

STRENGTH AND DURABILITY OF CONCRETES WITH A SUPER ABSORBENT POLYMER ADDITIVE

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Abstract. The article presents an analysis of the results of experimental studies of the effect of different types of a super absorbent polymer additive on the strength of different types of concrete. The study is aimed at the effectiveness of a new type of super absorbent additive in concrete structures. In the course of full-scale experiments, it was possible to identify the optimum dosage of SAP for fine-grained and heavy concretes. In addition, the results showed that the strength of concrete remains unchanged if the dosage of super absorbent polymer additive (SAP) is 0.5% of the weight of cement or less. The possibility of modern intelligent technologies (artificial neural networks) to predict the properties of concrete mixture and hardened concrete at given values of input parameters (SAP dosage and W/C), influence on concrete characteristics (slump of the cone, bending strength, compressive strength) has also been shown.

Keywords: new generation concretes, intelligent concretes, super absorbent additives, properties of concretes and concrete mixes, slump of the cone, strength, property prediction, neural systems

ПРОЧНОСТЬ И ДОЛГОВЕЧНОСТЬ БЕТОНОВ С СУПЕРВПИТЫВАЮЩЕЙ ПОЛИМЕРНОЙ ДОБАВКОЙ

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Аннотация. В работе представлен анализ результатов экспериментальных исследований влияния супервпитывающей полимерной добавки разных типов на прочность различных видов бетона, проведенных разными авторами. Изучение эффективности применения нового вида суперабсорбирующей добавки в бетонных конструкциях – такова цель данного исследования. В ходе проведения натурных экспериментов удалось выявить оптимальную дозировку САП для мелкозернистых и тяжелых бетонов. Кроме того, результаты исследований показали, что прочность бетона остается неизменной, если дозировка добавки суперабсорбирующего полимера (САП) составляет 0,5% от массы цемента или менее. Также показана возможность использования современных интеллектуальных технологий (искусственных нейронных сетей) для прогнозирования свойств бетонной смеси и затвердевшего бетона при заданных значениях входных параметров (дозировки САП и В/Ц), влияния на характеристики бетона (расплыв конуса, прочность на изгиб, прочность на сжатие).

Ключевые слова: бетоны нового поколения, интеллектуальные бетоны, супервпитывающие добавки, свойства бетонов и бетонных смесей, расплыв конуса, прочность, прогнозирование свойств, нейронные системы

INTRODUCTION

As it is known, the quality of concrete structures mainly depends on the following three parameters: compressive strength, permeability and resistance to aggressive media. The effective solution of the problem to obtain high-quality concretes is possible due to optimization of their composition, activation of components of concrete mixtures, as well as modification of materials structure by complex additives, which have different functional purpose and contribute to regulation of properties of both concrete mixtures and hardened concretes [1]. However, it should be noted that in the course of concrete products and reinforced concrete structures are often subjected to cracking. This reduces their quality and reduces the expected service life. And the cracks can be caused by both force loads and unfavorable environmental factors. Another reason for cracks in concrete is autogenous shrinkage.

To extend the service life of structures, minimizing the propagation of cracks in concrete is extremely important. Thus, there is an urgent economic incentive to develop concrete which is capable of self-repairing.

Animal and plant organisms are known to have a natural ability to cure small injuries in a relatively short period of time without any external influence. Back in 1712, the French scientist R. Rehomur suggested the term "regeneration", which means the process of restoration by the organism of the damaged structures. The papers [2, 3] described processes of regeneration of animal and plant organisms, from which it follows that regeneration can occur by tissue growth on the injured surface, restructuring of the remaining part of the organ into a new one or by growth of the organ remnant without changing its shape.

Numerous works by foreign and Russian researchers such as V. Achal [4], Chun Xiang Qian [5], W. De Muynck [6], V. Ramarkrichnan [7], J. Y. Wang [8], V. T. Erofeev, V. F. Smirnov, M. G. Brujako [9, 10, 11] have been devoted to creation of technology of concrete modified by various additives and the problem of restoration of

strength and durability of self-repairing reinforced concrete structures during crack repair.

