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RESEARCH ARTICLE

# INFLUENCE OF PLASTICIZING AND AIR-ENTRAINING ADMIXTURES ON CONCRETE PROPERTIES

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**Abstract.** *In the modern construction industry of Kazakhstan, to ensure the needs of the market, there is an urgent essential to improve the quality of concrete and expand its functional purpose. To a large extent, this is achieved by designing concrete as composite materials with different structures, quantities and nature of components. The multicomponent composition makes it possible to effectively manage the structure formation processes of the concrete cementing matrix and obtain concretes with the required properties. This article presented the effect of plasticizing and air-entraining admixtures on the properties of heavy concrete. The compositions of concrete mixture with plasticizing and air-entraining admixtures were selected. The results of study of plasticizing and air-entraining admixtures effect on average density, workability, compressive strength of concrete samples are presented. The effectiveness of introduction of a complex admixtures was evaluated in order to further improve operational properties of concrete. The plasticizing effect makes it possible to increase workability of concrete mortar while by reducing water-cement ratio from 0,5 to 0,38. Due to this, density and strength of concrete increased while improving operational characteristics. The combined effect of plasticizing and air-entraining admixtures had a positive effect on mobility of concrete mortar and its strength of concrete samples. The significant strength of 47,2 MPa was achieved with the combined introduction of a plasticizing and air-entraining admixtures in the amount of 1,2% and 0,5% of the cement weight, thereby increasing the strength of concrete samples by 32% compared to the control sample.*

**Keywords:** *concrete mortar, admixture, strength, density, air-entraining, slag-portland cement, plasticizers.*

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# ПЛАСТИФИКАЦИЯЛАУШЫ ЖӘНЕ АУА ТАРТАТЫН ҚОСПАЛАРДЫҢ БЕТОН ҚАСИЕТТЕРІНЕ ӘСЕРІ

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**Аңдатпа.** *Қазақстанның қазіргі заманғы құрылыс өнеркәсібінде нарықтың қажеттіліктерін қамтамасыз ету үшін бетондардың сапасын арттыру және олардың функционалдық мақсатын кеңейту қажеттілігі туындайды. Бұл көбінесе бетондарды құрамдас бөліктердің құрылымымен, санымен және сипатымен ерекшеленетін композициялық материалдар ретінде жобалау арқылы жүзеге асырылады. Композицияның көп компоненттілігі бетонның цементтеу матрицасының құрылымын қалыптастыру процестерін тиімді басқаруға және қажетті қасиеттері бар бетондарды алуға мүмкіндік береді. Бұл мақалада пластиктендіретін және ауа тартатын қоспалардың бірлескен әсерінің ауыр бетонның қасиеттеріне әсері қарастырылады. Пластификациялайтын және ауа тартатын қоспалары бар бетон қоспасының құрамы таңдалды. Пластификациялаушы және ауаны тартатын қоспалардың бетон үлгілерінің орташа тығыздығына, жұмысқа жарамдылығына, қысу беріктігіне әсерін зерттеу нәтижелері келтірілген. Бетонның пайдалану қасиеттерін одан әрі арттыру мақсатында кешенді қоспаны енгізу тиімділігін бағалау орындалды. Пластификациялау әсері су-цемент қатынасын 0,5-тен 0,38-ге дейін төмендету кезінде бетон қоспасының жұмыс қабілеттілігін арттыруға мүмкіндік береді, соның арқасында бетонның тығыздығы мен беріктігі артады, сонымен бірге пайдалану сипаттамалары жақсарады. Пластификациялаушы және ауа өткізгіш қоспаның бірлескен әсері бетон қоспасының қозғалғыштығына және оның бетон үлгілерінің беріктігіне оң әсер етті. 47,2 МПа ең жоғары беріктікке цемент массасының 1,2% және 0,5% мөлшерінде пластификациялаушы және ауа өткізгіш қоспаны бірлесіп енгізу арқылы қол жеткізілді, бұл бақылау үлгісімен салыстырғанда бетон үлгілерінің беріктігінің 32% - ға артуына әкелді*

**Түйін сөздер:** *бетон қоспасы, жұмыс қабілеттілігі, беріктігі, тығыздығы, ауа өткізгіштігі, шлакопортландцемент, пластификаторлар.*

