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Increasing the water resistance of magnesium binders

V V Shulgin^{1,3}, O V Demchenko¹, O M Gukasian¹, and R V Petrash²

¹ Construction Technologies Department, Poltava National Technical Yuri Kondratyuk University, Pershotravnevyi Avenue 24, 36011 Poltava, Ukraine

² Oil and Gas Engineering and Technologies Department, Poltava National Technical Yuri Kondratyuk University, Pershotravnevyi Avenue 24, 36011 Poltava, Ukraine

³ Email: shwlad17@gmail.com

Abstract. In this work, we have experimentally selected concrete compositions based on magnesium binders and optimized with the addition of a butonal. Effects on strength, water absorption and water resistance of concrete, consumption of magnesium binder, sugar mud, and polymer latex Butonal NS 198 additives are investigated. The study was conducted using a two-factor experiment. The algebraic equations of the tensile strength of concrete, water absorption, and softening coefficient were obtained based on magnesium binders, which characterize the dependence on the variables: magnesium binder consumption, sugar mud, and additives. Refined factor values when the optimal ratio of additive components is reached to obtain concrete based on magnesium binder with softening ratio $C_s = 0.98$, by introducing the butonal into the concrete. The conclusions provide quantitative indicators on the results of these studies.

1. Introduction

Recently, the production of products based on magnesium binders has expanded. By many indicators, magnesium binders are substantially higher than cement binders. General trends in the binder industry, such as high production growth, improved product quality, the organization of new, more efficient types of cement, the use of more powerful and advanced equipment and others, due to the requirements of technological progress, determine, in turn, the direction of further scientific research in this field [1].

Caustic magnesite obtained after burning at relatively low temperatures of some natural minerals, consisting of a considerable amount of carbonate or magnesium hydroxide (magnesite, dolomite), mixed with an aqueous solution of magnesium salts (sulfate or magnesium chloride - bischofite) similar to oceanic ones by the composition [2], forms a plastic paste that manifests the binding properties. The uniqueness of magnesium binder is that it combines its high binder properties and is compatible with virtually any type of aggregate, including organic natural and artificial origin. Magnesium binder cement is a solid solution of salts of complex composition. Various stone materials with predetermined properties under the common name “magnolite” are obtained on the basis of magnesium binder [3-4].

Depending on which fillers are used, the magnolite has mechanical compressive strength at the level of the most high-strength concretes (with bending strength exceeding concrete 3-5 times without the use of additional reinforcing materials), as well as short terms of its curing. In addition, it is the strongest of all known thermal insulation building materials on mineral binders at equal density [5].



This material is indispensable for the production of special purpose structures intended for protection against electromagnetic radiation. The surfaces of magnesite structures do not electrify and exclude the formation of sparks [6]. Magnesium floor coverings are dust-free, have virtually no shrinkage, that is they are arranged with a continuous coating, no need for cutting joints, durable and high-strength, have high hardness and low abrasion, resistant to shock loads [7]. They have high adhesion to virtually all types of organic and mineral aggregates in the binder, as well as good adhesion to concrete, brick, wooden bases. Among other advantages, the preserving properties of the magnolite allow the use of even toxic fillers in the production of construction products, which will subsequently have a background that meets sanitary standards [8, 9]. And the considerable amount of chemically bound water in magnesium cement stone makes magnolite the best of existing concretes for biological protection against radiation damage [10].

Magnesium binder and its products are biologically inert, that is environmentally friendly, but there is one problem – magnesite is not waterproof [11]. This problem is solved in this paper.

2. Research results

2.1. Materials for concrete on magnesium binders

The purpose of the work is to increase the water resistance of magnesium binder based concretes by selecting the composition of magnesium binder concrete and to optimize the cost of the additive.

A mixture of the following materials was selected for this study. As a binder we use caustic magnesite. The magnesite test was conducted in accordance with the requirements.