A number of authors were engaged in the development of various chemical methods for creating self-repairing concrete [12, 13]. According to one of the modern methods the restorative agent is placed inside microcapsules collapsing with cracking of concrete. Cracks are filled with the released restorative agent which can be epoxy resins [14], silicon dioxide solutions in alkali [15] etc. After the microcapsule is used up a permanent cavity is formed in its location in concrete [16]. Encapsulating tubes can be one of the tools for "treatment" of concrete [17]. Continuous glass tubes can be used to seal large cracks, allowing the replacement of the reducing agent [18]. Their use also gives the possibility of supplying an additional agent [19]. However, it should be considered that the use of some chemicals originally designed to seal cracks increases the fragility of the concrete. Thus, there is a risk of reducing the service life of concrete when implementing the above approaches.

Economic feasibility and expediency of using additives remain the key factors that affect the effectiveness of an additive [20, 21]. With a rather large nomenclature of domestic and imported chemical additives, the task to apply new types of concrete chemical modifiers remains relevant. It follows that these directions of research of SAP in concrete are the most promising.

The strength of hardened concrete is influenced by both the type of SAP additive and the characteristics of the components of the concrete mixture. In addition, the characteristics of the mixture and the hardened concrete depend on the size of SAP particles, the method of production and the dosage of the polymer. A number of experiments were conducted previously [22], which showed the dependence of the strength of hardened concrete on different dosages of SAP, W/C ratio and the curing time of concrete. The results of the experiments led to the conclusion that the strength of hardened concrete decreases with increasing the dosage of SAP. The correct ratio of water to cement in the mixture is a determining factor affecting the strength of

concrete. The rate of concrete strength gain also depends on the addition of super absorbent polymer. The results of experiments [23] investigating the properties of hardening concrete with the addition of SAP, showed that the strength of concrete specimens with SAP on the 7th day of hardening is much lower than the strength of concrete specimens without polymer, if the W/C ratio is constant when kneading the mixture. On the 14th day of hardening, specimens with and without SAP are identical in compressive strength. On the 28th day of hardening the compressive strength of concrete with a dosage of 0.33% of the cement mass increases by 5%. Experiments conducted in [22] also showed that the addition of SAP in a dosage equal to 0.3% does not cause a noticeable decrease in the strength on the 28th day of concrete curing. According to studies by other authors [25], the compressive strength of concrete increases up to 7% at a dosage of SAP at 3% of the weight of cement. Comparable results were obtained in [26], and [27] reported a slight increase in compressive strength only after adding 0.3% SAP combined with anti-shrinkage additive. Meanwhile, other studies have reported that dosages of 0.3% SAP do not increase the compressive strength. For example, an experiment with three types of SAP was conducted in [28], and all of them led to a decrease in the compressive strength of concrete by 5-15%. Comparable results were obtained in [29]: the compressive strength of concrete at a dosage of 0.3% of the weight of cement decreased by 10-12% after 7 and 28 days of hardening.

Analysis of studies conducted by the various authors allows us to conclude that there is an optimal dosage for each type of SAP. And the experimental results are often not comparable due to differences in the type of SAP, the composition of the concrete mixture and its W/C ratio. Despite this problem, the use of SAP can be an important tool to improve the quality of construction materials. Experimental studies will allow to investigate the effectiveness of the use of the tested types of SAP.

The present study focuses on the investigation of concrete with the addition of super absorbent

polymers that can absorb a large amount of liquid, hold it for a long time and gradually release it back. This property of SAP allows to solve the problem of increasing the strength of concrete due to the effect of internal curing. The SAP particles will gradually release the absorbed water, which ensures a more complete hydration of cement during the hardening of concrete. Internal curing can reduce the risk of cracking in the early stages of hardening and thus increase the strength of the concrete. The described effect can be useful in modern construction, where high-strength concretes with low W/C ratios are applied.

The purpose of the study is to investigate concrete mixtures and hardened concretes modified with a super absorbent additive for further development of effective concrete compositions.

