Possibilities of using aluminate cements in high-rise construction

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Abstract. The article describes preferable ways of usage of alternative binders for high-rise construction based on aluminate cements. Possible areas of rational use of aluminate cements with the purpose of increasing the service life of materials and the adequacy of the durability of materials with the required durability of the building are analyzed. The results of the structure, shrinkage and physical and mechanical properties of concrete obtained from dry mixes on the base of aluminate cements for self-leveling floors are presented. To study the shrinkage mechanism of curing binders and to evaluate the role of evaporation of water in the development of shrinkage was undertaken experiment with simple unfilled systems: gypsum binder, portland cement and «corrosion resistant high alumina cement + gypsum». Principle possibility of binder with compensated shrinkage based on aluminate cement, gypsum and modern superplasticizers was defined, as well as cracking resistance and corrosion resistance provide durability of the composition.

1 Introduction

Construction is one of the main branches of economy. A huge number of diverse resources is required when new buildings and structures are erected.

In particular, in the European Union (EU) the construction sector accounts for approximately 40% of energy consumption, more than 50% of recoverable materials, 30% of water and waste consumption and 35% of greenhouse gas emissions. This estimate takes into account all the stages of the life cycle of the buildings, including extraction of raw materials for the production of building materials and products, construction, operation and maintenance of buildings, their demolition and waste management. At the same time, the construction materials industry uses byproducts and waste from other industries (metallurgical slag, TPP ashes, woodworking waste etc.) as raw materials, contributing to the solution of environmental problems [1].

High-rise buildings have different purposes. The share of skyscrapers intended only for housing is about 30%. Among the buildings with a height of more than 200 meters, which were constructed in recent years, the share of office buildings has slightly decreased. But the majority of high-rise buildings is multifunctional. Apart from the general purpose rooms, they are fitted with parking lots, shops, offices, cinemas, etc. As more and more

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multifunctional facilities appear on the market, the demand for a combination of different types of building materials within a single building is growing. The invariable change of tenants means that offices are constantly being repaired using a large number of different finishing materials, leading to a large amount of waste. Waste produced during the demolition of buildings accounts for a large proportion of all solid waste generated worldwide; more than 50% of the waste comes from the construction industry. Reducing the loss of materials at construction sites is one of the main problems the industry is faced with. During the construction, operation and repair of high-rise buildings different types of waste are formed. These include that of concrete, reinforced concrete structures, steel, aluminum, ceramic materials, wood, plastics, glass, etc. Therefore, it is important to use durable materials even when decorating and repairing rooms of high-rise buildings with a significant working lifespan. In the 1970s the main structural material for high-rise construction was steel. Nowadays the share of all-metal structures is only 3%, and high-strength reinforced concrete structures are used everywhere. The main binder for the production of high-strength concrete is Portland cement and its varieties. Other binders are used extremely rarely. Without challenging the position of Portland cement in concrete structures building, we would like to propose the areas of usage for other binders (aluminous cement, construction and high-strength gypsum) in the construction and finishing of certain special-purpose rooms of high-rise buildings.

In the modern high-rise buildings, the share of auxiliary and technical premises (cars parks, sports halls, premises for accommodation of engineering systems of life support of buildings, climatic equipment, etc.) is high. Requirements for the floors of such premises are more technical than aesthetical. High strength, wear- and abrasion resistance and durability are required. Repair and replacement of such coatings requires significant investment. It is important that materials used are technological. From this point of view, self-leveling floors on the base of aluminate cement are the most interesting ones [2-9].

The production of aluminate cements causes less damage to the environment. Moreover, the use of aluminate cements eliminates losses caused by corrosion of cement stone. Corrosion is probable after a certain period of service in the underground and basement technical rooms of high-rise buildings.

