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The impact of modified cement with a special additive on construction mortar deformations

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Abstract. The study is devoted to the modification of 42.5 class ordinary Portland cement with a 10% special expanding additive (cement powder and gypsum in a 40:60 percentage ratio), and the impact of this cement on mortar is determined. Using modified cement and multi-fraction quartz sand in a ratio of 1:3, prism-shaped samples with a size of 4x4x16 cm were fabricated, and left in a water bath for 24±2 hours after formation. After one day of curing, the samples were demolded, their linear dimensional change was verified using an indicator, and they were then submerged in water. After three, seven, and 28 days of curing, the samples' changes in linear dimensions were examined again using an indicator. It has been revealed that introducing a 10% specially developed expansion additive to the composition of ordinary Portland cement also contributes to the maximum expansion of the construction mortar at 3–7 days of hardening. The expansion percentage of the 28-day curing time is very little different from the 7-day indicator. Considering the data on the linear dimensional change of the test samples, we can conclude that the modification of cement with the synthesized additive allows the production of non-shrinkable, expansive construction mortars and concretes, which are currently being studied.

1 Introduction

Ordinary Portland cement has a variety of beneficial properties, and sometimes its use becomes inconvenient depending on the importance of the designed structures, buildings, and operating conditions. As during strengthening, shrinkage phenomena are observed, which lead to the formation of internal micro-cracks in cement stone, violating the cohesion of structures during monolithic construction, increasing the water and gas permeability of hydraulic structures, and reducing the durability. Special forms of cement have been developed to avoid the aforementioned problems. This cement not only does not shrink during hardening but also expands the strengthening system. Non-shrinking, expanding, and tensioning cements are widely used in the manufacture of various types of construction facilities for a variety of purposes, including hydro-and nuclear power plants; marine waterproofing; industrial structures; and ordinary, pre-stressed reinforced concrete structures. The management of special cement productions became possible thanks to the improvement of the theory of binding materials and their production technologies.

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Several scientists were involved in the development of such special cement, in particular V.V. Mikhailov, I.V. Kravchenko, P.P. Budnikov, A.E. Sheikin, P.K. Meta, and those who, considering cement stone as a capillary-porous material, revealed the patterns of relationships between the structure of the resulting artificial conglomerate and its main properties: strength, deformation and stability in various aggressive environments, and also showed that the structure of cement stone depends on the mineral composition of cement, its hydration kinetics and the phase composition of hydrated new-formations.

The authors mentioned have developed different methods for obtaining special, particularly non-shrinkable, expanding cement, using quite expensive and scarce alumina cement, high alumina blast furnace slag, specially synthesized clinker, and different additives, as well as free CaO and MgO. According to their research, the expansion phenomenon is mainly explained by the formation of calcium hydrosulfaluminate as ettringite ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O$) in the hardening system. When the system gains enough stiffness, the growth of needle-shaped ettringite crystals contributes to the system's expansion. The formation of ettringite at later times, when the cement stone has gained high strength, leads not only to the expansion of the system but also to the formation of micro-cracks in the artificial stone and sometimes to its complete deterioration, which is often observed in reinforced concrete (1-17).

When examining the current state of expanding cement production technology, it is worth noting that, while previously the composition of these cements consisted primarily of costly alumina cement and insufficient high-alumina furnace slag, since the end of the twentieth century, new, cheaper, and more efficient methods for the production of cements have been developed, namely the chemical activation of ordinary Portland cement with special expanding additives.

We concluded that the most cost-effective and preferable method in our circumstances is the development of a special-purpose expanding additive for ordinary Portland cement activation. That was based on the effectiveness of the non-shrinking and expanding cement production methods' comparative evaluation and considering the current state and capabilities of cement factories in the Republic of Armenia.

2 Materials and methods

Based on the above and taking into account the lack of alumina cement and high alumina furnace slag in the Republic of Armenia as well as the complexity of the special clinker production scheme, we came to the conclusion that for the production of such cements it is more appropriate and more affordable to develop a special expanding additive based on local raw materials. For such an additive development of the country's raw material base and various production wastes were studied. For the first time, gypsum can be used as a sulfate-containing component for the additive, and for the first time, an attempt was made to use the production waste of the cement factory as a carbonate component. Electro filters absorb the dust from the flue gases removed from the furnaces, which contain a sufficient amount of CaO. The average chemical compositions of selected components are given in Table 1.

Table 1. Chemical composition of raw materials.

Component Name	**The content of oxides, %**							
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**R_2O**	**Loss on ignition**
Cement powder	13.05	9.90	2.25	42.90	1.03	1.37	3.40	26.10
Gypsum	15.66	3.21	2.11	24.84	4.06	35.41	1.15	13.56

Raw mixtures were prepared from the mentioned components with different percentage ratios, which were fired and the chemical composition of both the mixture and the sinter was determined.

3 Discussion of results

It has been proven by the calculation method (18) and physicochemical (x-ray, petrographic) studies that the sinter obtained from a 40:60 ratio (cement powder: gypsum) mixture, fired at 1000 ºC, is more preferable because, in this case, the formation of a high amount of the main expanding mineral, $3(CA)CaSO_4$, is observed. The further increase in temperature does not significantly affect the increase in the amount of mineral formation. The calculated average chemical composition of the raw mix and sinter is given in Table 2, and Table 3 shows the average modulus characteristics and mineral composition of the raw mixture and sinter.

Table 2. Calculated average chemical composition of the raw mixture and the sinter.