Research Objectives:

1. To evaluate the super absorbent additive as a potential modifier for the development of effective concrete compositions.
2. To define the regularities of changes in the rheological and structural-mechanical characteristics of concrete depending on the dosage of the additive.
3. To consider prospects of using neural network technologies in order to establish the possibility of crack curing and determine the autogenous shrinkage of concrete with SAP additive.
4. The obtained results will help to identify further prospects for the use of the studied types of SAP in concrete structures.

MATERIALS AND METHODS

Portland cement CEM I 42.5 N produced by Gornozavodskcement LLC, Perm region, Russia, was used as a binder.

As an additive was selected super absorbent polymer (SAP) manufactured by the Korean company "GV Holdings Co". Its absorption capacity is 400 g of water per 1 g of SAP, the average particle size is 300 microns. Since the

chosen additive had not been investigated before, the first stage of the research was to conduct experiments with different dosages of SAP and W/C ratios of concrete mortar. The purpose of this study was to determine the effectiveness of this type of SAP as an additive in concrete. The super absorbent polymer was added to the dry mixture of aggregate and cement. Then it was stirred manually before adding water.

A series of concrete specimens on fine aggregate as well as on a mixture of fine and coarse aggregate were investigated. In the first, fine river sand fraction of 0-2,5 mm was applied. In the second case, the same sand and dolomite crushed stone fraction of 5-10 mm were used.

Two series of specimens were molded for the experiment. The first series was performed in the

form of 4×4×16 cm beams, the second one contained specimens-cubes with a rib size of 10 cm. Two series of specimens were made of fine-grained concrete, each with four different compositions. The first four mixtures were prepared according to the normal consistency of the concrete mortar (cone slump of each was 106-115 mm). For the remaining four mortar mixes, a W/C ratio of 0.5 was adopted as constant. This value was chosen in order to obtain the cone slump of 106-115 mm at a SAP dosage equal to 1%. Cone slump of the mortar was determined after each mixture was stirred. Table 1 shows the compositions of the experimental mortars and concretes. The latter ones were formed with a constant ratio W/C = 0.55, the slump of the cone was determined after mixing each composition.

Table 1. Experimental compositions for the specimens

Composition No	SAP, % of the cement mass	W/C ratio	The quantity of materials for 1m ³ of mortar and concrete, kg				
			Cement	Sand	Crushed stone	Water	SAP
1-1	0	0.42	650	1950	–	273	0
1-2	0.25	0.44	650	1950	–	286	1.625
1-3	0.5	0.46	650	1950	–	299	3.25
1-4	1	0.5	650	1950	–	325	6.5
2-1	0	0.5	650	1950	–	273	0
2-2	0.25	0.5	650	1950	–	286	1.625
2-3	0,5	0.5	650	1950	–	299	3.25
2-4	1	0.5	650	1950	–	325	6.5
3-1	0	0.55	365	850	1200	200	0
3-2	0.5	0.55	365	850	1200	200	1.825

Concrete specimens were cured under normal temperature and humidity conditions for 28 days before compression testing. Each of the series of specimens was tested on the 28th day of hardening in accordance with modern regulatory documents.

RESULTS AND DISCUSSION

Among chemical additives in the construction practice the preference is given to additives of

poly-functional action providing maximum use of positive and minimization of negative properties of individual additives. At the first stage of research the rheological properties were considered, namely, the influence of additive SAP on the water-cement ratio and slumping was determined. At the same time, it is important to identify how much it is feasible to reduce or increase water consumption on gravitational slumping of cement compositions.

When forming test specimens No. 1-4 of fine-grained concrete, the dependence of W/C on SAP dosage for the normal consistency of the mortar was determined. Increasing the dosage of SAP led to an increase in the water consumption of the mixture. With the use of

SAP from 0 to 1%, the dependence of W/C on its dosage turned out to be linear (Fig. 1). This dependence is applicable only to the raw materials used in this experiment and only if the dosage of SAP is from 0 to 1% of the cement mass.

