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FINE-GRAINED CONCRETE BASED ON WASTE FROM THERMAL POWER PLANTS AND METALLURGICAL ENTERPRISES EAST KAZAKHSTAN REGION

ШЫҒЫС ҚАЗАҚСТАН ОБЛЫСЫНЫҢ ЖЭО ЖӘНЕ МЕТАЛЛУРГИЯ КӘСІПОРЫНДАРЫНЫҢ ҚАЛДЫҚТАРЫ НЕГІЗІНДЕ ҰСАҚ ТҮЙІРШІКТІ БЕТОН

МЕЛКОЗЕРНИСТЫЙ БЕТОН НА ОСНОВЕ ОТХОДОВ ТЭЦ И МЕТАЛЛУРГИЧЕСКИХ ПРЕДПРИЯТИЙ ВОСТОЧНО-КАЗАХСТАНСКОЙ ОБЛАСТИ

Abstract. *The relevance of industrial processing of waste from thermal power engineering and mining and metallurgical complex (MMC) enterprises in order to obtain effective concrete is due to the need to obtain building materials with improved characteristics and low cost, on the one hand, and the problem of catastrophic volumes and condition of man-made waste stored in the East Kazakhstan region, - with another.*

The purpose of the article is to analyze methods for producing effective fine-grained concrete solutions with the addition of waste from thermal power engineering and mining enterprises located in Eastern Kazakhstan.

The article describes the features and scope of application of fine-grained concrete mortars. The need, possibilities and prospects for using technogenic waste for the production of building materials, products and structures have been studied.

Compositions of fine-grained concrete were selected based on technogenic raw materials - ash and slag waste and metallurgical slag. The study showed that the introduction of fly ash and metallurgical slag into concrete improves the physical and mechanical properties of products with significant savings in cement. The applicability of the studied technogenic raw materials in fine-grained concrete has been proven, resulting in a wide range of applications for the material. The study showed that based on the obtained indicators of strength, frost resistance, abrasion, corrosion resistance, resistance to alternate wetting and drying and other improved characteristics, these concretes can be recommended for the production of small-piece concrete products (curbs, artificial paving stones, paving slabs, side stones, facing slabs, concrete tiles, etc.) and in road construction. The mobility of fine-grained concrete mortar allows it to be used for sealing seams and cracks in monolithic concrete and in the installation of reinforced cement structures, including large ones.

A significant environmental effect from the processing of technogenic deposits in the East Kazakhstan region is shown.

Keywords: *technogenic waste; fine-grained concrete; technogenic deposit; fly ash; dump; ash and* *slag waste; metallurgical slag; fine-grained concrete mortar.*

Аңдатпа. *Тиімді бетондар алу мақсатында жылу энергетикасы және тау-кен металлургия кешені (ТМК) кәсіпорындарының қалдықтарын өнеркәсіптік қайта өңдеудің өзектілігі бір жағынан өнімділігі жақсарған және өзіндік құны төмен құрылыс материалдарын алу қажеттілігіне, екінші жағынан Шығыс Қазақстан облысының аумағында жиналатын техногендік қалдықтардың апатты көлемі мен жай-күйі проблемасына байланысты.*

Мақаланың мақсаты – Шығыс Қазақстанда орналасқан жылу энергетикасы және тау-кен өндіру кәсіпорындарының қалдықтарын қосу арқылы тиімді ұсақ түйіршікті бетон ерітінділерін алу әдістерін талдау.

Мақалада ұсақ түйіршікті бетон ерітінділерін қолдану ерекшеліктері мен көлемі сипатталған. Құрылыс материалдарын, бұйымдарын және конструкцияларын өндіру үшін техногендік қалдықтарды пайдалану қажеттілігі, мүмкіндіктері мен перспективалары зерттелді.

Ұсақ түйіршікті бетонның құрамдары техногендік шикізат – күл мен қож қалдықтары және металлургиялық шлак негізінде таңдалды. Зерттеу бетонға күлді және металлургиялық қожды енгізу цементті айтарлықтай үнемдей отырып, өнімнің физикалық-механикалық қасиеттерін жақсартатынын көрсетті. Зерттелетін техногендік шикізаттың ұсақ түйіршікті бетонда қолданылуы дәлелденді, нәтижесінде материалды қолданудың кең ауқымы пайда болды. Зерттеу көрсеткендей, алынған беріктік, аязға төзімділік, тозуға төзімділік, коррозияға төзімділік, кезектесіп сулану мен кептіруге төзімділік және басқа да жақсартылған сипаттамалар негізінде бұл бетондарды ұсақ бетон бұйымдарын (бордюрлер, жасанды төсемдер) өндіруге ұсынуға болады. тастар, тротуар тақталары, бүйірлік тастар, қаптау тақталары, бетон плиткалары және т.б.) және жол құрылысында. Ұсақ түйіршікті бетон ерітіндісінің қозғалғыштығы оны монолитті бетондағы тігістер мен сызаттарды герметизациялау үшін және арматураланған цемент конструкцияларын, соның ішінде ірі құрылымдарды орнату үшін пайдалануға мүмкіндік береді.