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НАУЧНАЯ СТАТЬЯ

# ВЛИЯНИЕ ПЛАСТИФИЦИРУЮЩИХ И ВОЗДУХОВОВЛЕКАЮЩИХ ДОБАВОК НА СВОЙСТВА БЕТОНА

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**Аннотация.** *В современной строительной промышленности Казахстана для обеспечения потребностей рынка возникает острая необходимость повышения качества бетонов и расширения их функционального назначения. В значительной мере это достигается путем проектирования бетонов как композиционных материалов, отличающихся структурой, количеством и характером компонентов. Многокомпонентность состава позволяет эффективно управлять процессами структурообразования цементирующей матрицы бетона и получать бетоны с необходимыми свойствами. В данной статье рассмотрено влияние совместного действия пластифицирующих и воздухововлекающих добавок на свойства тяжелого бетона. Подобраны составы бетонной смеси с пластифицирующими и воздухововлекающими добавками. Приведены результаты исследования влияния пластифицирующих и воздухововлекающих добавок добавки на среднюю плотность, удобоукладываемость, прочность на сжатие бетонных образцов. Выполнена оценка эффективности введения комплексной добавки с целью дальнейшего повышения эксплуатационных свойств бетона. Пластифицирующий эффект позволяет повысить удобоукладываемость бетонной смеси при снижении водоцементного отношения с 0,5 до 0,38, за счет чего происходит повышение плотности и прочности бетона с одновременным улучшением эксплуатационных характеристик. Совместное действие пластифицирующей и воздухововлекающей добавки оказало положительное влияние на подвижность бетонной смеси и ее прочность бетонных образцов. Наибольшая прочность 47,2 МПа была достигнута при совместном введении пластифицирующей и воздухововлекающей добавки в колчестве 1,2% и 0,5% от массы цемента, тем произошло увеличение прочности бетонных образцов на 32% по сравнению с контрольным образцом.*

**Ключевые слова:** *бетонная смесь, удобоукладываемость, прочность, плотность, воздухововлечение, шлакопортландцемент, пластификаторы*.

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## 1 INTRODUCTION

In Kazakhstan, monolithic construction is one of the most promising technologies applied in the construction of various buildings and structures for different needs (**Tolegenova, 2021**). Nowadays, concrete is one of the main building materials. Modern building materials are being developed to improve their characteristics, rapid construction, efficient energy saving, lightweight, and above all they must be environmentally friendly (**Lian et al., 2018**). One of the main technical and technological tasks of production is to improve the composition of concrete, quality and reduce its cost (**Beste, 2022**). At the same time, modern materials should have important characteristics: strength and durability, which are the main factors when using a certain technology. At present, the use of complex chemical admixtures is an effective way to improve the quality and properties of ordinary heavy concrete. Admixtures improve the technological, rheological properties and technical indicators of concrete (**Strelenko et al., 2020**).

## 2 LITERATURE REVIEW

Numerous research have proved that an increase in the water and cement ratio leads to a decrease in the strength and durability of concrete (**Anisimov & Chikin, 2015**). The use of superplasticizers can reduce the water and cement ratio and improve the workability of the concrete mortar. In addition, plasticizers contribute to the homogenization of the concrete mortar and, as a result, its workability increases. Due to these characteristics, superplasticizers are the main elements for producing high-performance concrete (**Tarasov et al., 2018**). An important effect of using superplasticizers is the possibility of increasing the kinetics of concrete strength growth, which is a mandatory requirement for monolithic concrete.

Attract attention to the aspect of our research work issue the study of the effect of air-entraining admixtures on concrete mortar. The addition of air-entraining admixtures to the concrete mortar causes the formation of small and stable air bubbles, thereby improving the workability of the concrete mortar (**Lori, 2021**). When the fresh mortar begins to harden, the bubbles in it exposed mineralization and become an integral part of it. Therefore, an additional space is formed inside the concrete structure, in which the freezing water expands. The uniform distribution of pores with air over the entire volume of concrete increases its freezing-thawing resistance (**Yang et al., 2022**).

The study aims to compare the kinetics of heavy concrete's strength set and the workability of a concrete mortar modified with plasticizing and air-entraining admixtures.

## 3 MATERIALS AND METHODS

The technological properties of concrete modified with air-entraining (**CHRYSO Fliud 423**) and plasticizing (**Master Air200**) admixtures were investigated in the research laboratory.

The slag-Portland cement of the Standard Cement LLP CEM III/A-Sh 32H plant appropriate to ST RK EN 197-1-2011 was used as a binder. The composition of cement clinker, the chemical composition of electrothermophosphoric granular slag and the chemical composition of slag-Portland cement, including its physical and mechanical properties are presented in **Tables 1, 2, 3** and **4**. Granular electrothermophosphoric slag is used as the main component of cement. This material is used as an active mineral additive in cement, moreover, slag is the main component in the production of slag-alkaline binders and products based on them (**Gryizlov et al., 2014**).