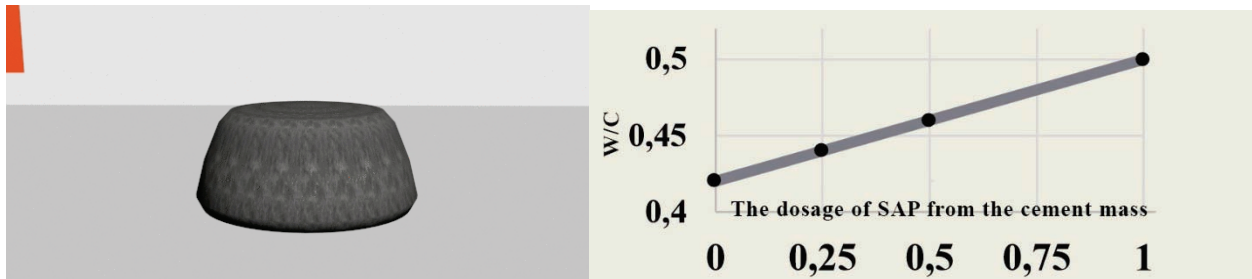


Figure 1. W/C ratio for cone slump of 106-115 mm depending on the dosage of SAP

At the same stage, the dependence of the influence of the quantity of additive on cone slump at a constant water-cement ratio was

revealed. Increasing the dosage of SAP led to a decrease in cone slump at a constant W/C equal to 0.5 (Fig. 2).

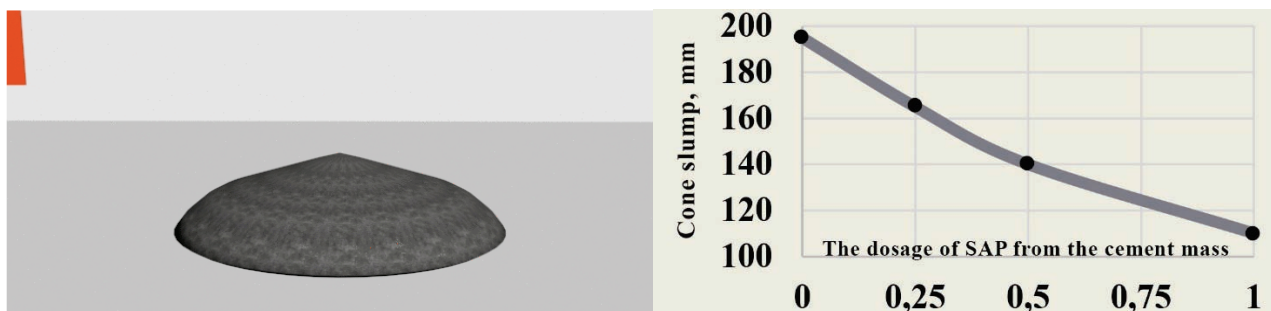


Figure 2. Cone slump depending on the dosage of SAP at a constant W/C ratio equal to 0.5

The detected dependence is not linear, it is limited by the permissible values of cone slump and is also applicable only for raw materials used in this experiment, and only if the dosage of SAP is from 0 to 1% of the weight of cement. The performance of the additive is very often evaluated by the physical and mechanical properties of the resulting concrete. Among the physico-mechanical properties of structural materials are the strength indicators.

A comparative assessment of the effect of SAP additive on the strength of cement composite was performed. The strength values determined in accordance with the standards and its average values have been determined. The dependences of bending and compressive strength of concrete specimens on the dosage of the studied type of SAP were obtained (Fig. 3, 4).

