OPPORTUNITIES FOR DRYING SHRINKAGE MINIMIZING IN FIBER-REINFORCED CONCRETE OVERLAYS FOR REPAIRING OF CORRODED INDUSTRIAL STRUCTURES

Valeriy B. Naidenov, Mirona K. Mironova

Institute of Mechanics, Bulgarian Academy of Sciences, Acad. G. Bonchev Street, Block 4, 1113 Sofia, Bulgaria

Abstract

The reinforced concrete structures of most industrial sites suffer severe corrosion damage caused by various factors - mainly from the environment corrosion and specific production conditions. The need to design and perform the necessary repairs becomes urgently important. In recent years, the implementation of such repair works by using of properly reinforced thin overlays of concrete with special mix design has become increasingly relevant. Meanwhile these special composites have to be fully completely protected against any type of cracking especially from shrinkage ones. The use of special concrete with compensated drying shrinkage based on ordinary Portland cement and special shrinkage compensating admixtures is a much more attractive option - simply because the provision of special cements for each case is (to say the least) inconvenience of different types. This is exactly the approach used in the current research aimed at assessing the effectiveness of shrinkage compensating chemical admixture KEPTONITE applied in exactly the same concrete mix design made with the most commonly used different types of cement produced by Bulgarian factories. In this direction special testing program is fulfilled and original testing results are obtained and discussed. It is concluded that KEPTONITE demonstrates very good performance in direction to strongly minimize the final shrinkage of the concrete tested. The different dosage rate of KEPTONITE is optimal for Bulgarian cement used for testing.

Keywords: *concrete compressive strength, concrete structures, drying shrinkage, shrinkage compensating admixture, thin repair overlays*

1. INTRODUCTION

In the course of many years of operation, the reinforced concrete structures of most industrial sites suffer severe corrosion damage caused by various factors - mainly from the environment corrosion and specific production conditions. At some point, the need to design and perform the necessary repairs becomes urgently important.

In recent years, the implementation of such repair works by using of properly reinforced repair thin overlays of concrete with special mix design has become increasingly relevant. In this sense, designing such thin repair overlays with the necessary full security against cracks of different nature is the most important condition for the quality of the repair work.

Generally speaking, cracks in concrete structures usually mean problems – of course the potential damages strongly depend on the type of cracks observed. A popular cracks classification and basic prerequisites for their occurrence could be as follows:

Cracks before concrete hardening (fresh concrete plastic stage):

- rare - early frost damages;
- plastic - plastic shrinkage, plastic settlement;
- constructional movement - formwork movement, sub-grade movement.

Types of cracks after concrete hardening:

- physical - shrinkable aggregates, drying shrinkage, crazing;
- chemical - corrosion of reinforcement, alkali-aggregate reaction, cement carbonation shrinkage;

- thermal - freeze-thaw cycles, temperature variation, early thermal contraction (external restraint, internal temperature gradient);
- structural - accidental overload, creep, design loads.

The common cause of cracking in concrete is shrinkage due to drying. This type of shrinkage is caused by the loss of moisture from the cement paste constituent, which can shrink by as much as 1% per unit length. Unfortunately, aggregate provides internal restraint that reduces the magnitude of this volume change to about 0.05%. Upon wetting, concrete tends to expand. These moisture-induced volume changes are an inherent characteristic of concrete. If the shrinkage of concrete could take place without any restraint, the concrete would not crack. It is the combination of shrinkage and restraint, which is usually provided by another part of the structure or by the subgrade that causes tensile stresses to develop. When the tensile stresses of concrete are exceeded, it will crack. Cracks may propagate at much lower stresses than are required to cause crack initiation.

In massive concrete structure elements, tensile stresses are caused by differential shrinkage between the surface and the interior concrete. The larger shrinkage at the surface causes cracks to develop that may, with time, penetrate more deeply into the concrete.