**Table 1**
Composition of cement clinker [author's material]

| Name of components | Amount,% |
|---|---|
| The total content of tricalcium and bicalcium silicates ($C_2S$, $C_2S$) | 75 |
| Mass ratio of calcium to silicon oxide ($CaO/SiO_2$) | 2,8 |
| Magnesium oxide (MgO) | 1,6 |

**Table 2**
Chemical composition of electrothermophosphoric granular slag [author's material]

| Name of components | Amount,% |
|---|---|
| Silicon dioxide ($SiO_2$) | 40,3 |
| The total content of calcium oxide and magnesium oxide (CaO, MgO) | 47,2 |
| Phosphorus pentoxide ($P_5O$) | 1,1 |
| Chloride-ion ($Cl^-$) | 0,03 |

**Table 3**
Chemical composition of slag-portland cement [author's material]

| Name of components | Amount,% |
|---|---|
| Mass loss during calcination | 0,7 |
| Insoluble residue | 1,4 |
| Sulfur oxide ($SO_2$) | 2,2 |
| Magnesium oxide (MgO) | 1,6 |
| Chloride-ion ($Cl^-$) | 0,05 |

**Table 4**
Physical and mechanical properties of slag-portland cement [author's material]

| Properties | Properties |
|---|---|
| Compressive strength, at the age of 7 days, МПа | 18 |
| Compressive strength at the age of 28 days, МПа | 34,2 |
| Setting time of cement paste: beginning, min, not earlier | 81 |
| Uniformity of volume change (expansion), mm, no more | 6 |

Dolomite crushed stone of a fraction of 5-20 mm with a crushing mark of M1000 and a bulk density of 1,310 t/m$^3$ was used as a coarse aggregate (**Table 5**). This aggregate responds to the requirements of ST RK 1284-2004. The standard defines the basic requirements for crushed stone from dense rocks used as a coarse aggregate for heavy concrete.

**Table 5**
Grain composition of coarse aggregate [author's material]

| Fractions of crushed stone | Quarry | Sieve sizes | | | |
|---|---|---|---|---|---|
| | | d, mm | 0,5(d+D), 12,5 mm | D, 20 mm | 1,25D, 25 mm |
| 5-20 | Test | 97,4 | 66 | 2,4 | 0 |

Natural fine-grained quartz sand with a grain size modulus equal to $M_k$ = 2,4 and a bulk density of 1,450 kg/m$^3$ responding to ST RK 1217-2003 was used as a fine aggregate. The grain composition of the sand is presented in **Figure 1**.

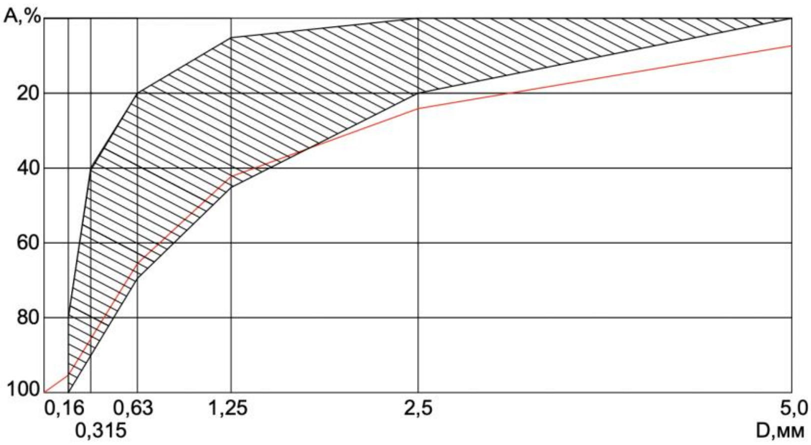


**Figure 1** – Grain composition of sand [author's material]

Drinking water was used to prepare concrete mortar. Water confirms the requirements of GOST 27732-2011, standard ST RK 1015-2000 «Water. Gravimetric method for determining the content of sulfates in natural wastewater».

The plasticizer CHRYSO Fluid 423 (PCE) was used as a plasticizing admixture to improve the workability of concrete. The chemical and physical properties of the admixture are presented in **Table 6**.