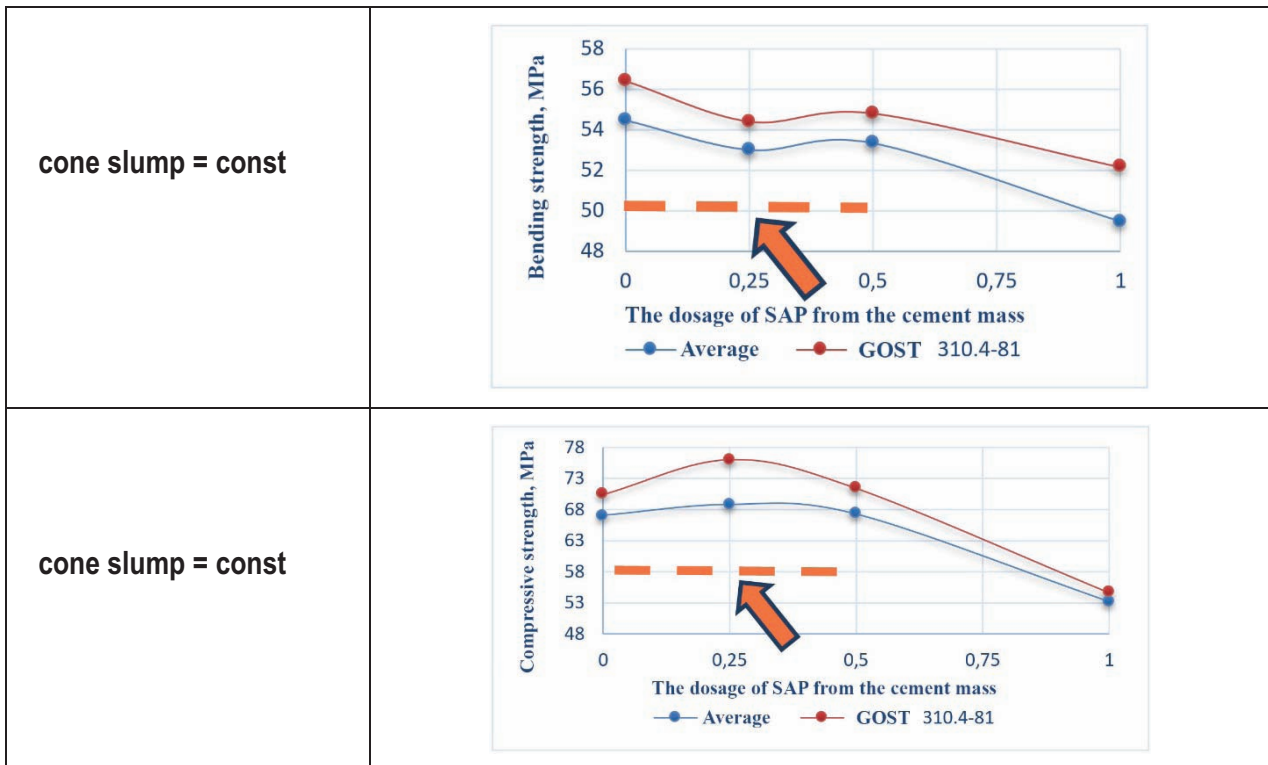


Figure 3. Dependence of the bending strength and compressive strength on the SAP dosage at a constant cone flowequal to 106-115 mm