There are some conventional ways to minimize the drying shrinkage – optimal concrete mix design with as much as possible lower water-cement ratio (especially by using HRWRA), specific fiber-reinforcement, different type of joints organizing (if it is possible, at all) and proper curing procedures.

In most specific cases of the application of thin repair overlays to repair corroded reinforced concrete structures in industrial plants, these measures are not sufficient to ensure continuity and impermeability of the newly overlays - without any cracks in the fully cured the concrete drying shrinkage.

The designing and implementation of thin concrete-based repair overlays, etc. compensated drying shrinkage concrete is a revolutionary technology with indisputable technical advantages *(Neubauer, 1997), (Collepardi, 2005), (Maltese, 2005), (He, 2006), (Collepardi, 2008), (Monosi, 2011), (Jason, 2017), (*Cao*, 2017)*

As it is written in **ACI 223R-10 Guide for the Use of Shrinkage-Compensating Concrete (**Reported by ACI Committee 22) "*Shrinkage-compensating concrete is made with an expansive cement or expansive component system in which initial expansion, if properly restrained, offsets strains caused by drying shrinkage."*

Three types expansive cement are specified:

- **type K -** a mixture of portland cement, anhydrous tricalcium trialuminate sulfate (C_4A_3S), calcium sulfate ($CaSO_4$), and lime (CaO);
- **type M -** interground or blended mixtures of portland cement, calcium-aluminate cement, and calcium sulfate suitably proportioned;
- **type S -** portland cement containing a high computed tricalcium aluminate (C_3A) content and an amount of calcium sulfate above the usual amount found in portland cement.

Four types expansive component systems (a combination of portland cement and expansive component that when mixed with water forms a paste that, after setting, increases in volume to a significantly greater degree than portland cement paste) are specified :

- **expansive component Type K -** a blend of calcium sulfoaluminate and calcium sulfate that produces ettringite when mixed with portland cement and water.
- **expansive component Type M -** blend of calcium aluminate cement and calcium sulfate that produces ettringite when mixed with portland cement and water.
- **expansive component Type S -** blend of tricalcium aluminate (C3A) cement and calcium sulfate that produces ettringite when mixed with portland cement and water.

- **expansive component Type G -** a blend of calcium dioxide and aluminum dioxide that produces calcium hydroxide platelet crystals when mixed with portlan cement and water.

Practically speaking, the use of concrete with compensated drying shrinkage based on ordinary Portland cement and special shrinkage compensating admixtures is a much more attractive option - simply because the provision of special cements for each case is (to say the least) inconvenience of different types. This is exactly the approach used in the current research aimed at assessing the effectiveness of shrinkage compensating chemical admixture (KEPTONITE) applied in exactly the same concrete mix design made with the most commonly used different types of cement produced by Bulgarian factories.

2. MATERIALS AND METHODS

2.1. Materials

Three type of cement are used - TITAN CEM II 42,5 A-LL, HOLCIM CEM I 52,5 R and DEVNYA CEM I 52,5 R. The chemical and mineralogical compositions of the cement are presented in **Tables 1** and **2.**

Cement type	**Chemical Composition (% by mass)**							
	CaO	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**K_2O**	**Na_2O**	**SO_3**
TITAN CEM II 42,5 A-LL	65,99	21,60	4,40	4,20	1,50	-	0,60	0,50
HOLCIM CEM I 52,5 R	66,10	21,06	5,72	3,69	1,01	0,70	0,32	0,83
DEVNYA CEM I 52,5 R	65,80	20,90	5,20	3,60	1,20	0,90	0,50	1,00

Table 1. Cements - Chemical composition

Cement type	**Mineralogical Composition (% by mass)**			
	Tri-calcium Silicate (C_3S)*	**Di-calcium Silicate (C_2S)**	**Tetracalcium Aluminate (C_3A)**	**Tetracalcium Alumino-ferrite (C_4AF)**
TITAN CEM II 42,5 A-LL	64,40	13,00	4,60	12,80
HOLCIM CEM I 52,5 R	66,90	11,40	9,80	9,20
DEVNYA CEM I 52,5 R	65,50	15,50	7,20	9,7

