LOW CLINKER SLAG PORTLAND CEMENT WITH HIGH ACTIVITY

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Abstract

The article presents the results of study on effective ways to improve the strength of Low clinker slag Portland cement (LCSPC) with having a clinker content of 5-19% with complex sulfate-alkaline and sulfate-alkaline-fluoride activation of slags. The increase of specific surface area of LCSPC led to a significant improvement of the strength and two stage grinding was very effective on increase of grain size of clinkers. The addition of additives such as sodium silicofluoride Na_2SiF_6 , $Fe_2 (SO_4)_3$, and $MgSO_4$ were investigated and results show that Na_2SiF_6 was effective to improve the strength. The influence of complex sulfate-fluoride and sulfate-fluoride-alkaline activation is investigated. The results obtained shown that a complex sulfate-fluoride-alkaline activation of LCSPC increased significantly the strength of LCSPC by increasing the pH from 10 to 12-13.

Keywords:

Activators additives, cement clinker, energy saving technology, phosphogypsum, slag Portland cement

1 INTRODUCTION

One of the trends in the modern development of the construction industry is the transition to energy-saving technologies for the production of building materials. The most energy-intensive industry is Portland cement production due to high fuel consumption for the producing of Portland cement clinker. The main way of reducing the content of clinker in the Portland cement composition is increasing the active mineral additives content and in particular blast furnace slag. At the world's total cement production Slag-Portland cement are for about 20% [Black L. 2016].

The European standard EN 197-1 includes of the production of low clinker slag Portland cement "CEM III/C" with content of Portland cement clinker 5-19%. Low clinker slag Portland cement (LCSPC) is characterized by relatively low compressive strength at 28 days between 20 to 30 MPa [Dvorkin 2015]. It is used, first of all, for constructions that should have high corrosion resistance and also massive constructions with low concrete exotherm [Topçu 2013].

The strength of slag Portland cement is formed due to the strength of the clinker component, as well as the hydraulic activity of slag, which is provided the interaction with clinker hydration products. The desirable amount of alito-aluminate clinkers is C_3A+C_3S=65-75% and provides an increase in the specific surface of cement which led to an increase in strength of slag Portland cement.

To increase the strength of cement, especially with the maximum content of slag, the optimal content of the sulfate component had a great importance. A positive effect is achieved when adding plasticizers, alkalis and curing accelerators during the milling process of the slag cements.

The paper presents the results of an experimental investigation which indicates the effectiveness of the complex sulfate-alkaline and sulfate-alkaline-fluoride activation of slags for the production and application of LCSPC.

2 THE REVIEW OF PREVIOUS RESEARCH

In the slag Portland cement, the activation of the binding properties of slags is realized due to the calcium hydroxide, which is released as a result of the hydrolysis of clinker minerals, and gypsum, which is part of the cement. The intensity of the curing processes, the structure and composition of the hydrate compositions are depending on the conditions of hardening and the type of used slag activator. The alkaline and sulfate activation are used to increase the strength of slag binders [Gruskovnjak 2008, Glukhovsky 1978, Kryvenko 1993, García-Lodeiro 2015]. According to the results [Bolshakov 1998], for the blast furnace slag also acid activation of slags is possible.

In the presence of Ca^{2+} and SO_4^{2-} ions, the hydration of both the crystalline and glassy phases of the blast furnace slag is accelerated. Moreover, hardening under normal conditions requires the presence of both ions, and in conditions of heat treatment sufficient excess of Ca^2+ [Gruskovnjak 2008] is present. At the room temperature, in the presence of Ca^{2+} and SO_4^{2-} ions, gelinite and oxermanite are hydrated. The other slag minerals require hydrothermal treatment.

In the presence of SO_4^{2-} (and also Ca^{2+}) ions in the hardening system of blast furnace slag -water, crystals of calcium hydro-sulphoaluminates are formed, which prevents the formation of waterproof shells from aluminum hydroxides and silicon on glass particles, and in the case of early formation of such membranes, they contribute to their destruction. In this case, the ion exchange in the surface layer of particles, which causes deformation of the glass structure, is also intensified. In the solution in the presence of SO_4^{2-} needle-like crystals of calcium hydro-sulfoaluminate are formed [Gruskovnjak 2008], which contribute to the strengthening of the hardening mass. Simultaneously, the formation of low-alkaline calcium hydrosilicates also occurs.