Шығыс Қазақстан облысындағы техногендік кен орындарын өңдеудің айтарлықтай экологиялық әсері көрсетілген.

***Түйін сөздер**: техногендік қалдықтар; ұсақ түйіршікті бетон; техногендік кен орны; ұшатын күл; үйінді; күл және қож қалдықтары; металлургиялық шлак; ұсақ түйіршікті бетон ерітіндісі*

Аннотация. *Актуальность промышленной переработки отходов предприятий теплоэнергетики и горно-металлургического комплекса (ГМК) в целях получения эффективных бетонов обусловлена необходимостью получения строительных материалов с улучшенными характеристиками и низкой себестоимостью с одной стороны, и проблемой катастрофических объемов и состояния техногенных отходов, складируемых на территории Восточно-Казахстанской области, – с другой.*

Целью исследования является анализ способов получения эффективных мелкозернистых бетонов растворов с использованием отходов предприятий теплоэнергетики и горнодобывающих предприятий расположенных на территории Восточного Казахстана.

В статье приведены особенности и сферы применения мелкозернистых бетонных растворов. Изучены необходимость, возможности и перспективы использования техногенных отходов для производства строительных материалов, изделий и конструкций.

На основе техногенного сырья – золошлаковых отходов и металлургических шлаков – подобраны составы мелкозернистого бетона. Исследование показало, что введение в состав бетона золы, уноса и металлургических шлаков улучшает физико-механические свойства изделий при значительной экономии цемента. Доказана применимость исследуемого техногенного сырья в мелкозернистом бетоне, обусловлена широкая сфера применения материала. Исследование показало, что по полученным показателям прочности, морозостойкости, истираемости, коррозионной стойкости, стойкости к попеременному увлажнению и высушиванию и другим улучшенным характеристикам эти бетоны можно рекомендовать для производства мелкоштучных бетонных изделий (бордюров, искусственной брусчатки, тротуарной плитки, бортовых камней, облицовочных плит, бетонной черепицы и пр.) и в дорожном строительстве. Подвижность мелкозернистого бетонного раствора позволяет использовать его для заделки швов и щелей в монолитных бетонах и в монтаже армоцементных конструкций, в том числе крупногабаритных.

Показан значительный экологический эффект от переработки техногенных месторождений Восточно-Казахстанской области.

Ключевые слова: *техногенные отходы; мелкозернистый бетон; техногенное месторождение; зола уноса; отвал; золошлаковые отходы; металлургический шлак; мелкозернистый*

бетонный раствор

Introduction. Fine-grained concrete is considered to be of dense structure with an average density of more than 2000 to 2500 kg/m^3 inclusive on cement binder and dense fine aggregate [1].

The compressive strength of fine-grained concrete is 10-40 MPa and higher. The strength depends on such factors: cement activity; type of slag used; grain composition of sand; hardening conditions, temperature and duration of heat and moisture treatment, etc. Fine-grained concrete is somewhat more amenable to deformation.

Fine-grained concrete is a very popular building material today.

The main advantage of fine–grained concrete is its mobility, so the mixture is often used in the repair of seams, cracks, when sealing various deformations of building structures. Before waterproofing works, the screed is often prepared by pouring a fine-grained concrete mortar. It is suitable for the production of curbs, paving slabs, arches and other small-piece construction products intended for the improvement of urban areas. High indicators of strength, water resistance, frost resistance of fine-grained concrete allow the effective use of fine-grained concrete for road construction [2].

We will highlight the main areas of application of fine–grained concrete mortars:

– production of small-piece construction products by casting;

– sealing of seams and cracks in monolithic concrete;

– installation of various reinforced cement structures, including canopies and arches for large spans and impressive spaces;

– manufacture of concrete pipes of small and large diameters, including pipes for the removal of aggressive media;

– construction of thin-walled structures with complex or thick reinforcement;

– construction of rubble buildings and structures;

– installation of road surfaces;

– construction of structures and buildings on sand pits;

– manufacture of elements and structures for the installation of hydraulic structures, etc.