*$C_3S = 4{,}071*(CaO - f.CaO) - 7{,}6*SiO_2 – 6{,}718*Al_2O_3 - 1{,}43*Fe_2O_3$

Table 2. Cements - Mineralogical composition

The mix design of ordinary reference concrete and respective ones with ShCA KEPTONITE (12, 15 and 18 kg/m^3, respectively) was used to perform the studies - **(Table 3)**.

№	Materials	Quantity, kg/m^3
1.	Portland cements: - **TITAN CEM II 42,5 A-LL**; - **HOLCIM CEM I 52,5 R;** - **DEVNYA CEM I 52,5 R**	330
2.	River sand, fraction 0-4 mm, Quarry "Chepinzi"	810
3.	Crushed stone, fraction 4-11,2 mm, Quarry "Studena"	1060
4.	ShCA KEPTINITE	0; 12; 15; 18
5.	Mixing water for fresh concrete slump 13 cm (S3)	≈250 (for reference concrete)

Table 3. Concrete mix design

Apart from the various shrinkage compensating admixtures in the market, ShCA KEPTONITE is based on single one component - calcium oxide super-synterizated with granulometric selected control with the sequential advantage:

- average dosages half of competition ones;
- no need to use in combination SRA admixtures;
- major early-stage reaction control and major stability at the long period phase;
- minor curing period;
- can be used any wet and chemical curing;
- major economic advantage.

The ShCA KEPTONITE chemical composition is approved by using X-ray and DTA-analysis – **Fig. 1** and **2.**