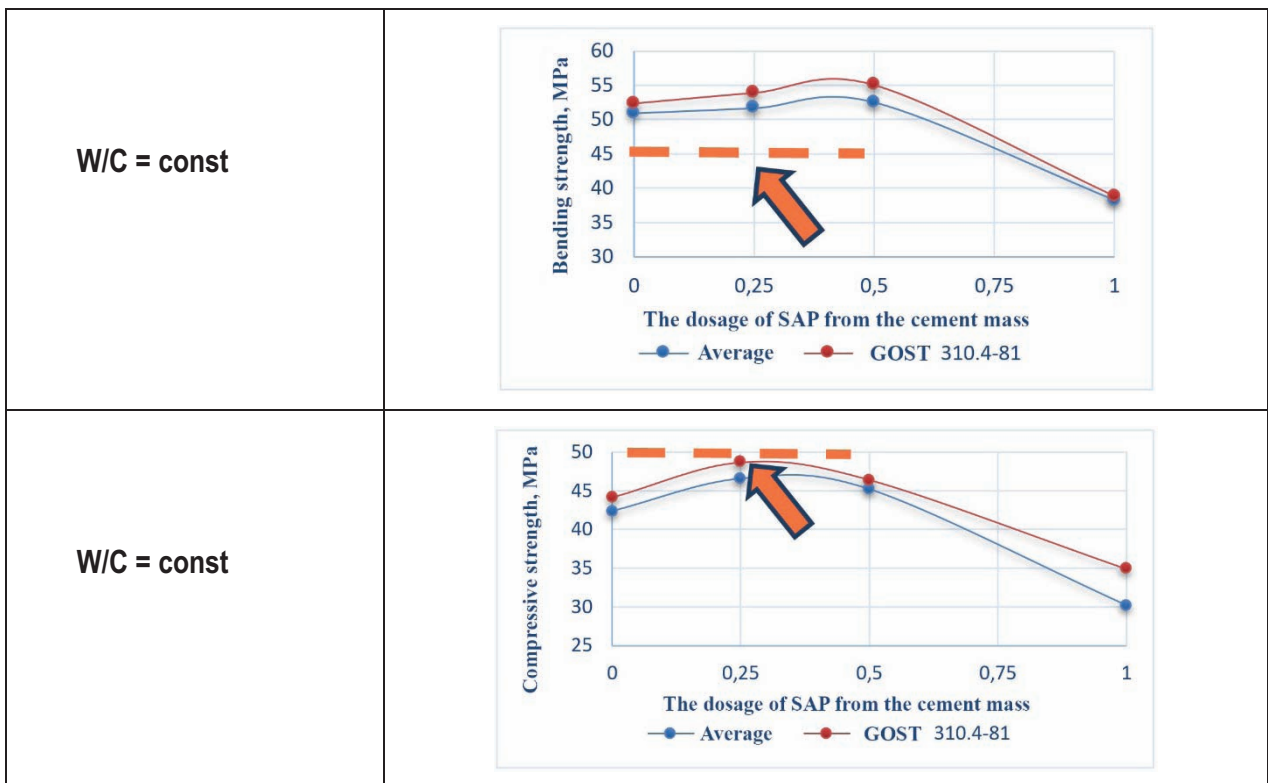


Figure 4. Dependence of the bending strength and compressive strength of concrete depending on the SAP dosage at a constant W/C ratio equal to 0.5

Fig. 3 shows the dependence at a constant cone slump equal to 106-115 mm. Fig. 4 provides the relationship for a constant W/C ratio of 0.5. The above curves can be represented in the form of the surface shown in Fig. 5, which is formed by

three quantities: W/C, the percentage of SAP additive and the strength of the concrete. This allows the results of the study to be seen in a more comprehensible way.

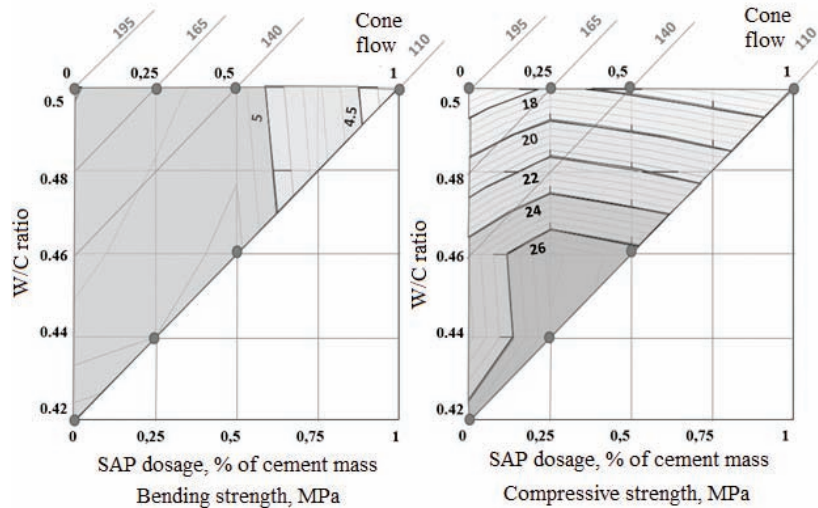


Figure 5. Dependence of the bending strength and compressive strength depending on the SAP dosage and concrete W/C ratio

Analysis of the results shows that the bending and compressive strength of fine-grained concrete does not change at dosages up to 0.5%. However, it decreases by 20-25% when the dosage is increased to 1%. It can be concluded that for further studies of this type of SAP should be selected its dosage not more than 0.5% of the weight of cement. The compressive strength of concrete increases insignificantly

with the dosage of the additive, equal to 0.25% of the weight of cement. It is interesting to compare the test results of mortar mixes with the results obtained by testing specimens of heavy concrete (Fig. 6). Only the additive dosage equal to 0.5% of the weight of cement was investigated in this study, and the compressive strength of concrete was taken as a parameter of properties.