The main component of the investigated fine-grained concrete is slag sand and granular slag.

The technology of high-strength fine-grained concrete provides for the optimization of the grain composition of the aggregate, intensive mixing in forced mixers, the use of effective methods of compaction and hardening of concrete.

Products made of fine-grained concrete must have high strength, frost resistance, wear resistance, durability. It is not always possible to obtain products with such characteristics from ordinary cement-sand concrete. Natural sands often have a low size modulus (for example, sands mined in the quarries of the East Kazakhstan region have a size modulus of 1.2-1.4 and higher). According to the requirements of regulatory documents and the recommendations of scientists, the use of such sands in concrete is not allowed, since this inevitably leads to a significant overspending of cement [3].

Therefore, for fine-grained concrete, it is advisable to use other aggregates that ensure the achievement of the necessary characteristics of concrete within the established norms of cement consumption. In this regard, attention should be paid to the possibility of using additives and aggregates of concrete prepared on the basis of waste from coal-fired thermal power plants and the mining and metallurgical complex of the East Kazakhstan region. It should be noted that the resource in the form of man-made waste on the territory of East Kazakhstan region and other regions of Kazakhstan is truly not limited, although their properties in different dumps may have significant differences.

The purpose of the article (work) is to analyze the methods of preparation of effective fine-grained concrete solutions based on waste from coal thermal power and enterprises of the mining and metallurgical complex of the East Kazakhstan region.

The objectives of the study are defined as:

1) perform a literature review on the research problem;

2) to study the composition of waste from the dumps of thermal power plants and metallurgical enterprises of East Kazakhstan region;

3) experimentally investigate the characteristics of fine–grained concrete prepared with the addition of ash and slag - waste of East Kazakhstan enterprises;

4) formulate conclusions about the efficiency of using man-made waste from the heat power plant and the MMC for the preparation of fine-grained concrete.

Literary review. Currently, the issues of the use of man-made waste in order to reduce the cost of construction materials have become very relevant. The importance of the research topic is also due to the difficult environmental situation in the East Kazakhstan region, on the territory of which there are huge volumes of man-made waste. The dumps of coal-fired thermal power plants and mining and metallurgical enterprises have a particularly heavy environmental burden on the region, as they adversely affect the state of three environments: the lithosphere, air and reservoirs. The situation is also aggravated by the fact that most of the toxic industrial waste storage facilities in the East Kazakhstan region are in an emergency condition or close to it. Processing of man-made waste, thus, not only reduces the cost of concrete building materials and products, improves environmental quality indicators in the region, but also reduces the amount of investment (and very significant) for the construction of new dumps.

The idea of using man-made waste for the production of building materials is by no means new.

At the moment, scientists have proved that the secondary use of ash can improve the environmental situation that occurs after the generation of energy by coal-fired thermal power plants. In a number of works [4], [5], [6] and others. It is shown that the chemical composition of this type of waste improves the physical, mechanical and operational characteristics of concrete and construction products.

In addition, convincing data have been obtained that the involvement of heat power plants [7] and mining and metallurgical industries [8] in the processing of technogenic waste can significantly reduce the cost of construction materials and products.

On the issue of the use of ash and slag waste for the production of concrete, the work was studied [9]. The authors of the article analyze in detail the ways of effective use of ash and fuel slags in the construction industry. The methods of obtaining effective concretes with the use of waste from the mining and metallurgical complex are substantiated.

Studies have been conducted on the use of man-made waste as raw materials for the production of building materials, taking into account the environmental factors of their impact on the environment [10].

In articles [11] and [12], an ecological and toxicological assessment of artificial mixtures created on the basis of ash and slag waste is given.

At the same time, the problem of manufacturing fine-grained concrete based on man-made waste has not been studied enough to date. Here we can mention only a few works published in the last three or four years.

The analysis of methods of utilization of ash and slag of thermal power facilities for the needs of production of fine-grained solutions is presented in the work of N.I. Buravchuk and O.V. Guryanova, where the authors experimentally proved the effectiveness of compositions of fine-grained solutions based on raw materials of technogenic deposits for the construction of road surfaces [13].

Evaluation of the effectiveness of combining mineral additives in fine-grained concrete was performed by A.K. Khalyushev [14].

It should be noted that there are earlier (10-15 or more years ago) studies of the properties of concretes produced on the basis of ash and slag waste and metallurgical slags, including on the basis of technogenic deposits of the East Kazakhstan region. However, we cannot fully use the results of these studies: firstly, because the properties of raw materials obtained from man-made deposits vary greatly depending on the timing of their storage in dumps, secondly, the requirements of standards for the quality of building materials are being tightened, thirdly, construction and production technologies are being rapidly updated construction materials and products.