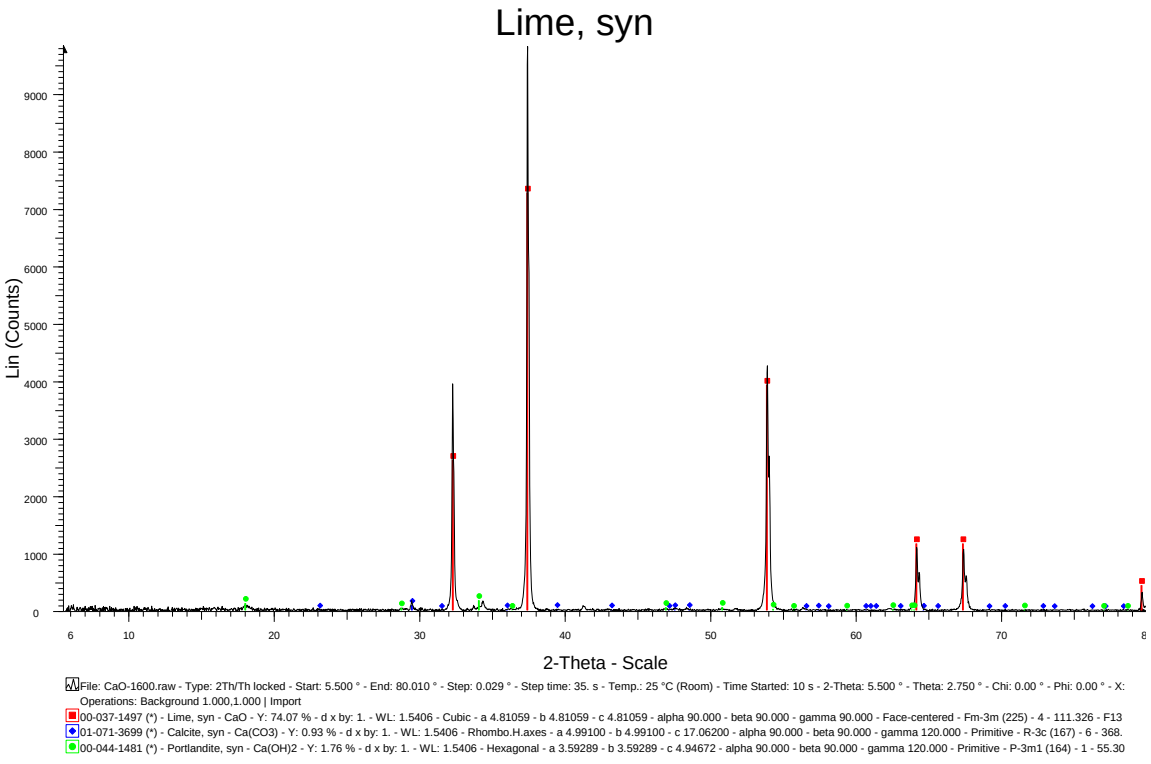


Fig. 1. ShCA KEPTONITE X-ray analysis

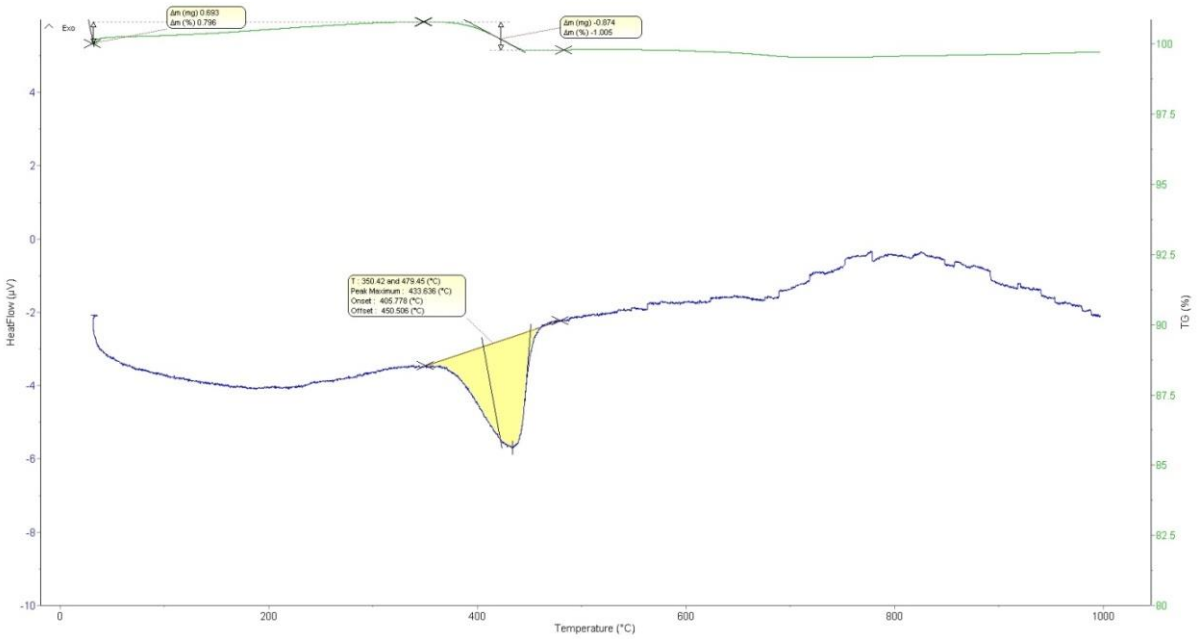


Fig. 2. ShCA KEPTONITE DTA- analysis

2.2. Methods

The concrete mixture for the various compositions tested was manufactured under laboratory conditions by mechanical homogenization. The samples (cubes 10x10x10 cm) and prisms (beams) (10x10x40 cm) are cured in lab-condition until the day of testing. The compressive strength was determined at 7- and 28 days of age, and the change in linear dimensions (free deformations) of the beams - every day up to 30 days by using special strain gauge device with accuracy of 0,001 mm (**Photo 1** and **2**).