Table 1. Magnesite test results

Indicator	Requirements of regulatory documents	Test results
The fineness of the grind, %	passing through sieve № 009 not less than 85 %	91.47%
The curing of magnesite:		
onset	not earlier than 30 minutes	40 minutes
end	no later than 6 hours	2 hours
Bulk density	-	1.04 g/cm ³

Bischofite solution of Poltava deposit is a crystalline substance $MgCl_2 \cdot 6H_2O$, which lies at a depth of 2400 - 2600 m. Obtained by the method of underground leaching in the form of an aqueous solution with a density of 1.25 to 1.31 g/cm³. Salt composition of bischofite solution (mass. %): NaCl – 0.59; KCl – 0.31; $MgCl_2$ – 36.15; $CaSO_4$ – 0.05; $FeCl_3$ – 0.038; H_2O – 62.8. Sugar mud (waste of sugar production) bulk density 0.766 g/cm³. Polymer latex was used as the additive Butonal NS 198.

2.2. Experimental planning using mathematical and statistical methods

The planning of experiments and the selection of the optimal amount of admixture for magnesium binder concrete using mathematical and statistical methods were performed using several concrete compositions with different mortar mix mobility; in the construction of the dependencies required to adjust the composition of concrete in the process of its manufacture.

The value of the factor in the main source is called the main (middle or zero level).

Table 2. The value of the intervals of variation.

Code	Code value	Factors value	
		X_1 (ratio d/m)	X_2 (additive), kg
Basic level	0	1.75	4.16
Variation interval	X_i	0.9	2.08
The higher level	+	2.65	6.24
The lower level	-	0.85	2.08

The results of the experiments are processed using the methods of mathematical statistics. The algebraic equation obtained reflects the relationship between the investigated material properties and the initial factors. Material costs were calculated for the two-factor matrix.

2.3. Selection of concrete composition based on magnesium binders

The minimum composition of magnesite 100 kg over 1 m³ was taken as the basis for concrete composition selection. Concrete compositions were selected per 1 m³ of concrete.

Table 3. Selection of concrete composition.

Composition No.	Materials consumption per 1 m ³ of concrete			
	Magnesite, kg	Sugar mud, kg	Bischofite, kg	Butonal NS 198; kg
1	100	265	255	2.08
				4.16
				6.24
				2.08
2	100	175	170.3	4.16
				6.24
				2.08
				4.16
3	100	85	104.8	4.16
				6.24
				2.08
				4.16

We first weigh the required amount of magnesite and sugar mud, and measure the required amount of bischofite and additives with a measuring cylinder, then mix all these materials for three minutes and fit into the molds. For research, samples were made of cubes. In addition to the test specimens with the additive, base samples were prepared to compare the properties. Determination of compressive strength is performed at the age of 7 and 28 days.

To determine the water absorption, the samples dried to constant weight at a temperature of 60-70°C are weighed and lowered for 2 days in water. To determine the softening factor, the samples with and without additives were dried in a drying oven at 60-70°C to constant weight and immersed in water for 2 days. Then, after 2 days, determine the tensile strength of compression of wet samples. In parallel, determine the tensile strength of compression of specimens that have cured in air. Test results are processed by the mathematical statistical method.

3. Analysis of magnesium binder studies

As a result of the processing of the experiments, algebraic equations of water absorption, softening coefficient and ultimate compressive strength of the concrete were obtained based on magnesium binders within the studied limits of the change of factors

3.1. Investigation of the butonal consumption effect on the properties of 7-day magnesium binder concrete

The experiments were conducted using mathematical and statistical methods of experiment planning. The factors selected were the consumption of the additive and the ratio of sugar mud to magnesite (d/m). The design of the experiments and the results of the experiments are shown in Table 4. The curing period of the samples is 7 days.

As a result of processing of the experiments, algebraic equations of water absorption, softening coefficient and ultimate compressive strength of the concrete were obtained based on magnesium binders within the studied limits of the change of factors.

Investigation of the effect of butonal consumption on the ultimate compressive strength of concrete based on magnesium binders aged 7 days.

Algebraic equation of the tensile strength of concrete based on magnesium binders:

$$Y_R = 24.94 - 6.735X_1 + 2.11X_2 - 3.57X_1^2 - 0.11X_2^2 - 0.59 X_1X_2 \quad (1)$$

The Fisher criterion equation is suitable for describing the initial dependence within the studied limits of change of factors, since $0.71 < 19.3$.