We see that the scale of the research problem clearly does not correspond to the number of scientific research in this area undertaken in the last few years. In addition, there is no data on the implementation of new projects for the processing of man-made deposits in the East Kazakhstan region and on the organization of mass or serial production of fine-grained concrete based on waste from thermal power plants or MMC enterprises in the region.

Thus, further studies of the properties and characteristics of fine-grained solutions prepared on the basis of waste from technogenic deposits of the East Kazakhstan region are necessary.

Materials and methods of research. In this paper, the influence of fine additives and fillers from ash and slag waste and metallurgical slags on the properties of fine-grained concrete is investigated.

The objects of the study were selected ash and slag wastes of Ust-Kmayenogrsk thermal power plant and non-ferrous metal slags of enterprises of the East Kazakhstan region.

Experimental studies were carried out on the basis of the laboratory of D. Serikbayev EKTU (Ust-Kamenogorsk, Kazakhstan).

Fine additives were used for research: fly ash, ground copper-nickel slag, fine-grained aggregate from ash and slag wastes and metallurgical dumps.

In order to use ash and slag waste from thermal power plants and metallurgical slags in the technology of fine-grained waste, technological samples of technogenic were selected and a comprehensive assessment of its quality was carried out.

Sampling was carried out in accordance with the instructions of generally accepted methods, the requirements of regulatory and governing documents, state standards. According to the current legislation and standards, sampling of technogenic waste is carried out by employees of thermal power plants and metallurgical enterprises together with representatives of the environmental service or environmental authorities (in the case of sampling from man-made waste landfills or ash dumps).

The total specific activity of natural radionuclides is determined by gamma-spectrometric method according to GOST 30108.

For our research, employees of thermal power plants and metallurgical enterprises transferred only those technogenic raw materials that successfully passed radiation and toxicological control in factory laboratories.

The method used in our study is based on the principle of point sampling. The selected slag samples are placed for natural drying in air at a temperature of 18-20 °C and then ground to pieces passing through a sieve with a cell of 3 3 mm, and samples weighing 200 g are taken from them by quartering for subsequent analyses. The remaining part of the sample serves as a backup (control). Ash and slag samples weighing 200 g are crushed to an analytical powder according to GOST 10742 and used for subsequent analyses.

Analytical-laboratory and physico-mineralogical studies of technogenic raw materials consisted in obtaining primary information about the chemical and material composition of ash slag and metallurgical waste based on GOST 25592. The chemical analysis of ash and slag components and the content of sulfide sulfur were determined in accordance with GOST 8269.1. The grain composition of slags was determined according to GOST 8735. The specific surface of fine–grained ash and slag mixtures and the residue on the sieve № 008 were determined according to GOST 310.2, the bulk density and grain density of the slag component were determined in a dry state according to GOST 9758.

The uniformity of the volume change of fine-grained ash and slag mixtures was carried out in a mixture with Portland cement at a ratio of 1:1 (cement : ash) according to GOST 310.3 by boiling samples in water. The resistance of slag crushed stone against silicate and ferruginous decay, frost resistance was determined according to GOST 8269.0, weight loss during calcination in ash and slag components – according to GOST 11022. The content of free calcium oxide in the waste was determined according to GOST 23227. The humidity of ash and slag and metallurgical slag mixtures was determined according to GOST 8735.

After the assessment of the chemical and material compositions of technogenic raw materials, prototypes of fine-grained concrete mortar with the addition of waste were made and their physico-mechanical and technological tests were carried out in accordance with the requirements of standards (GOST 18105, GOST 10180, GOST 27006, GOST 10060, GOST 13087 GOST 12730.5, etc.). Samples of fine-grained concrete mortars were tested on workability, bending strength, compressive strength, sulfate resistance. frost resistance, abrasion resistance, corrosion resistance, resistance to alternating moisture and drying.

Results and their discussions. Ash and slag waste is formed as a result of thermochemical transformations of coal, and stored on the surface in dumps, and the inorganic part of the fuel in boilers. The genesis of their formation is different, as are the properties. Their composition and properties are influenced by both the composition of the carbon-containing rocks of the mineral components of the fuel, and the conditions of firing and combustion. The formation of burnt rocks occurs during a long (decades) self-ignition in ash dumps [15].