**Table 6**
Chemical and physical properties of CHRYSO Fluid 423 [author's material]

| Name | Properties |
|---|---|
| Colour | Brown |
| Consistency | Liquid |
| Density | 1,180 g/cm$^3$ |

Master Air 200 (AIR) was used as an air-entraining admixture (**Table 7**). Admixture was injected into the mortar together with the mixing water. The content of admixtures is indicated as a percentage of the cement mass based on the dry agent of the admixture.

**Table 7**
Physical and chemical properties of Master Air 200 [author's material]

| Name | Properties |
|---|---|
| Colour | Light brown |
| Consistency | Liquid |
| Density | 1,02 ± 0,02 g/cm$^3$ |
| Chlorine ion content | < 0,01% |

The composition of concrete mortar and density (determined according to GOST 27006-2019) are presented in **Tables 8, 9** and **10**. Specimen C1 was prepared as a control specimen. The first four specimens were mixed with a plasticizer and designated as PCE1, PCE2, PCE3 and PCE4. In specimens with a plasticizer, the main difference between the mixtures is a different water and cement ratio, which varies from 0,45 to 0,38. When the water and cement ratio changes, the amount of cement and water remains unchanged. In the case of a mortar with an air-entraining admixture, the water and cement ratio were equal to 0,4 for all specimens.

**Table 8**
Compositions of concrete mortar with a plasticizing admixture [author's material]

| Name of specimen | Cement, g | Sand, g | Water, g | Crushed stone fractions, mm, g, 5-20 | W/C | Plasticizer (PCE), % |
|---|---|---|---|---|---|---|
| C1 | 460 | 670 | 230 | 1100 | 0,5 | - |
| PCE1 | 460 | 670 | 207 | 1100 | 0,45 | 0,6 |
| PCE2 | 460 | 670 | 184 | 1100 | 0,4 | 0,8 |
| PCE3 | 460 | 670 | 175 | 1100 | 0,38 | 1 |
| PCE4 | 460 | 670 | 175 | 1100 | 0,38 | 1,2 |

**Table 9**
Compositions of concrete mortar with an air-entraining admixture [author's material]

| Name of specimen | Cement, g | Sand, g | Water, g | Crushed stone fractions, mm, g 5-20 | W/C | Master AIR 200 (AIR) % |
|---|---|---|---|---|---|---|
| AIR1 | 460 | 670 | 185 | 1100 | 0,40 | 0,2 |
| AIR2 | 460 | 670 | 185 | 1100 | 0,40 | 0,3 |
| AIR3 | 460 | 670 | 185 | 1100 | 0,40 | 0,4 |
| AIR4 | 460 | 670 | 185 | 1100 | 0,40 | 0,5 |

**Table 10**
Compositions of concrete mortar with plasticizing and air-entraining admixtures [author's material]

| Name of specimen | Cement, g | Sand, g | Water, g | Crushed stone fractions, mm, g 5-20 | W/C | Plasticizer (PCE), % | Master AIR 200 (AIR) % |
|---|---|---|---|---|---|---|---|
| (PCE+AIR)1 | 460 | 670 | 185 | 1100 | 0,4 | 0,6 | 0,2 |
| (PCE+AIR)2 | 460 | 670 | 185 | 1100 | 0,4 | 0,8 | 0,3 |
| (PCE+AIR)3 | 460 | 670 | 185 | 1100 | 0,4 | 1 | 0,4 |
| (PCE+AIR)4 | 460 | 670 | 185 | 1100 | 0,4 | 1,2 | 0,5 |

The workability of the freshly prepared concrete mortar for each specimen was determined using a cone in accordance with GOST 10181-2000 «Concrete mortar. Test methods».

For strength testing, cubes of 100×100×100 mm in size were made, four samples for each specimen. When reaching the age of 7 and 28 days, compression tests were carried out in accordance with GOST 10180-2012 by the following formula **(Akmalaiuly, 2023)**:

$$R = \alpha \cdot F/a \cdot K_w \tag{1}$$

where $F$ — destructive load, N;

$A$ — working cross-sectional area of the sample, mm$^2$;

$\alpha$ — scale coefficient for reduction of concrete strength to the concrete strength in samples of basic size and shape;

$K_w$ — correction coefficient for cellular concrete, considering the humidity of the samples at the time of testing.

The results of tests of samples for compressive strength at the age of 7 and 28 days are shown in **Figure 2 and 3**.

## 4 RESULTS AND DISCUSSION

The results of determining the workability of concrete mortar with different content admixtures are presented in **Table 9**.