Photo 1. Concrete test specimens prepared



Photo 2. Shrinkage strain gauge device

3. RESULTS

3.1. Compressive strength

The test results are presented in **Table 4**.

ShCA KEPTINITE, kg/m^3	CEMENT					
	TITAN CEM II 42,5N-A-LL		HOLCIM CEM I 52,5R		DEVNYA CEM I 52,5R	
	Compressive strength (MPa) at					
	7 days	28 days	7 days	28 days	7 days	28 days
0,00	21,90	32,70	24,80	36,20	25,20	37,50
12,00	22,40	33,10	25,30	37,40	25,90	38,40
15,00	22,90	33,60	25,80	37,30	26,40	38,60
18,00	23,40	33,90	25,60	37,40	26,80	38,90

Table 4. Compressive strength

3.2. Shrinkage

The measured changes in linear dimensions (free deformations) of the beams are graphically presented **- Fig. 3, 4** and **5**. The results visualizations give enough possibilities to perform reasonable analysis in direction to make respective conclusions about ShCA KEPTONITE efficiency to minimize concrete free deformations.

In **Table 5** concrete free deformations (expanding "+" and shrinkage "-") are presented as their maximal value in parallel of the age of appearances. This approach is practically usable to gaining an idea of ShCA KEPTONITE (in different dosage rates) efficiency compared to different type of cement involved in testing program.