Table 4. Plan of experiments and results of experiments

Test No.	Experiment plan		Natural variables values		The limit of compressive strength, MPa	Water absorption, %	Coefficient of softening
	X ₁	X ₂	D/M	Butonal consumption, %			
1	1	1	2.65	3	16.0	9.96	0.99
2	1	-1	2.65	1	13.072	22.36	0.68
3	-1	1	0.85	3	30.869	6.06	0.92
4	-1	-1	0.85	1	25.592	12.74	0.76
5	1	0	2.65	2	14.661	9.20	0.94
6	-1	0	0.85	2	27.674	10.18	0.88
7	0	1	1.75	3	26.852	11.82	0.97
8	0	-1	1.75	1	22.407	13.06	0.83
9	0	0	1.75	2	25.938	12.02	0.92
10	0	0	1.75	2	25.939	12.01	0.93
11	0	0	1.75	2	25.937	12.03	0.91

Equation analysis shows that the greatest effect on the compressive strength is the ratio of sugar mud to magnesite (d/m). The graphical analysis, presented in three variations, shows that when finding the factors at the maximum level, the highest strength is obtained with the minimum value of sugar mud to magnesite (d/m = 0.85) and the maximum consumption of the additive (3% of the magnesite consumption).

Investigation of the effect of butonal consumption on water absorption of concrete based on magnesium binders at the age of 7 days.

Algebraic equation for water absorption of concrete based on magnesium binders:

$$Y_w = 11.5 + 2.1X_1 - 3.4X_2 - 0.9X_1^2 + 1.8X_2^2 - 1.4 X_1X_2 \tag{2}$$

The Fisher criterion equation is suitable for describing the initial dependence within the studied limits of change of factors, since $1.07 < 19.3$.

Equation analysis shows that the greatest influence on water absorption is the ratio of sugar mud to magnesite (d/m) and the amount of additive. The graphical analysis, which was carried out in three variations, shows that when finding the factors at the maximum level, the lowest water absorption is obtained with the minimum value of sugar mud to magnesite (d/m = 0.85) and the maximum consumption of the additive (3% of the magnesite consumption).

Investigation of the effect of butonal consumption on the softening ratio of concrete based on magnesium binders at 7 days of age.

Algebraic equation for water absorption of concrete based on magnesium binders:

$$Y_k = 0.93 + 0.008X_1 + 0.1X_2 - 0.04X_1^2 - 0.05X_2^2 + 0.04 X_1X_2 \tag{3}$$

The Fisher criterion equation is suitable for describing the initial dependence within the studied limits of change of factors, since $9.75 < 19.3$.

Equation analysis shows that the greatest impact on the softening factor is the ratio of sugar mud to magnesite (d/m) and the amount of additive. The graphical analysis, which is presented in three variations, shows that when the factors at the maximum level are found, the highest softening factor is obtained with the maximum value of the deficiency ratio for magnesite (d/m = 2.65) and the maximum consumption of the additive (3% of the magnesite consumption).

3.2. Investigation of the effect of butonal consumption on concrete properties based on magnesium binders at 28 days of age

The experiments were carried out in accordance with the adopted plan of the experiment. The design of the experiments and the results of the experiments are shown in table 5. The term of hardening of the samples is 28 days.

Table 5. Plan of experiments and results of experiments at the age of 28 days

Test №	Experiment plan		Natural variables values		The limit of compressive strength, MPa	Water absorption, %	Coefficient of softening X ₁
	X ₁	X ₂	D/M	Butonal consumption, %			
1	1	1	2.65	3	20.85	8.17	0.98
2	1	-1	2.65	1	17.33	9.20	0.85
3	-1	1	0.85	3	39.87	9.24	0.94
4	-1	-1	0.85	1	34.89	9.79	0.81
5	1	0	2.65	2	19.29	8.79	0.94
6	-1	0	0.85	2	37.45	9.97	0.89
7	0	1	1.75	3	35.59	8.98	0.96
8	0	-1	1.75	1	32.09	9.74	0.82
9	0	0	1.75	2	35.83	9.30	0.91
10	0	0	1.75	2	35.83	9.31	0.92
11	0	0	1.75	2	35.83	9.29	0.90

Algebraic equation of the compressive strength of concrete based on magnesium binders

$$Y_R = 35.579 - 9.126X_1 + 1.999X_2 - 6.571X_1^2 - 1.109X_2^2 - 0.361 X_1X_2 \tag{4}$$

The Fisher criterion equation is suitable for describing the initial dependence within the studied limits of change of factors, since 17.1 < 19.3.

By equation (1) the graphs in Figures 1, 2, 3 are plotted.