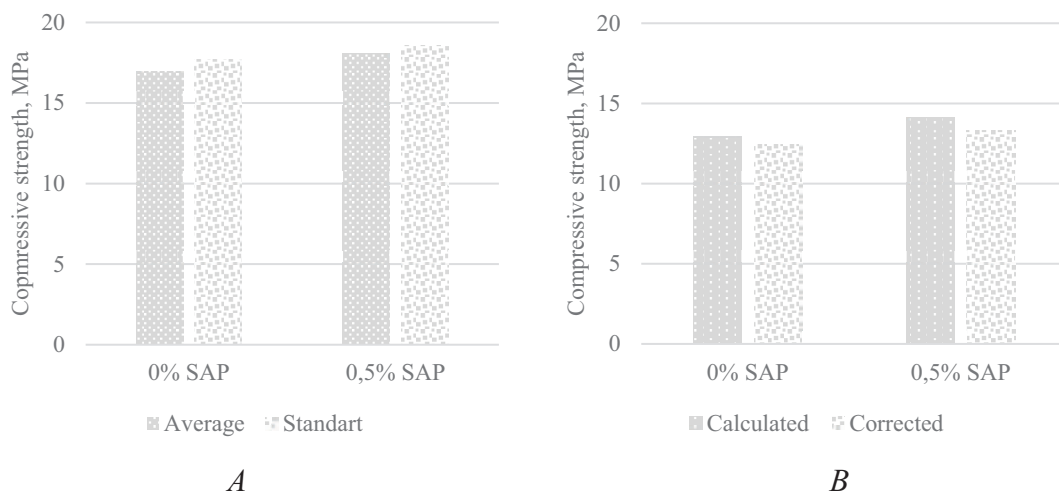


Figure 6. Compressive strength of heavy (A) concrete and fine-grained (B) concrete

The results show that the inclusion of SAP in an amount of 0.5% of the weight of cement increases the compressive strength of heavy concrete by 9% at a constant W/C equal to 0.55. The strength of fine-grained concrete under the same conditions increased by 7%.

As the experimental data accumulate, their generalization and statistical processing become relevant. The solution of this problem allows to pass to the creation of prediction methods for the set of concrete properties.

In 2000-2020s there is a growing interest in theory and practice of artificial neural networks for research of structure-property relations of different materials. Depending on a type of a property they can solve the problems of classification (at a discrete set of values of properties), and also the problems of regression (at continuous values of modelled property).

Neural networks, in a certain sense, represent an alternative to the traditional regression analysis and open up the possibility of creating materials with predetermined properties.

A neural network trained on the information gathered as a result of the study can predict the properties of the obtained material. This

allows to optimally plan further studies and reduce the number of necessary experiments.

Due to the ability to approximate nonlinear dependences of arbitrary form, neural networks are best suited for modeling and predicting the physical and mechanical properties of concretes, depending on such parameters as the composition of mortar and mixtures, temperature, pressure, etc. [30, 31, 32].

This study was conducted on the eight types of concrete compositions in which only the dosage of SAP and W/C varied. All other parameters were the same, so the named variables can be taken as input values. As a result of the study, data such as mortar slump, flexural strength, and compressive strength were obtained for each concrete mixture (see Table 2). These values are the output data.

To create a primitive version of the neural network, the Python programming language was applied. As a training sample, the results of the experiments on the compositions No. 1-8 shown in Table 2 were used. The values of the table were normalized in the range from 0 to 1 with respect to the maximum values of the output data and are presented in Table 3.

