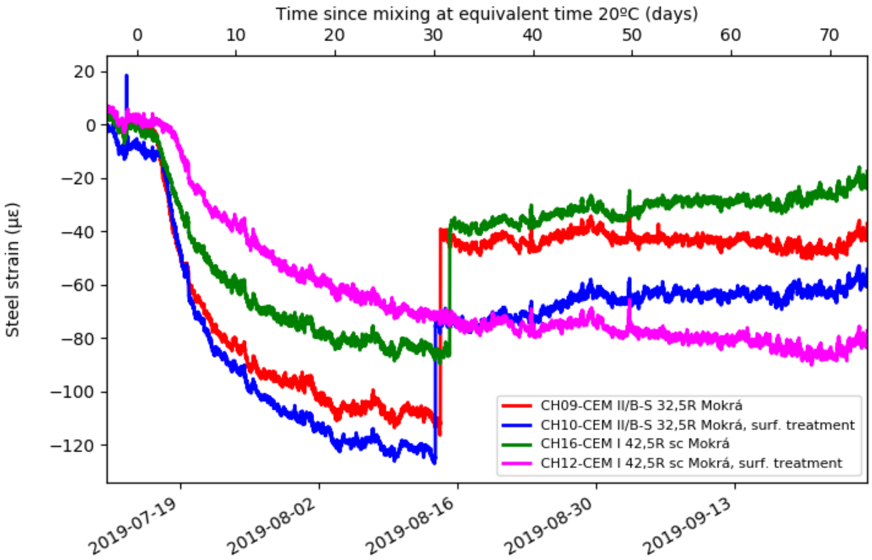

Figure 2. Results of the restrained shrinkage tests.

These results document the problem of concrete cracking during production of concrete pavement. Drying shrinkage, which is controlled by the diffusion, motivates to use binder with higher kinetics of hydration. On the other hand, higher kinetics contributes to the evolution of hydration heat and initial chemical shrinkage resulting in microcracks initiation. Generally, it is necessary to balance both preventive intervention. During past years CEM II 42.5 N/ B-S was often used during production of concrete pavement, the motivation for the selection of this type of cement was lower hydration kinetics, which positively mitigates risks of cracking. However, number of cracks has occurred shortly after the casting. It was caused by increased finesses of the cement to fulfill a required mechanical parameters, which caused higher hydration kinetics in comparison with CEM I 42.5.

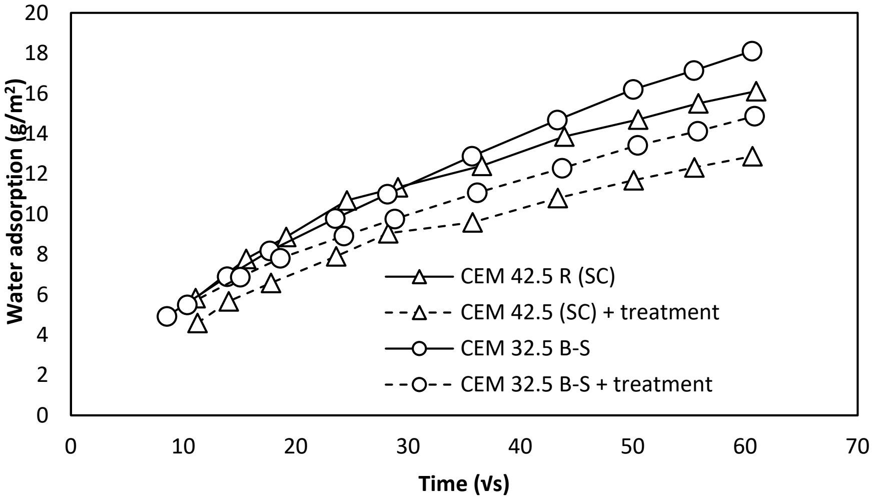

Figure 3. Results of water adsorption test.

4 Conclusions

Performed experimental program was focused on the evaluation of the efficiency of surface treatment, which is applied to prevent sudden evaporation of the water and subsequent progress of cracks due to drying shrinkage. The program conducted on standard cement mortars declared, that blended binding systems are prone to loss of the moisture. In addition, blended cement exhibited higher tendency to cracking in terms of restrained shrinkage test, the studied surface treatment did not improve this property as well. Achieved results confirmed the improvement of water impermeability, however short-term water adsorption was nearly similar for all sets of samples, except of samples made from road cement, which were treated on their surface; they exhibited slightly lower permeability of the surface layer. Obtained results indicate suitability of Portland cement, which is produced for the specific application in transport concrete structures.

Acknowledgements

This research work was financially supported by project of over project COST No. LTC18063 and FV30062.

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