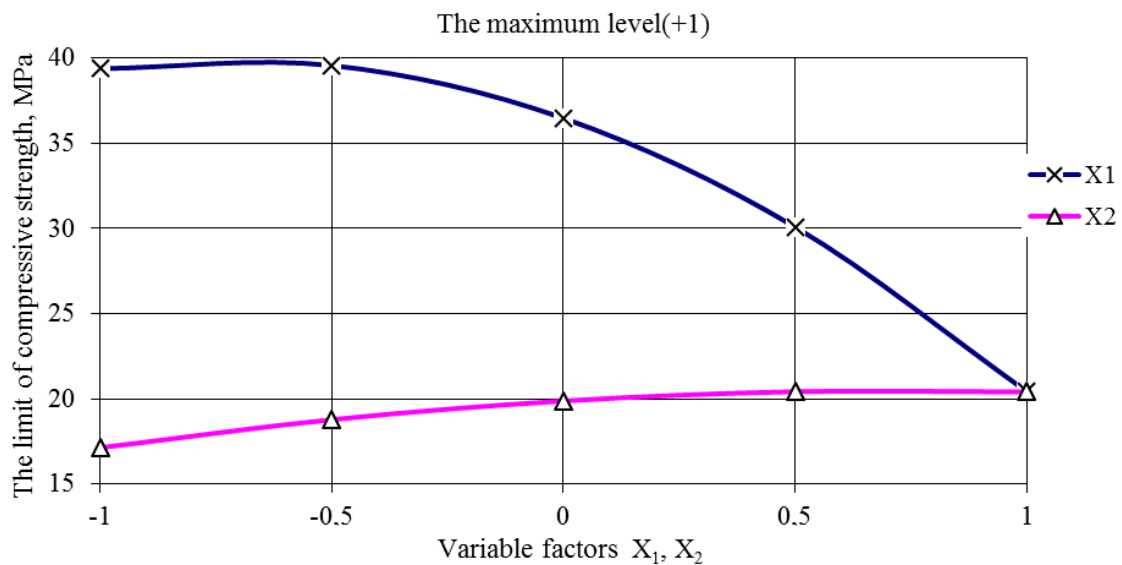


Figure 1. The dependence of the strength of the sample cubes on the amount of butonal and the ratio of sugar mud to magnesite at the age of 28 days.

Equation analysis shows that the greatest effect on the compressive strength is the ratio of sugar mud to magnesite (d/m). The graphical analysis, which is presented in three variations, shows that when finding the factors at the maximum level, the highest strength is obtained with the minimum value of sugar mud to magnesite ($d/m = 0.85$) and the minimum consumption of the additive (1% of the cost of magnesite). Figure 3 shows that the highest strength can be obtained with the maximum value of sugar mud to magnesite ($d/m = 2.65$) and the maximum consumption of the additive (3% of the consumption of magnesite).