Table 2. Neural network base

Mixture №	Input parameters		Output parameters – Results		
	SAP, % of cement mass	W/C ratio	Slump flow, mm	Bending strength, MPa	Compressive Strength, MPa
1	0	0.42	120	5.44	26.84
2	0.25	0.44	120	5.3	27.54
3	0.5	0.46	120	5.33	26.92
4	1	0.5	120	4.96	21.29
5	0	0.5	195	5.09	16.96
6	0.25	0.5	165	5.17	18.64
7	0.5	0.5	140	5.25	18.57
8	1	0.5	120	3.83	12.07

Table 3. Training matrix for neural network

Mixture №	Input parameters		Output parameters – Results		
	X1	X2	Y1	Y2	Y3
1	0	0.84	0.615	1	0.974
2	0.25	0.88	0.615	0.974	1
3	0.5	0.92	0.615	0.979	0.977
4	1	1	0.615	0.911	0.773
5	0	1	1	0.935	0.616
6	0.25	1	0.846	0.95	0.676
7	0.5	1	0.718	0.965	0.674
8	1	1	0.615	0.704	0.438

To determine the prospects of applying the neural network, new compositions were selected for which the input values were known: the dosage of SAP and W/C, while the output values of cone slump, bending and compressive

strength were unknown. New normalized input values were fed into the trained neural network (Table 4). Here is also the result of the neural network.

Table 4. Input and output parameters of neural network

Mixture №	Input parameters		Output parameters - Results		
	X1	X2	Y1	Y2	Y3
Neiro-1	0.75	1	0.656	0.917	0.713
Neiro-2	0.3	1	0.751	0.983	0.823
Neiro-3	1	1.2	0.662	0.924	0.722

After converting the obtained values from normalized to calculated values, the results of

the neural network presented in Table 5 were obtained.

Table 5. Results of neural network

Mixture №	Input parameters		Output parameters – Results		
	SAP, % of cement mass	W/C ratio	Slump flow, mm	Bending strength, MPa	Compressive strength, MPa
Neiro-1	0.75	0.5	128	4.988	19.636
Neiro-2	0.3	0.5	146	5.347	22.665
Neiro-3	1	0.6	129	5.026	19.884

The obtained values allow predicting the properties of the concrete mixture and hardened concrete at given values. It can be assumed that the investigated type of SAP does not reduce the strength of concrete at dosages up to 0.5% of the weight of cement, therefore it can be used to improve other characteristics of concrete. Inclusion of SAP into the concrete mixture

causes the increase of W/C, therefore the effect of its application in combination with plasticizers and anti-shrinkage additives should be accounted for more effective use of the additive.

The interest in the theory and practice of artificial neural networks lies in their ability to approximate non-linear dependences of arbitrary

type by means of algorithms, which the neural networks themselves find.

The disadvantage of the presented system is the absence of a large training sample, so the neural network may have errors.

CONCLUSIONS

1. The possibility of obtaining effective concretes with improved physical-mechanical and operational characteristics by their modification with a super absorbent additive has been theoretically substantiated and confirmed experimentally.

2. The dependence of changes in the characteristics of the quality of concrete mixture depending on the presence of the introduced additive has been established. Increasing the dosage of SAP increases water consumption of concrete mixture, cone slump decreases at a constant W/C ratio. The dependence of the ratio W/C on the dosage of SAP to achieve the slump of the cone 106-115 mm proved to be linear

3. The most effective impact of the additive on the compressive strength can be recognized as follows: the dosage of super absorbent additive in an amount of 0.5% of the weight of cement increases the compressive strength of fine-grained concrete to 7% at a constant ratio $W/C = 0.5$ and increases the compressive strength of heavy concrete to 9% at a constant ratio $W/C = 0.55$. The increase in the dosage of SAP to 1% of the weight of cement decreases the strength of hardened concrete to 20-25% and significantly reduces the slumping of heavy concrete.

4. The obtained results allow further comparative experiments to determine autogenous shrinkage and the possibility of crack curing. The results of the research will also help to substantiate the effectiveness of the presented type of SAP in concrete structures. It can be effective in reducing autogenous shrinkage of concrete without reducing its strength, and may also find application in the creation of self-curing concrete.

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