The cone sediment of freshly prepared concrete mortar of the control specimen was 13 cm. With the injection of admixtures, the workability of concrete mortar is significantly improved. Table 10 shows that all investigated admixtures increased the mobility of the concrete mixture by 10-30%. At the same time, the maximum value is observed in specimen №13 and is 22 cm, which is 36% more than in the control specimen C1. When determining workability after 120 minutes, the maximum result of cone sediment -19 cm was also recorded in specimen №13. In specimens with air-entraining and plasticizing admixtures the largest cone sediment was observed in compositions №4 and № 9, which is 15% and 30% more than in the control composition C1.

**Table 10**

The effect of plasticizing and air-entraining admixtures on the workability of concrete mortar [author's material]

| № | Name of specimen | Cone sediment, cm | | Density, kg/m³ |
|---|---|---|---|---|
| | | After 15 min. | After 120 min. | |
| 1 | C1 | 14 | 8 | 2440 |
| 2 | PCE1 | 15 | 12 | 2470 |
| 3 | PCE2 | 16 | 13 | 2400 |
| 4 | PCE3 | 18 | 16 | 2360 |
| 5 | PCE4 | 20 | 17 | 2350 |
| 6 | AIR1 | 13 | 10 | 2360 |
| 7 | AIR2 | 14 | 12 | 2345 |
| 8 | AIR3 | 16 | 13 | 2240 |
| 9 | AIR4 | 17 | 15 | 2355 |
| 10 | (PCE+AIR)1 | 15 | 13 | 2355 |
| 11 | (PCE+AIR)2 | 17 | 15 | 2336 |
| 12 | (PCE+AIR)3 | 19 | 16 | 2308 |
| 13 | (PCE+AIR)4 | 22 | 19 | 2285 |

When using the PCE admixture in comparison with the control sample (**Figure 2**), an increase in strength was observed at the ages of 7 and 28 days from 37,2 MPa to 38,4 MPa and from 46,8MPa to 48,2MPa.

The increase in strength indicators is related to a result of the action of the plasticizing additive in the cement paste, the volume of the intergranular space decreases. Thereby providing closer contact between the shells of hydrated products on the surface of adjacent cement grains, which promotes combining them into a denser and more durable conglomerate. From the diagram presented in Figure 2, with the injection of PCE, the water and cement ratio of the mortar decreased by 10-24%. At the same time, a significant reduction is achieved with the injection of a plasticizing admixture in the amount of 1,2% by weight of cement.

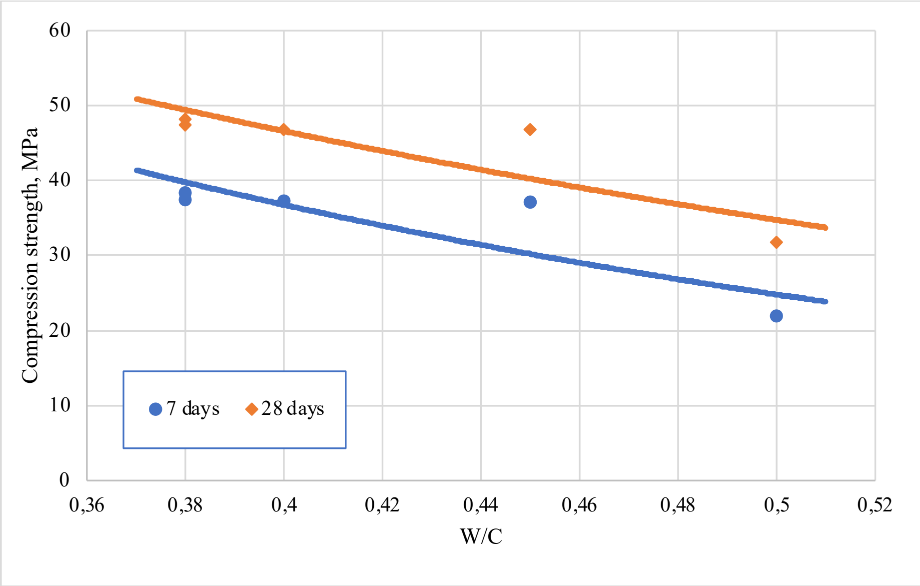


**Figure 2** – The effect of the water and cement ratio on the compressive strength of concrete [author's material]

When modifying the concrete mixture with plasticizing and air-entraining admixtures, a gradual increase in strength was observed at the ages of 7 and 28 days from 21,2 MPa to 34,5 MPa and from 38,0MPa to 47,2MPa, as a presented on **Figure 3**.