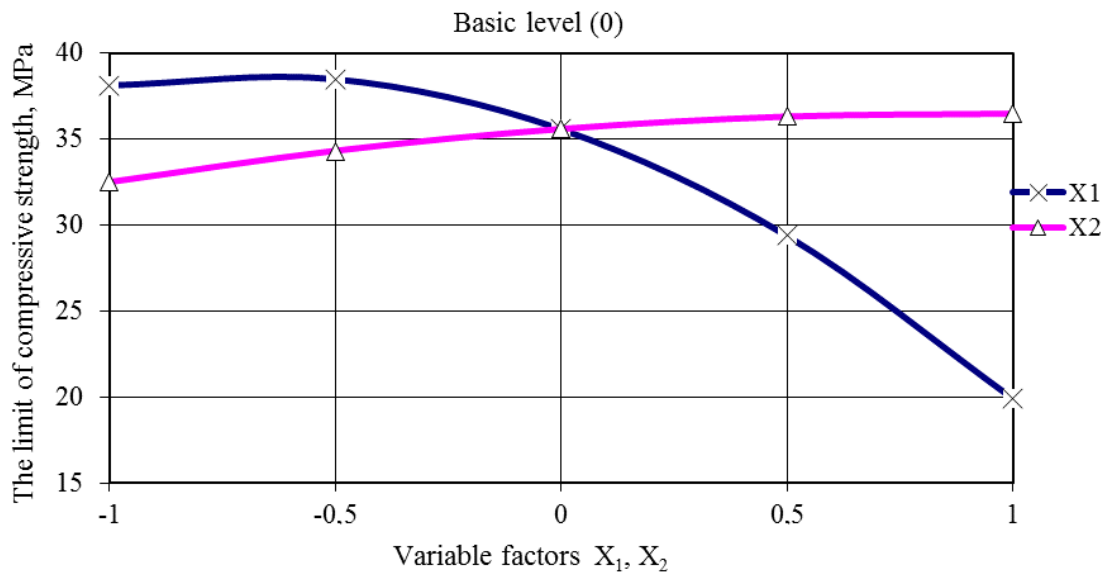


Figure 2. The dependence of the strength of the sample cubes on the amount of butonal and the ratio of sugar mud to magnesite at the age of 28 days.

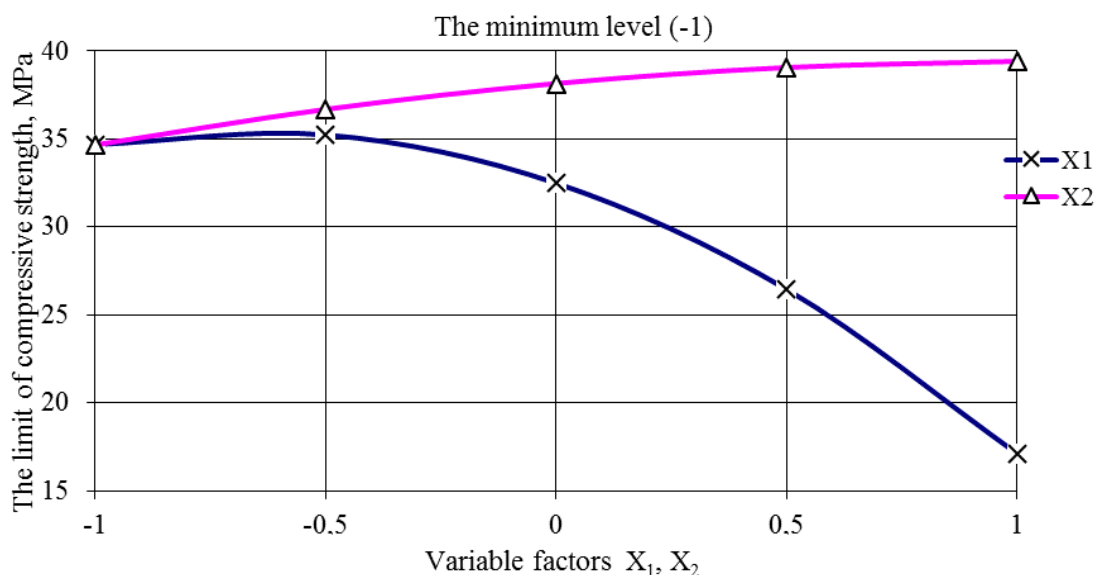


Figure 3. The dependence of the strength of the sample cubes on the amount of butonal and the ratio of sugar mud to magnesite at the age of 28 days.

3.3. Investigation of the effect of butonal consumption on water absorption of concrete based on magnesium binders

Algebraic equation for water absorption of concrete based on magnesium binders:

$$Y_w = 9.39 - 0.47X_1 - 0.39X_2 - 0.11X_1^2 - 0.14X_2^2 - 0.12 X_1X_2 \tag{5}$$

The Fisher criterion equation is suitable for describing the initial dependence within the studied limits of change of factors, since $13.5 < 19.3$.

By equation (5), the most characteristic graphs are shown in Figure 4.

Equation analysis shows that the greatest effect on the water absorption is the ratio of sugar mud to magnesite (d/m) and the additive consumption. The graphical analysis, which is presented in three variations, shows that when finding the factors at the maximum level, the lowest water absorption is obtained with the maximum value of sugar mud to magnesite (d/m = 2.65) ratio and the maximum consumption of the additive (3% of the cost of magnesite).