The appearance of cracks on the surface of the floors is the main type of defects. Cracking is caused by deformation of the material. It causes stress which exceeds the tensile strength and is not compensated by relaxation processes. Such deformations arise during curing and exploitation and are of different nature (have different causes). The main types are deformation caused by physical and chemical processes in the curing binder (contraction, expansion), and shrinkage caused by the evaporation of moisture from the cement material both immediately after its placement (plastic shrinkage) and in the process of curing (drying shrinkage). Drying shrinkage is the main reason for cracking.

Shrinkage of two kinds, contractual and humid, can occur during the curing of concrete. The contraction has almost no effect on the volume of construction, and leads to an increase in porosity of the concrete. Humid shrinkage is associated with the evaporation of water from the curing concrete and exceeds the contraction by 5-10 times [10, 11].

The problem of cracking resistance of thin-film coatings of cement compositions can be solved by binders with controlled shrinkage (expandable binders, whose shrinkage is compensated by the expansion). Resistance to cracking would be higher in the case when expansion and shrinkage are close not only in size, but also in the development time.

For shrinkage compensated concrete can be used organic expanding components in an amount of 0.5-2% [12-15]. More widespread has expanding mineral supplements, the application of which produce products of hydration and cause the expansion of the system and increase the strength of the cement stone. Using the expanding additive requires a high production standards. Expansion effect depends on many factors and is not stable [16-18].

The most promising method is the use of binders based on aluminate cements, which expansion is provided by the formation of ettringite $3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}31\text{-}32H_2O$ (CASH) [19].

2 Materials, methods and mixture proportioning

For the experiment were analyzed compositions and properties of the produced aluminate cements. The data on the chemical composition of aluminate cements are given in Table 1.

Table 1. The chemical composition of aluminate concretes, (%).

Composition	Al_2O_3	CaO	Fe_2O_3	SiO_2	SO_3	R_2O
CRHAC -75-0,5 (Russia)	no less than 75	no less than 20	no more than 0.5	no more than 1.3	no more than 0.15	no more than 0.35
CRHAC -70-1 (Russia)	no less than 70	no less than 20	no more than 1	no more than 2	no more than 0.15	no more than 0.5
ISTRA 40 (Germany)	39 –42	37 – 40	14 – 17	2 – 5	0,4	MgO 1.2
SECAR 51 (France)	50.8 – 54.2	35.9 – 38.9	1.5 – 2.5	4.0 – 5.5		MgO < 1,0 TiO_2 < 4.0 K_2O+Na_2O < 0.5

Of the proposed cements for study was selected corrosion resistant high alumina cement (CRHAC), because it contains at least 70% Al_2O_3. The chemical composition of used cement: Al_2O_3 – 70.5%, CaO – 28.1%, SiO_2 – 0.87%, Fe_2O_3 – 0.3%.

The mineral composition of used cement: calcium aluminate (CA and CA_2) in the ratio 1:1. As a result of x-ray curing products principally consist of CAH_{10}. In the age of 3 days hydration degree of CA is about 80-85%, CA_2 - about 50%. Selected cement is characterized by high strength.

Curing speed is less high compared with other aluminate cements, that corresponds to the task (Table. 2). As a second component of binder necessary for expansion, was used natural gypsum ($CaSO_4{\cdot}2H_2O$) and hemihydrate gypsum ($CaSO_4{\cdot}0,5H_2O$).

Table 2. Technical characteristics of the material.

Value	CRHAC -75-0,5	CRHAC -70-1	ISTRA 40	SECAR 51
Specific surface area, m^2/kg	no less than 450	no less than 450	300 – 340	375 – 425
Curing time: the beginnig –the end, hour	not earlier than 2, not later than 12	not earlier than 2, not later than 12	not earlier than 1, not later than 5	not earlier than 2, not later than 5
Compressive resistance, MPa	after 3 days of curing no less than 50	after 3 days of curing no less than 50	after a day of curing 65–75	after a day of curing 55–85

3 Results and Discussion

For experimental verification of the component composition of binder and the type of gypsum were conducted studies in a wide range of ratio of the components at a fixed value of the plasticity of the mixture (Table 3).