It should be noted that with the double activation of the slag with calcium hydroxide and the sulfate component, along with the positive sides, under certain conditions, and in particular at a higher concentration of the latter, destructive processes may occur - deceleration of hardening and even drop of strength. This is due to the fact that in the system under certain conditions possible recrystallization processes associated with the formation of compounds that cause an increase in the volume of solid phase. This leads to a concentration of local stresses, loss of strength and even destruction. Therefore, it is necessary to take into account the optimal quantitative ratio of used activators.

Another method of activating slag cements is the introduction of alkali metal compounds into their compositions. The idea of creating such hydraulic binders reported by Glukhovsky [Glukhovsky 1978], who analyzed geological data on the natural processes of mineral and rock formation occurring with the participation of alkaline and alkaline earth metals, as well as the physical and chemical processes of forming a cement stone on their basis. In Glukhovsky`s works developed theoretical foundations for the production of alkaline and alkaline earth aluminosilicate hydraulic binders. On the basis of further studies of these binders [Kryvenko 1993; Peukert 2000; García-Lodeiro 2015] the physico-chemical bases and principles of alkali synthesis binders (and in particular slag-alkaline) with the given properties were developed.

The composition of the slag-alkaline binder hydrate compositions is determined by the composition of the blast granular slag, the type and concentration of the alkaline component and the curing conditions. In general, these hydrate compositions can be divided into three groups: low basic calcium hydrosilicates, sodium-calcium hydrosilicates and hydro-aluminosilicates.

As alkaline components, it is most expedient to use alkaline wastes of different types of industry: soda melt, soda-sulfate mix, sodium aluminates, etc.

There is a lot of information in the literature on the effect of slag-Portland cement grinding fineness [Peukert 2000, Usherov-Marshak 2004, Niu 2002] on the compressive strengths. It is stated the growth of strength, depending on the type and the slag composition, in the initial or subsequent curing periods. In a separate method of milling the cements, with containing 50 and 60% slag, it was found that the strength at an early age is determined by the clinker milling fineness, in the later age – granulated slag. An increase in the amount of slag to 75% showed that the clinker milling degree does not significantly increase the strength, but the leading role is played by slag, whose hydraulic properties are largely dependent on the grinding fineness [Usherov-Marshak 2004].

Svatovskaya and Sychov showed that hydration activation and increase of cement stone strength is achieved by introducing into a binder system of substances, mainly ionic by the chemical nature of the connection, as well as substances with oxidizing properties. According to [Usherov-Marshak 2004], ion salts CaF_2, MgF_2 and Na_2SiF_6 have an activating effect on the curing of slag and slag Portland cement. The activation slag mechanism by the fluorite consisted in activating the surface of its particles and, thus, increasing their reactive ability. The binder complex activity is increased and acid-base reactions are activated, in particular, the reaction of hydration are activated [Svatovskaya 1983].

When activated by fluorine salts, not only the chemical modification of the surface but also the regulate surface electronic processes is achieved.

Thus, in spite of the extensive slag binder properties study, the low clinker slag Portland cement improvement of the technology is a rather topical problem, which requires further research and the search for effective ways to solve it.

3 EXPERIMENTAL PROGRAM

3.1 Research aim

The purpose of this work was to find effective ways to activate low clinker slag Portland cement (LCSPC).

To achieve the purpose, an experimental program was implemented that included four series of experiments. In the first series of experiments, the effect of the specific surface and the method of grinding the components on the strength characteristics of the LCSPC were studied.

The second series was devoted to the study of the influence of the type and the content of sulfate activator on the LCSPC properties. Phosphogypsum, prolonged storage (more than 10 years in the dumps) and gypsum stone-dihydrate were used to investigate the sulfate activation of blast-furnace granulated slag. The chemical composition of the initial materials is given in Table 1.

The third series investigated the influence of various curing activators additives (sodium silicofluoride, calcium chloride and ferric chloride, as well as sodium carbonate) on the LCSPC properties.

The fourth series was aimed to establish the LCSPC optimal composition with improved compressive strength, made on the basis of clinker, blast-furnace granulated slag and activators additives.