The maximum strength at the age of 28 days was obtained with compression R = 47,2 MPa, using PCE and AIR admixtures in the amount of 1,2% and 0,5% by weight of cement. These complex admixtures make it possible to obtain a strength of 32,62% higher than the strength of the control specimen. The density of the concrete mortar at the age of 28 days was 2440-2285 kg/m$^3$. This phenomenon is due to the fact that the combined action of admixtures causes the uniform formation of small and stable bubbles throughout the volume of concrete, thereby increasing its frost resistance.

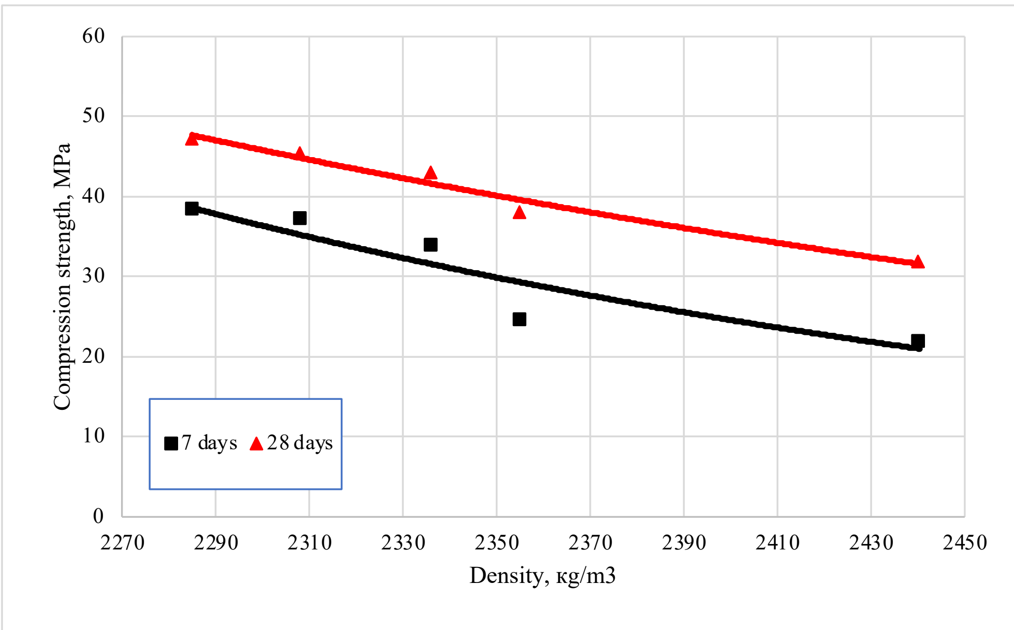


**Figure 3** – Effect of plasticizing and air-entraining admixtures on concrete density [author's material]

## 5 CONCLUSIONS

To date, the use of complex admixtures is an effective way to improve the quality of heavy concrete. Admixtures improve the technological properties of the concrete mortar and the construction and technical indicators of concrete.

Based on the conducted experimental research, the following conclusions can be drawn:

1. Due to the formation of the appropriate structure of capillary pores in the hardened cement mortar, the durability of the cement-based material depends on the ratio of W/C. The water-cement ratio can be reduced by using plasticizers and increasing the air content in the mortar. An increase in the amount of plasticizing admixture from 0,6% to 1,2% led to a decrease in water demand in the concrete mortar to 23,9%.

2. The use of air-entraining admixture significantly increased the workability of the concrete mortar and increased the stability of the air-entrained mortar. An additional effect of the use of air-entraining admixture is a decrease in the actual density of the concrete mixture by 6,35% of the control specimen.

3. The injection of plasticizing and air-entraining admixtures into the concrete mortar has a positive effect on the strength set of concrete. Plasticizer CHRYSO Fliud 423 in the dosage range from 0,8% to 1,4% by weight of cement increases the strength of concrete at the age of 7 and 28 days by 74,5% and 51,5%. The combined action of CHRYSO Fliud 423 and Master Air200 in the dosage range of 1,2% and 0,5% by weight of cement increases the strength of concrete at the age of 7 and 28 days by 56,8% and 48,4%.

Modern building materials require the use of technically and economically reasonable materials with high operational and technical characteristics, therefore, the use of composite materials is more actively included in the field of construction and has prospects for widespread use.

## CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

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