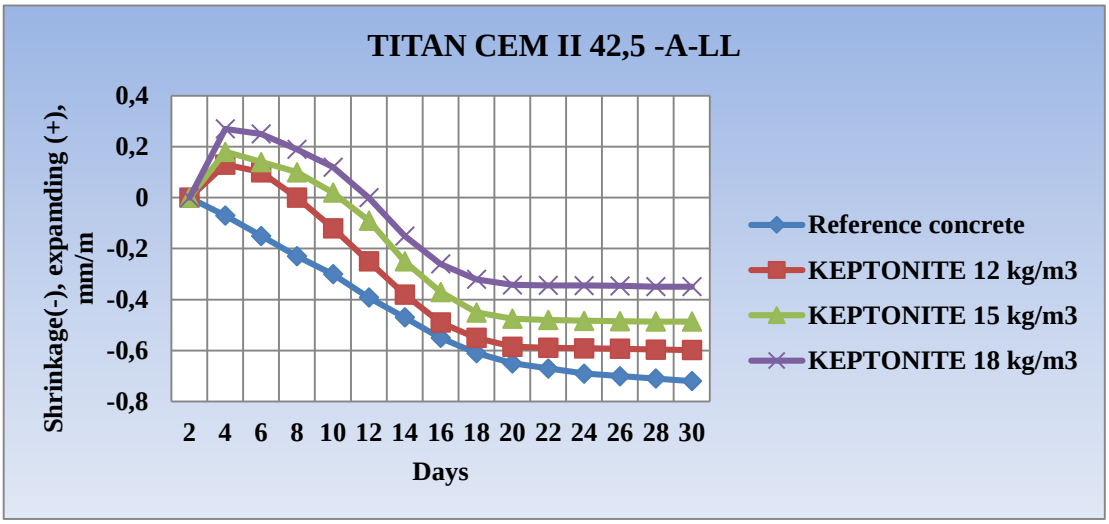


Fig. 3. Shrinkage/expanding kinetics of the concrete with TITAN CEM II 42,5-A-LL

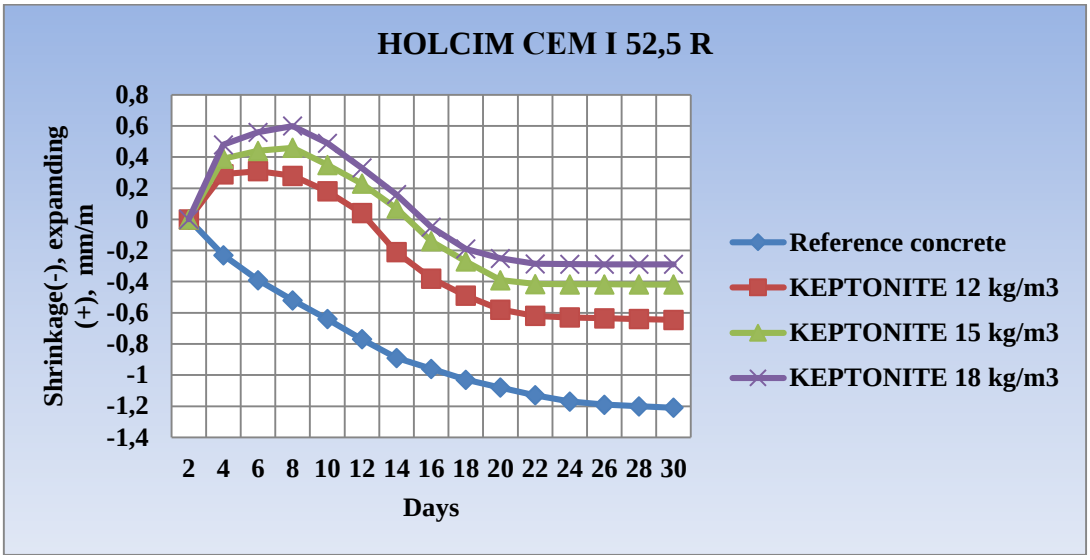


Fig. 4. Shrinkage/expanding kinetics of the concrete with HOLCIM CEM I 52,5R

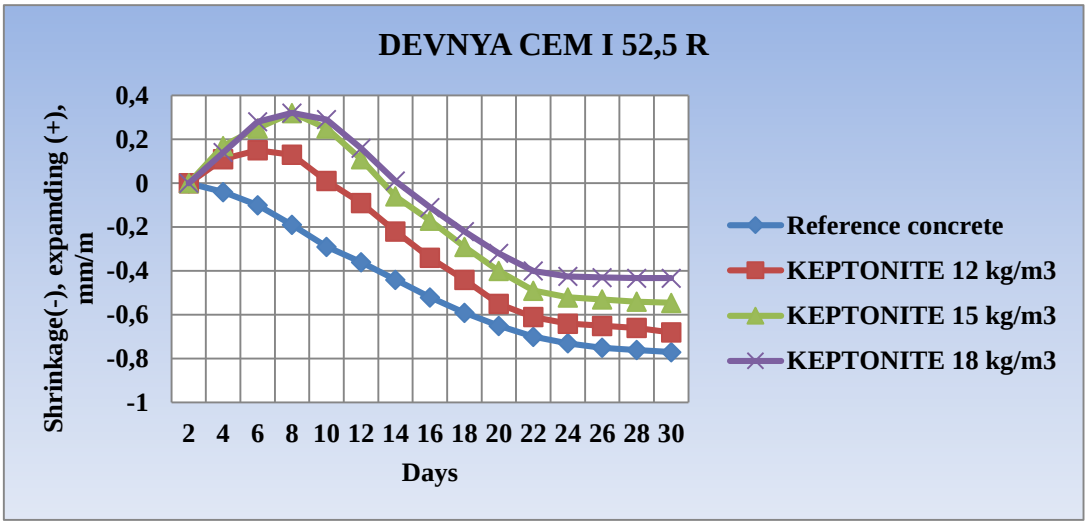


Fig. 5. Shrinkage/expanding kinetics of the concrete with DEVNYA CEM I 52,5R

ShCA KEPTINITE, kg/m³	**CEMENT**					
	TITAN CEM II 42,5N-A-LL		**HOLCIM CEM I 52,5R**		**DEVNYA CEM I 52,5R**	
	Concrete free deformations (expanding "+" and shrinkage "-") up to 30 days of age					
	max "+" (at days)	**max "- " (at 30th day)**	**max "+" (at days)**	**max "- " (at 30th day)**	**max "+" (at days)**	**max "- " (at 30th day)**
	mm/m					
0,00	-	-0,720	-	-1,210	-	-0,770
12,00	0,13 (4)	-0,598	0,31 (6)	-0,645	0,15 (6)	-0,680
15,00	0,18 (4)	-0,486	0,46 (8)	-0,418	0,32 (8)	-0,545
18,00	0,27 (4)	-0,349	0,60 (8)	-0,289	0,32 (8)	-0,433