3.2 Materials

For the LCSPC in the course of research, blast furnace granulated slag, which can be attributed to basic slag, Portland cement clinker (C_3S=57,1 %, C_2S=21,27 %, C_3A=6,87 %, C_4AF=12,19 %), which according to the mineralogical composition can be attributed to typical average aluminate clinkers produced by cement plants, have been used. Phosphogypsum-dihydrate (FG) and gypsum stone was used as the sulfate components of slag Portland cement. The chemical composition of the initial materials is given in Table 1.

For the mix composition, cement sand mortar (1:3 by mass) the standard sand (EN 196-1) was used. The superplasticizer naphthalene-formaldehyde type SP-1 and polycarboxylic type Sika VC 225 were used.

Tab. 1: Chemical composition of the initial materials

Materials type	The content of oxides, wt. %							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	MnO	P_2O_5
Blast furnace slag	39.52	6.49	0.12	47.13	3.10	1.74	1.15	-
Phosphogypsum	-	0.36	0.15	38.4	0.003	59.7	-	0.67
Clinker	22.47	5.26	4.07	66.18	0.64	0.46	0.29	-
Gypsum stone	8.71	0.55	0.32	29.65	0.56	42.45	-	-

Determination of the LCSPC strength characteristics, in the course of all experimental studies, was carried out by testing half of cement-sand specimen size 40×40×160 mm. The water-cement ratio was assigned from the condition of ensuring the required the mortar cone flow ranged between 106 to 115 mm after 30 shakes on the shaking table. The specimens before the tests were curing in a special chamber at a temperature 20±2°C and 90% relative humidity.

4 RESULTS AND DISCUSSION

4.1 Influence of the surface area on LCSPC strength characteristics

This stage of research is devoted to the determination of the surface area effect on the LCSPC strength characteristics, as well as the ways of reducing energy consumption during grinding. For this purpose, a number of experiments were carried out on the comparison of one-stage and two-stage grinding methods, as well as studies were carried out to determine the effect of the grinding intensifier additive – propylene glycol and superplasticizer additive – Sika VC 225 on the binder grinding kinetics. At the same time, the effectiveness of using a superplasticizer when grinding a binder and mixing the mortars was compared. The results of the studies are shown in Table 2.

Low clinker slag Portland cement with a clinker content of 12% and a phosphogypsum content of 7.5% (4.5%, on SO_3) was used. The grinding of binder was carried out in a laboratory with ball mill. At one-stage grinding there was a compatible milling of all components of the binder. In the two stage - at first, the cement clinker grinding to a specific surface of 250 m²/kg was performed separately, and then, the milling of all components of the binder.

Tab. 2: Influence of the grinding method on the LCSPC strength

№	Additive		One-stage grinding				Two-stage grinding			
	Type of additive	Grinding time, hours	Specific surface area, m^2/kg	Normal consis-tency, %	Compressive strength, MPa 7d	Compressive strength, MPa 28 d	Specific surface area, m^2/kg	Normal consis-tency, %	Compressive strength, MPa 7 d	Compressive strength, MPa 28 d
1	No additives (control)	1.5	302	26.5	7.3	21.1	301	24	10.2	29.4
		2.0	366	25.0	9.2	26.0	355	22	11.8	31.0
		3.0	454	25.0	12.2	31.3	453	23	15.6	41.9
2	Propylene glycol (0.05%)	1.5	356	25.5	11.0	23.9	358	24.5	19.2	30.1
		2.0	451	25.0	13.6	34.4	457	24.5	21.2	42.5
		3.0	559	31.0	14.8	32.0	554	29	22.2	36.0
3	Sika VC 225 (0.3%) when grinding	1.5	311	20.0	6.5	13.8	300	19	19.6	34.6
		2.0	356	18.5	10.2	19.4	356	17	25.2	38.0
		3.0	443	17.0	15.6	30.1	450	17	28.6	41.4
4	Sika VC 225 (0.3%) when mixed	1.5	322	26.5	7.6	22.4	301	24	10.8	39.6
		2.0	366	25.0	9.0	27.0	355	22	14.8	48.1
		3.0	454	25.0	12.2	36.4	453	23	19.5	55.2
5	SP-1 (0.5%) when grinding	1.5	318	25.0	8.5	20.9	311	23	9.3	29.5
		2.0	369	23.0	11.6	26.5	360	21	13.8	32.2
		3.0	460	23.5	13.0	33.3	457	22	22.5	43.4
6	SP-1 (0.5%) when mixed	1.5	322	26.5	9.8	23.3	301	24	10.5	30.8
		2.0	366	25.0	11.6	27.2	355	22	16.3	39.2
		3.0	454	25.0	14.8	33.5	453	23	22.8	45.0