Composition of raw Material, %	The content of oxides, %							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	R_2O	Loss on ignition
Cement powder -40	5.22	3.96	0.90	17.16	0.41	0.55	1.36	10.44
Gypsum-60	9.40	1.93	1.27	14.90	2.44	21.25	0.69	8.14
Raw material mix	14.62	5.89	2.17	32.06	2.85	21.80	2.05	18.58
Sinter	17.98	7.24	2.67	39.43	3.50	26.81	2.52	-

Table 3. Average modulus characteristics and mineral composition of the raw mixture and sinter.

Saturation coefficient, (KH)	CH_{SO3}	Mineral composition, %		
		$2(C_2S)CaSO_4$	$3(CA)CaSO_4$	C_4AF
0.38	2.11	58.48	8.82	6.58

Thus, considering that there is a sufficient amount of gypsum in the chemical-mineral composition of the processed raw material mixture, it can be assumed that with special additive synthesis and the sharp cooling of the resulting sinter, the formation and stabilization of individual minerals are possible, especially calcium sulfaaluminate, $3(CaO{\cdot}AI_2O_3)CaSO_4$, which is important for the production of non-shrinkable and expansive cement and similar construction mortars based on them.

It has been studied and proven that introducing 10% of this additive into the composition of ordinary Portland cement has a favorable effect on the expansion of cement mortar of normal density (19), which is clearly visible in the case of the cement stone microstructure petrographic study. It has been revealed that with the introduction of the additive, well-formed needle-shaped crystals of calcium hydrosulfaaluminate are formed in the cement stone, the indicators of which are Ng = 1,463± 0,002. The microstructure of the cement stone was studied with an electron microscope and is shown in the Fig 1.

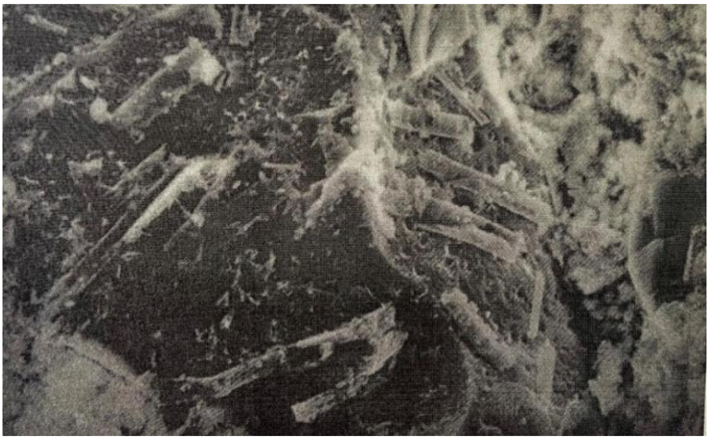

Fig.1. Calcium hydrosulfaluminate needle-shaped crystals.

The obtained data served as a basis for checking the effectiveness of the synthesized special additive on the change of linear dimensions of construction mortars. For this purpose, a cement mortar composition was prepared based on modified cement and multi-fraction quartz sand in a ratio of 1:3, from which 4x4x16 cm prism-shaped samples were formed, which were kept in a water bath for 24 ±2 hours after preparation.

The samples were then removed from the mold. After one day of curing, they were submerged in water and the change in linear dimensions was detected using an indicator. The samples were then tested for changes in their linear dimensions using the indicator at three, seven, and 28 days of curing. The data is shown in a graph and is shown in the Fig 2.

The phenomenon of expansion is also explained by the formation of calcium hydrosulfaluminate, i.e., ettringite ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O$) as a result of the hydration of the mineral $3(CaO \cdot Al_2O_3)CaSO_4$ during hardening. The growth of these crystals contributes to the volume expansion of the cement-sand composition system.

Moreover, the main expansion of the system is also observed at 3–7 days of hardening, which is explained by the intensive growth of ettringite crystals. Some reduction in the degree of linear expansion at 28 days of curing is because of the evaporation of system residual moisture.

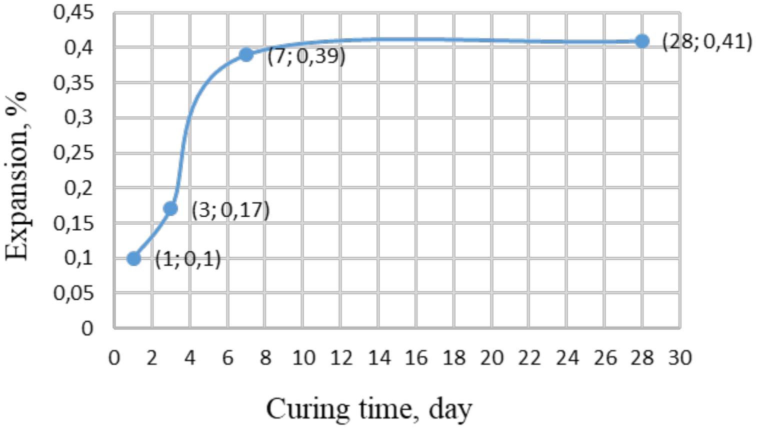

Fig. 2. Dependence of additive expansion on curing time.

From the data presented in the graph, it is clear that in pure cement and construction mortars, the effective influence of the additive is also observed at the age of 3–7 days of hardening.

4 Conclusion

Studying the effective influence of the cement, which is modified with a 10% special expansion additive (40:60 percentage ratio of cement powder and gypsum) on the changes of construction mortar linear dimensions at different curing times, it has been revealed that the most expansion is observed at 3–7 days. The mortar does not have enough stiffness after one day of hardening, and the small quantity of ettringite does not guarantee system expansion. At 28 days, when the system has enough stiffness, ettringite formation does not affect system expansion.

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