Table 3. Test results of two-component binders of different composition

CRHAC, %	100	80	70	60	50	40	0
gypsum, %	0	20	30	40	50	60	100
$CaSO_4 \cdot 2H_2O$							
W/C	0.50	0.50	0.50	0.50	0.50	–	–
compression strength, MPa	54.5	50.2	53.1	48.4	34.6	–	–

Composition contents 60 ... 80% of CRHAC (the amount of gypsum 40 ... 20%) have a high compression strength. Both in terms of strength and economic reasons more efficient use of natural gypsum.

Composition was fixed after 3, 7, 24 and 72 hours. In first hours of hydration was observed rapid formation of CASH, decaying after 24 hours (Table 4).

Table 4. Changes in the phase composition of the system «CRHAC + gypsum», depending on time of hydration.

Hydration time, hour	Relative intensity of peaks, %		
	ettringite		
	9.83Å	5.65Å	3.89Å
0	0	0	0
3	50	50	50
7	83	75	83
24	90	90	95
72	100	100	100

To study the shrinkage mechanism of curing binders and to evaluate the role of evaporation of water in the development of shrinkage was undertaken experiment with simple unfilled systems: gypsum binder, portland cement and «CRHAC + gypsum» (70% + 30%). Selection of the first two systems was defined as sufficient of their study, and the fact that in the first is observed a rapid formation of a solid skeleton formed of crystalline neoplasms ($CaSO_4 \cdot 2H_2O$), and in the second - a solid skeleton is formed of several phases, a large share of which is occupied by phase of gel. So, on the example of these two systems are easier to specify the new features of binder deformation «CRHAC+gypsum» (Figure 1).

Deformation of curing two-component (CRHAC + gypsum = 70 : 30) binder developed as a result of the superposition of two competing processes: the expansion due to the formation of CASH and formation on its basis of the cement stone structure and shrinkage caused by the evaporation of water from the curing composition.
As in the initial period is very active the formation of cement stone structure, we observe the rapid expansion, reaching after 4...5 hours – 0.6 mm/m.

As a result, the deceleration rate of hydration, sealing, but not the extension of curing system due to hydration products (indicated by a rapid increase of the strength of the composition after 4...5 hours after mixing) and the evaporation of water from the cured material, we observe a sharp decline in the rate of expansion, and then the resulting transition effect process after 5...6 hours from expansion to shrinkage. Although at this time, continues the process of expansion by hydration of the remaining share of CA and, in particular, CA_2. After 3…4 days the rate of shrinkage is stabilized and the initial expansion is compensated by shrinkage. The shrinkage of the composition is terminated after 10...12 days at a value of shrinkage of 0.8...0.9 mm/m. (to compare according to our measurements of Portland cement, it is about 8...10 times higher).