The obtained results indicate that the specific surface area is an essential factor affecting the LCSPC strength. With its increase from 300-320 m²/kg to 450 m²/kg the strength increased by an average of 25-30%. It was also found that the two-stage grinding method was more efficient. At this method, the binder strength increased by 30% compared with the one-stage grinding. This can be explained by the fact that in the case of one-stage grinding, due to the adherence of slag grain to the grain of clinker, the clinker component was not regrinding. These results coincide with the data of Ludwig and Schneek, which found that with two-stage grinding, it is possible to significantly reduce the size of the clinker grains, which significantly affects the LCSPC strength [Stark 2004].

In order to reduce energy consumption for grinding, the grinding intensifier additive – propylene glycol was used. Increasing its content to 0.05% of the binder weight can reduce the duration of grinding and, accordingly, the energy consumption by 30%. It also allows increasing the early strength of specimens, which is due to an increase in the number of fine particles. The introduction of superplasticizer Sika VC 225 and SP-1 practically does not affect the binder grinding kinetics. Positive effect is observed at the introduction of these additives when mixing cement-sand mortar. In this case, the strength of the specimens increased by an average of 25%, with the use of SP Sika VC 225, and 15% when using SP-1.

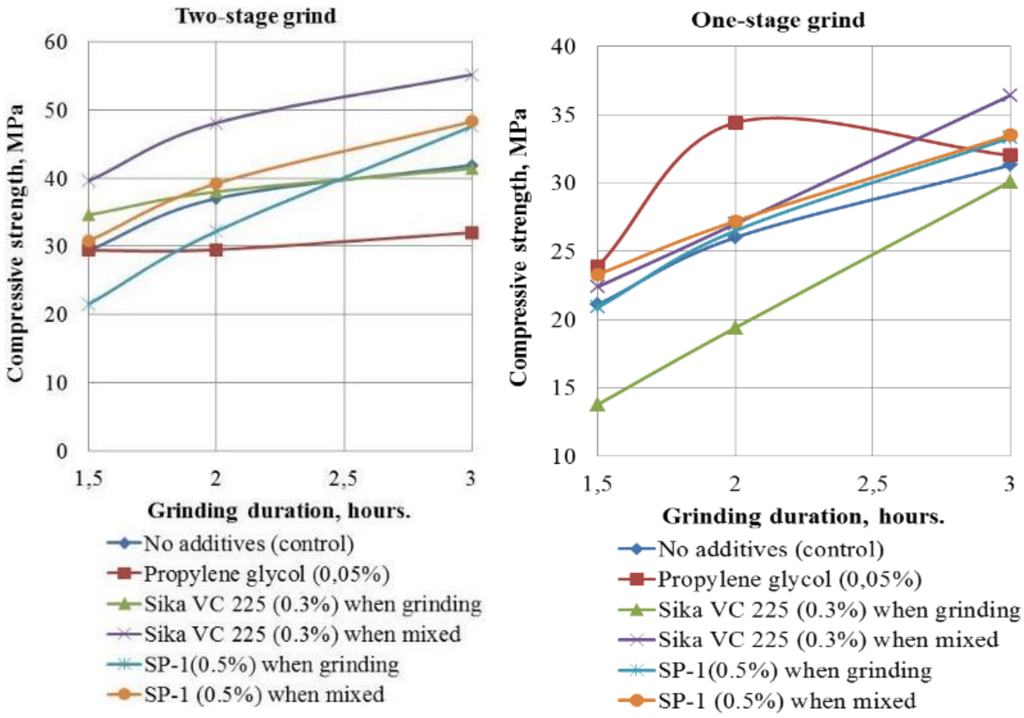

Fig. 1: Effect of the binder grinding duration on its compressive strength

4.2 Sulphate activation of LCSPC

Phosphogypsum, prolonged storage (more than 10 years in the dumps) as well as, for comparison, gypsum stone-dihydrate, were used to investigate the blast-furnace granulated slag sulfate activation

As a binder, a low clinker slag Portland cement with a clinker content of 12% was used. The content of the sulfate component varied from 3.5 to 5.5% by SO_3 at an interval of 1%. The binder grinding was carried out by two-stage scheme to achieve specific surface area of 450 m^2/kg. At all experiments, to reduce the water consumption, SP-1 was used of 1% of the weight of the binder. The results of the LCSPC sulfate activation on the basis of low-alumina blast furnace granulated slag are presented in Table 3.