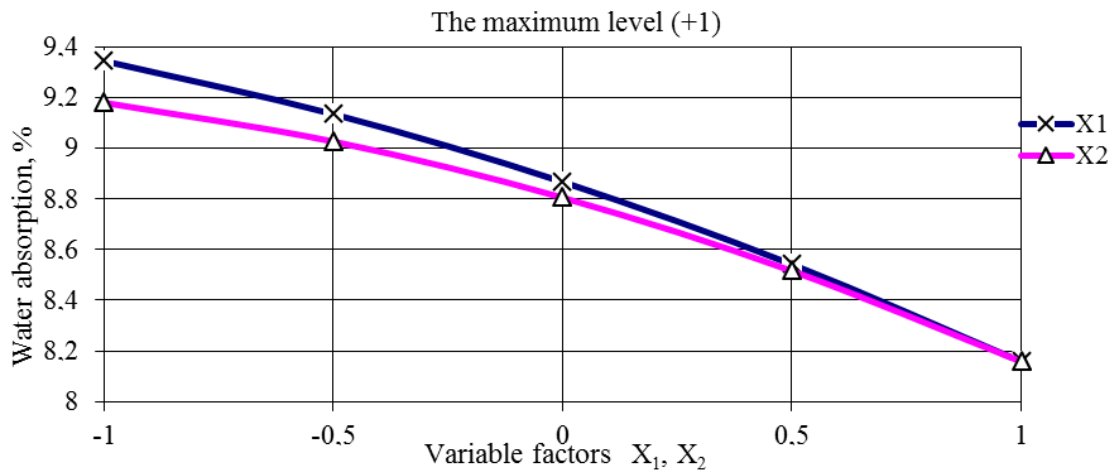


Figure 4. The dependence of water absorption of the sample cubes on the amount of butonal and the ratio of sugar mud to magnesite at the age of 28 days.

3.4. The study of the effect of the consumption of butonal on the coefficient of softening of concrete based on magnesium binders

Algebraic equation for water absorption of concrete based on magnesium binders:

$$Y_K = 0.91 + 0.022X_1 + 0.067X_2 + 0.03X_1^2 - 0.02X_2^2 + 0.17 X_1X_2 \tag{6}$$

The Fisher criterion equation is suitable for describing the initial dependence within the studied limits of change of factors, since $4.6 < 19.3$.

According to equation (6) the graphs in Fig. 5, 6, 7 are generated.

Equation analysis shows that the greatest impact on the softening factor is the ratio of sugar mud to magnesite (d/m) and the amount of additive. The graphical analysis, which is presented in three variations, shows that when the factors at the maximum level are found, the highest softening factor is obtained with the maximum value of the sugar mud to magnesite ratio (d/m = 2.65) and the maximum consumption of the additive (3% of the costs of magnesite).

The optimal composition for the production of concrete based on magnesium binders with $C_s = 0.98$ is the ratio d/m = 2.65 and the cost of the additive 3% of the consumption of magnesite.

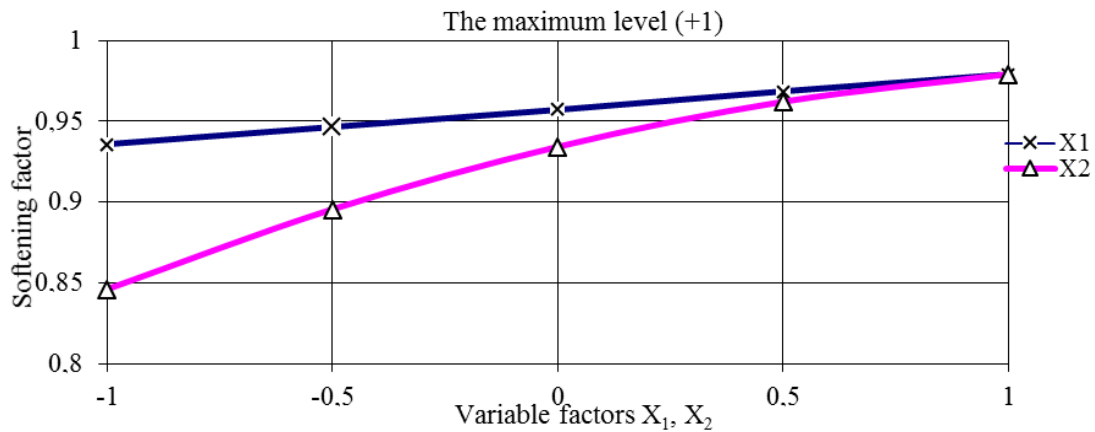


Figure 5. The dependence of the softening coefficient of the sample cubes on the amount of butonal and the ratio of sugar mud to magnesite at the age of 28 days.