Table 5. Concrete free deformations (expanding "+" and shrinkage "-") up to 30 days of age

4. DISCUSSION

The results obtained provide an opportunity for a comprehensive analysis of the behavior of the tested concrete with different types of cement in function of the dosage of ShCA KEPTONITE.

The results obtained for the compressive strength of 7- and 28-days of reference concretes (excluding ShCA KEPTONITE) are within the expected range. They are strongly influenced by the type of cement, and as a whole, the investigated concrete with cement CEM type I show higher strengths. In addition, it can be confidently predicted that ShCA KEPTONITE (regardless of dosage) has virtually no effect on the compressive strength of the test ages, regardless of the type of cement in the concrete.

In this sense, the design of the concrete composition with the participation of ShCA KEPTONITE should be approached in a conventional manner without expecting the effect of this admixture on the mechanical characteristics of the concrete.

Discussion is possible in several different aspects regarding the linear expansion (expanding / shrinkage) of the tested concretes with different dosage rates of ShCA KEPTONITE.

As an initial conclusion, with respect to reference concretes, it can be noted that HOLSIM cement based concrete have the highest absolute shrinkage rate - of the order of 1,210 mm/m. For the other two types of concrete, this size is reduced by about 40%.

It is also apparent significant influence of this admixture dosage rate, regardless of the type of the cement in the composition of the test concretes. For different types of cements, different dosages practically greatly reduce the final drying time of 30 days. The effect of ShCA KEPTONITE on HOLSIM-based concrete is particularly emphasized - the maximum dosage reduces about 3.5 times the nominal final drying shrinkage. For concretes with the other two types of cement, the shrinkage is reduced by almost half.

Of interest is the analysis of the absolute value of the initial expanding as a function of the dosage of the admixture relative to the different types of cements used in the test compositions. It is evident that the HOLCIM cement based concrete shows the highest expanding values at different dosages of the ShCA KEPTONITE. This occurs at 6-8 days of age after process monitoring. At the same age, for the cement concrete from DEVNYA, the amount of crimping is about 50% of that for the cement based on HOLCIM cement. The lowest is the expanding of concrete based on TITAN cement.

Another possible direction of analysis is that of the efficiency of the different dosages of ShCA KEPTONITE for the tested concrete based on the different cements. Most categorical is the effect of this admixture in HOLSIM cement based concrete - the dosage of 18 kg/m^3 reduces about 2,2 times the final shrinkage, compared to that of concrete with 12 kg/m^3 ShCA KEPTONITE. For the other two types of concrete based on TITAN and DEVNYA cement under these conditions the decrease is within 1,5-1,6 times.

5. CONCLUSIONS

The original scientific results obtained from the study make it possible to evaluate the application of ShCA KEPTONITE as particularly effective in reducing drying shrinkage of concrete produced on the basis of various typical for Bulgaria cement. The different cements in the composition of the tested concretes predetermine the different kinetics of free deformation, which, obviously, was provoked primarily by the different chemical and mineral composition of the base clinker.

The tested dosage range of the ShCA KEPTONITE is within the optimum ratio between technical characteristics and reasonable price.

In conclusion, the use of ShCA KEPTONITE in the composition of thin repair overlays for repair and restoration of defective reinforced concrete structures in industrial sites is particularly promising and further research is needed to develop special concrete mix design for this purpose.

ACKNOWLEDGMENTS

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