Tab. 3: Influence the type of sulfate component on the LCSPC properties

№	Component content, mass%				Normal consis-tency, %	Setting time		Flexural strength, MPa		Compressive strength, MPa	
	Slag	Clinker	Phospho-gypsum (on SO_3)	Gypsum stone (on SO_3)		Initial, hours.	Final, hours.	7 d	28 d	7 d	28 d
1	88	12	3.5	-	22.7	3.5	6.5	6.8	10.8	13.4	34.1
2	88	12	4.5	-	23.3	3.2	7.5	7.4	10.8	15.6	41.9
3	88	12	5.5		24.5	4.0	8.0	5.3	9.8	14.5	36.2
4	88	12	-	3.5	23.5	3.9	7.4	5.5	8.2	12.3	30.8
5	88	12	-	4.5	25.5	3.5	8.6	5.9	10.5	25.8	33.5
6	88	12	-	5.5	26.2	4.5	9.0	4.5	7.6	13.2	31.5

On the basis of the obtained results, it can be concluded that the phosphogypsum was most effective sulfate component. The probable cause of this is the peculiarities of the phosphogypsum structures, which is characterized by the high dispersion and porosity of the particles, which persists even after grinding, as well as the presence of fluorite admixture in it. With these results, fluorite is an activator of the slag binders hardening [Svatovskaya L.B. 1983]. In addition, phosphogypsum is also the cheapest sulfate component, its use contributes to solving environmental problems of storage and disposal potentially dangerous industrial waste. However, it should be noted that an increase in the content of the sulfate component of more than 7.5%, as in the use of phosphogypsum and gypsum stone, led to a decrease in the LCSPC strength. This is due to the fact that, with the double activation of the slag by phosphogypsum and calcium hydroxide, which is formed as a result of the hydration of the clinker, the destructive processes are also possible. These processes are result of the hydrosulphoaluminates recrystallization, which led to hardening slowing and the compressive strength drop. Therefore, it is necessary to take into account the optimal quantitative ratio of used activators. In general, the increase of percentage of phosphogypsum or gypsum stone increased the final sitting time.

Sulfate activators can also include relatively common and inexpensive water-soluble salts of various metals – Na_2SO_4, $MgSO_4$, $Fe_2(SO_4)_3$. To investigate these activator action, the following composition binder was used: clinker – 12%, blast furnace granulated slag – 88%, phosphogypsum-dihydrate – 7.5% (in SO_3 4.5%). To reduction of water consumption, SP-1 was used at 1% by the binder weight. The content of activators fluctuated within 1-2%. The results are presented in Table 4.

Tab. 4: The affectivity of the various sulfates metals as LCSPC sulfate activators

№	Additives		Specific surface 350 m²/kg					Specific surface 450 m²/kg				
			W/C	Flexural strength, MPa		Comp-ressive strength, MPa		W/C	Flexural strength, MPa		Compressive strength, MPa	
	Type	% by weight		7 d	28 d	7 d	28 d		7 d	28 d	7 d	28 d
1	No additives (control)	-	0.33	5.1	9.1	13.6	34.4	0.32	7.4	10.8	21.2	42.4
2	Na_2SO_4	1.0	0.36	5.6	9.6	20.2	40.8	0.34	8.6	9.8	26.6	42.5
3	Na_2SO_4	2.0	0.36	5.0	8.4	16.2	36.0	0.36	7.4	11.1	26.2	40.5
4	$Fe_2(SO_4)_3$	1.0	0.34	5.4	8.9	17.6	40.5	0.34	7.7	10.1	27.6	39.7
5	$Fe_2(SO_4)_3$	2.0	0.36	5.2	8.8	13.4	21.8	0.36	6.5	11.2	24.2	38.1
6	$MgSO_4$	1.0	0.34	4.5	7.3	12.4	23.4	0.34	7.1	10.7	24.4	38.5
7	$MgSO_4$	2.0	0.36	4.7	7.9	13.0	23.0	0.36	5.1	9.4	15.4	37.0