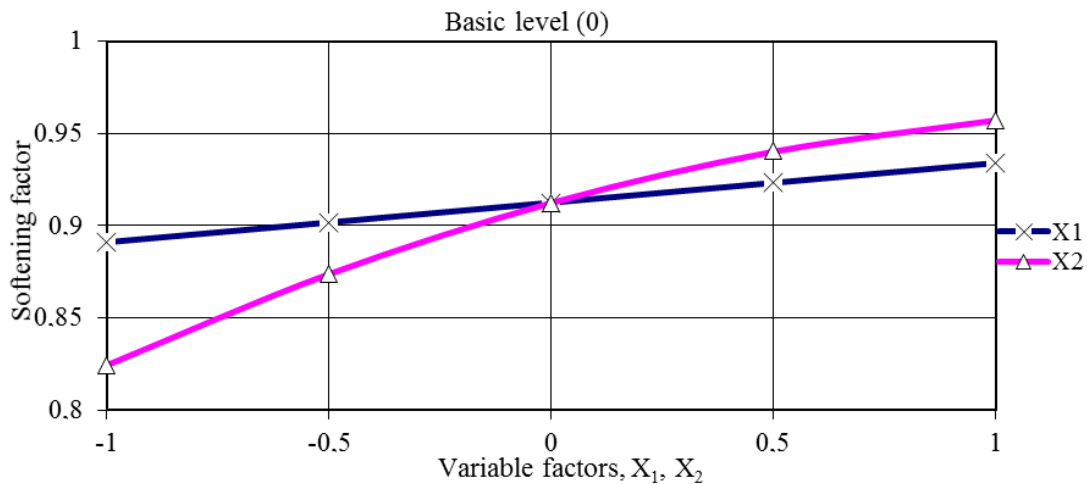


Figure 6. The dependence of the softening coefficient of the sample cubes on the amount of butonal and the ratio of sugar mud to magnesite at the age of 28 days.

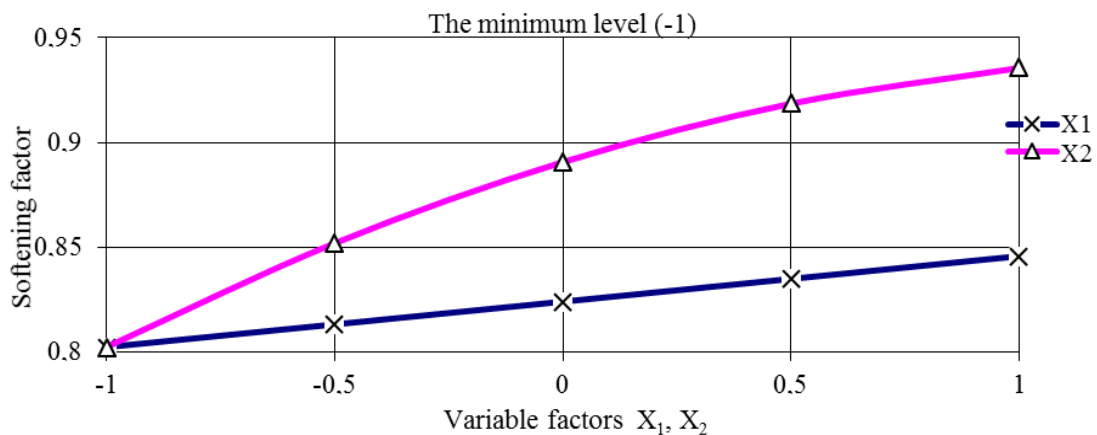


Figure 7. The dependence of the softening coefficient of the sample cubes on the amount of butonal and the ratio of sugar mud to magnesite at the age of 28 days.

4. Conclusion

The ability to increase the water resistance of magnesium-based binder concrete has been demonstrated by the addition of a butonal additive to concrete.

Selected composition of concrete based on magnesium binders with a coefficient of softening $C_s = 0.98$, by introducing into the concrete the butonal.

The optimal composition for producing concrete based on magnesium binders with $C_s = 0.98$ is $d/m = 2.65$ and butonal consumption of 3 % from the magnesite amount.

To reduce the cost of production and increase water resistance, it is proposed to enter a filler - sugar mud.

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