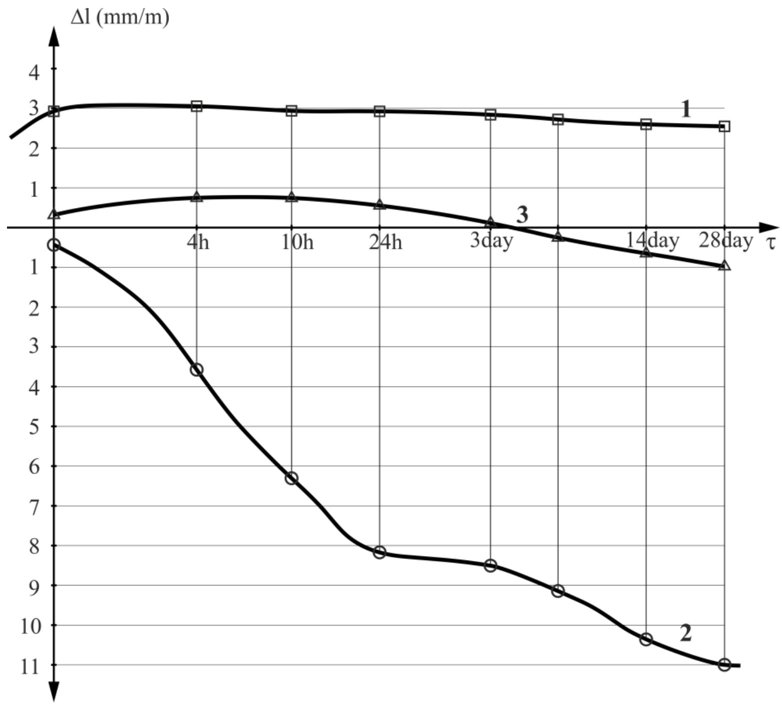

Fig. 1. Deformations of various binders (mm/m): 1 – gypsum; 2 – Portland cement; 3 – two-component binder

Using aluminate cement as a main component for dry mixtures for self-leveling floors requires an adequate selection of the superplasticizer.

Commercially available additives for use with aluminate cement to produce dry mixtures for floors were analyzed. Supplements of three main groups were selected for study: polymeric sulfomelamin (Peramin SMF20 Perstorp Construction Chemicals Inc., Sweden) modified with polyethylene glycol (Melflux PP100F, Melflux PP200F, SKV Polymers GmbH, Germany) and polycarboxylate (Sika Viscocrete 105P, Swiss). Evaluating of the effectiveness of the superplasticizer joint venture was carried out in accordance with GOST 30459-2008 "Admixtures for concretes and mortars. Determination and estimate of efficiency". (EN 934-6:2002 Admixtures for concrete, mortars and grout – Part 6 Sampling, conformity control and evaluation of conformity). All the properties were determined on the samples with dimensions of 4x4x16 cm according to ASTM and GOST for the tests. Water-reducing effect is 57...63%. The study works were done by the equipment of MSUCE.

It is known that using aluminate cements mixtures with superplasticizers a rapidly lose flowability. Cause of this were made studies for saving flowability of mixture after 20, 40 and 60 minutes after mixing. Additives were introduced in the amounts recommended by the manufacturer. Saving flowability (decrease no more than 10% in 60 minutes) showed only superplasticizers based on polycarboxylate.

The two-component composition based on a two-component binder (CRHAC + gypsum), filled with quartz sand (Binder:Sand. = 1:1.5) and modified by superplasticizers based on polycarboxylates (Sika Viscocrete 105P, Swiss) characterized by the following technological and operational properties:

- average density - 1750 ... 1850 kg/m^3;
- saving of self-leveling for 30…60 minutes. after mixing;
- setting time: beginning - 2 h 00 m ... 2 h 20 m, end - 3 h 00 m… 3 h 15 m;

- strength of composition: compressive strength after 7 hours is about 5 ... 6 MPa, after 1 day. - 23 ... 25 MPa, after 3 days. - 42 ... 44 MPa;
- flexural strength after 3 days. - 11…12 MPa.

4 Conclusion

During the construction of high-rise buildings, it is possible and rational to use binders alternative to Portland cement for some special purpose rooms. For construction of floors for technical premises (cars parks, sports halls, premises for accommodation of life support engineering systems of buildings, climatic equipment, etc.) is expediently to use mixes based on aluminate cements. The production of aluminate cements causes less damage to the environment. Moreover, the use of aluminate cements eliminates losses caused by corrosion of cement stone. Corrosion is probable after a certain period of service in the underground and basement technical rooms of high-rise buildings.

Producing dry mixtures for self-leveling floors became possible after the creation of modern superplasticizers, which provide a shear strength. Analysis of the results shows that for dry mixtures (with the use of portland cement) modern superplasticizers based on polycarboxylates work effectively. At the same time, there is no consensus about the factors that have influence on the compatibility of superplasticizers with portland cement, aluminate cement, gypsum and mixtures of these materials.

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