It can observed that the sulfates metals do not significantly affect the LCSPC strength with a specific surface of 450 m^2/kg, with an increase in their content of more than 1% is even a negative impact. This can be explained by the fact that an increase in the content of the sulfate component led to a deficiency of Ca^{2+} ions in the binder system, which are necessary for the formation of hydrosulfoaluminates, and as a consequence, to reduce the compressive strength of the binder. This conclusion is also confirmed by the appearance of a large quantity the efflorescences on the specimens surface with an increase in the content of metal sulfates. However, some positive influence of sulfates on the LCSPC strength is observed with a decrease the binder specific surface to 320-350 m^2/kg. The addition of Na_2SO_4 and $Fe_2(SO_4)_3$ in amounts up to 1% are leads to a strength increase of about 10-15%.

The main factor that affects the LCSPC strength, as in previous studies, was the increase of the specific surface from 320-350 m^2/kg to 400-450 m^2/kg, this led to almost 2 times increase in the compressive strength.

4.3 Efficiency of use the various additives of the low clinker slag Portland cement curing activators

As additives for curing agents, the following were used: sodium silicofluoride, calcium chloride and ferric chloride, as well as sodium carbonate. The low clinker slag Portland cement with a specific surface of 350 and 450 m^2/kg (composition, %: blast furnace granulated slag – 88, phosphogypsum – 7.5, clinker – 12) was used as control composition of the binder (Table 5). SP-1 of 1% of the binder weight was used.

The results indicate that with the increase of the specific surface to 450 m^2/kg, the influence of the curing activators on the binder strength become insignificant. However, these activators allow to an increase of strength of binder with specific surface 350 m^2/kg. The study have shown that sodium silicofluoride (Na_2SiF_6), which belongs to a group of fluorite salts, is the most efficient activator curing for LCSPC.

The strength of low clinker slag Portland cement with the addition of Na_2SiF_6 increased by more than 1.5 times compared with the strength of the control composition. The stronger influence of Na_2SiF_6 on the strength of the LCSPC, in comparison with other additives, can be explained by the appearance of significant amounts of gel $Si(OH)_4$ in the hydrolysis of Na_2SiF_6 in water by the reaction:

$$Na_2SiF_6 + 4H_2O = Si(OH)_4 + 2NaF + 4HF$$

The resulting gel $Si(OH)_4$ actively interacts with the LCSPC, contributing to the hydrosilicates formation. Fluoric acid, HF, is well soluble in water and is more actively interact with slag particles.

Thus, the use of relatively inexpensive and widespread salt Na_2SiF_6 can significantly increase the LCSPC strength ((by 35 by 40%) at a moderate consumption of additive and the value of the binder specific surface.

Tab. 5: Influence of the various additives of the low clinker slag Portland cement curing activators

№	Additives		W/C	Specific surface 350 m²/kg				W/C	Specific surface 450 m²/kg			
				Flexural strength, MPa		Compressive strength, MPa			Flexural strength, MPa		Compressive strength, MPa	
	Type	Content by weight,%		7 days	28 days	7 days	28 days		7 days	28 days	7 days	28 days
1	No additives (control)	-	0.33	5.1	9.1	16.3	33.1	0.32	7.4	10.8	23.4	45.3
2	Na_2SiF_6	1.0	0.35	7.1	9.5	28.4	33.2	0.34	7.5	10.0	28.7	46.1
3	Na_2SiF_6	2.0	0.38	6.8	9.5	29.6	44.3	0.37	7.4	10.0	29.9	49.6
4	$CaCl_2$	1.0	0.31	6.0	8.2	16.8	33.4	0.35	7.1	10.9	24.5	45.3
5	$CaCl_2$	2.0	0.32	6.7	8.6	22.0	33.6	0.36	7.1	10.0	25.1	45.8
6	$FeCl_3$	1.0	0.34	6.9	8.6	19.0	33.8	0.34	7.2	10.2	26.4	45.6
7	$FeCl_3$	2.0	0.35	6.7	8.9	19.2	35.7	0.36	8.1	10.7	27.2	46.1
8	Na_2CO_3	1.0	0.38	6.0	10.8	20.8	37.5	0.34	7.7	10.2	29.2	46.2
9	Na_2CO_3	2.0	0.40	6.4	10.1	21.2	38.4	0.37	7.7	10.6	31.4	47.4

4.4 Sulphate-fluoride-alkaline (SFA) activation of low clinker slag Portland cement

From the results of previous studies, it follows that the addition to binder of substances, mainly ionic nature, as well as substances with oxidative properties, contributes to the hydration activation and the increase of the strength of the binder. However, the disadvantages of the previously described types of activation of LCSPC are low pH of concrete made on this binder, which do not provide a passivation of reinforcing steel.

As is known, the effective method of activating slag binders, with simultaneously increasing the pH, is the adding of caustic alkalis. However, the main disadvantage of this method is the very fast setting of the binding system.

It was of interest to determine the possibility of enhancing the effect of sulfate-fluoride activation by adding $Ca(OH)_2$ into the binder system. From the general chemical positions between these substances must pass the reaction:

$$Na_2SiF_6+3Ca(OH)_2=3CaF_2+2NaOH+Si(OH)_4$$

That is, in the cement paste, along with calcium fluoride (CaF_2), an caustic alkali (NaOH) is formed, which provides additional alkaline activation. The results of the study of the effectiveness of SFA activation are shown in Table 6.

All studies were carried out on the binder of the following composition: Portland cement clinker - 12%, blast furnace granulated slag - 88%, phosphogypsum dihydrate - 7.5% (4.5%, based on SO_3).

Tab. 6: SFA activated LCSPC tests results

№	binder Type	W/C	Cone flow, mm	Flexural strength *at 7 d*, MPa	Compre-ssive strength *at 7 d*, MPa	Flexural strength *at 28 d*, MPa	Compre-ssive strength *at 28 d*, MPa
1	LCSPC	0.4	130	2.0	17.0	5.6	29.4
2	LCSPC	0.5	215	2.6	13.3	3.2	24.1
3	LCSPC+ Lime (3%)	0.4	120	3.6	19.9	8.2	36.3
4	LCSPC+ Lime (3%)	0.5	205	2.9	16.3	5.9	30.8
5	LCSPC+ Lime (7%)	0.4	200	3.0	17.8	6.9	31.4
6	LCSPC+ Lime (7%)	0.5	120	2.8	15.5	6.1	30.2
7	LCSPC+Na_2SiF_6(2%)	0.4	120	4.4	24.7	6.7	38.3
8	LCSPC+Na_2SiF_6(2%)	0.5	205	3.9	21.3	6.7	30.5
9	LCSPC+ Lime (3%)+ Na_2SiF_6(2%)	0.4	115	6.7	28.9	7.2	46.7
10	LCSPC+ Lime (3%)+ Na_2SiF_6(2%)	0.5	200	6.4	24.3	7.5	39.2
11	LCSPC+ Lime (7%)+ Na_2SiF_6(2%)	0.4	115	7.1	24.9	8.5	44.9
12	LCSPC+ Lime (7%)+ Na_2SiF_6(2%)	0.5	195	5.4	23.3	7.2	35.4

With the results, it can be concluded that the addition of SFA into the composition of the LCSPC which contains a sulfate activator, the complex additive in the form of a mixture of sodium silicon fluoride (Na_2SiF_6) and lime allows increase the pH of the binder (from 9-10 to 12-13) and the strength of the LCSPC. In the case of complex sulfate-fluoride-alkaline activation, the LCSPC strength is almost doubled. The providing these characteristics significantly extend the limits of this cement application. It can be used both for the manufacture of concrete and reinforced concrete structures.

5. CONCLUSIONS

Based on the results presented in this paper, the following conclusions can be drawn:

1. It is possible to obtain a low clinker slag Portland cement with a compressive strength greater than 40 MPa using two-component additive modifiers: the superplasticizer SP-1 and the curing activator of sodium silicofluoride (Na_2SiF_6). In this case, the binder has the following composition: the content of clinker – 12%, the content of blast furnace slag – 88%, phosphogypsum content – 7.5% (by SO_3 – 4.5%). The specific surface of the binder was 400-450 m^2/kg, the consumption of the naphthalene-formaldehyde superplasticizer– 1%, and the addition of the sodium silicofluoride (Na_2SiF_6) – 1% of the total weight of the binder.

2. Complex sulfate-fluoride-alkaline activation of LCSPC allowed significantly an increase in the strength of LCSPC and the cement composites pH.

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