Ash and slag waste from Ust-Kamenogorsk thermal power plant is represented by fly ash (dry selection ash) and ash and slag mixture. Fly ash is captured by electrofilters and shipped to cement trucks. Part of ash and fuel slag (ash-slag mixture) the hydraulic ash and slag removal system is sent to the dumps. The ash-slag mixture contains, as a rule, up to 30% of fly ash [16]. The chemical composition of the studied technogenic raw materials is acidic, the content of silicon oxide is more than 50%.

The chemical composition of metallurgical technogenic deposits of the East Kazakhstan region is represented by silica (67+72%), alumina (10+12%), calcium oxide (2,6+4,5%) [17].

Table 1 provides information on the chemical composition of ash and slag used for the preparation of prototypes of fine-grained concrete.

Table 1. Chemical composition of the initial technogenic raw materials, weight %

Name of the sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	SO_3	$Na_2O·K_2O$	п.п.п *
Fly ash	51,27	22,49	9,32	2,95	1,69	0,95	0,93	4,67	5,63
Metallurgical slag	69,75	10,21	4,25	2,78	1,08	1,06	2,18	4,12	4,57
Fuel slag	53,88	24,40	11,20	2,40	2,15	0,56	0,50	3,89	0,97
*Calcination losses									

Table 1 shows that technogenic raw materials contain mainly free and bound oxides of silicon, aluminum, iron, calcium, magnesium, potassium, sodium, sulfur.

In addition, crystalline, vitreous and organic substances can be isolated in the composition of waste from technogenic deposits of East Kazakhstan region. According to the results of physico-mineralogical studies, the crystalline substance is represented by quartz of various modifications, magnetite, hematite, mullite. Of the minerals that are neoplasms, silicates, aluminates and calcium aluminoferrites, similar to cement stone minerals, are noted. When burning coal, a number of thermochemical transformations do not have time to complete before the equilibrium state occurs. The product of such an incomplete process is a vitreous phase of variable composition. It makes up a significant part, especially in the halls of acid composition. The products of clay minerals occupy an intermediate position between the crystalline and vitreous groups of substances. The unburned fuel particles present in ash and slag wastes and in metallurgical slags are amorphized to varying degrees, are different from the initial solid fuels and charge and are in the form of coking products and graphitized carbonaceous matter. These substances are resistant to oxidation and environmental influences.

Table 2 shows the compositions of experimental and control samples of fine-grained concrete.

Table 2. Compositions of fine-grained concrete containing technogenic raw materials

Composition number	Component content, kg/m^3					Saving cement, %
	Cement	Fly ash	Ash and slag mixture	Metallurgical slag	Sand	
1	500	200	–	1570	–	43,8
2	600	150	1520	–	–	32,6
3	700	–	1570	–	–	21,3
4	600	150	–	1520	–	32,6
5	500	200	1570	–	–	43,8
Control	890	–	–	–	1520	–

The study showed that the introduction of fly ash can improve the workability of rigid concrete mixes, reduce cement consumption, reduce voidness by 3-7 %, water demand by 5-7 %. The strength gain of fine-grained concrete on technogenic raw materials can occur both under normal hardening conditions at a relative humidity of at least 90 % and a temperature of 20 (± 2) °C, and during heat and moisture treatment [18].

The data obtained indicate that concretes containing technogenic raw materials (ash and slag waste or metallurgical slag) have high bending strength. Figure 1 shows the dependence of bending strength on compressive strength for three types of concrete: ash concrete (curve 1), concrete based on copper-nickel slag (curve 2) and ordinary fine–grained concrete (curve 3 – control).

It can be seen from Figure 1 that the highest values of bending strength have ash concrete, the lowest – ordinary concrete. The increased strength of ash concrete is associated with a pronounced plasticizing effect of ash, which contributes to the formation of a more homogeneous and dense structure of concrete.

It should be noted that particularly dense and durable concretes of classes B22.5 – B40 can be obtained using the technology of vibration compression (vibration stamping) [19].

Another distinctive feature of concretes based on technogenic raw materials is increased sulfate resistance. Observations of the expansion of samples during alternating saturation in a solution of sodium sulfate and drying show that in ash concrete and concrete based on metallurgical fine slag deformations comparable in magnitude to deformations of conventional concrete appear with a significantly larger number of test cycles.

In figure 2, the curve for ordinary concrete is located to the left and has a steeper rise than the curves for concrete with heat power plant and metallurgical copper-nickel slag. The influence of ash and slag on the sulfate resistance of concrete has a physical and chemical character. The physical nature of this phenomenon is associated with a relative increase in contacts between particles and the formation of a more homogeneous and dense concrete structure [20].

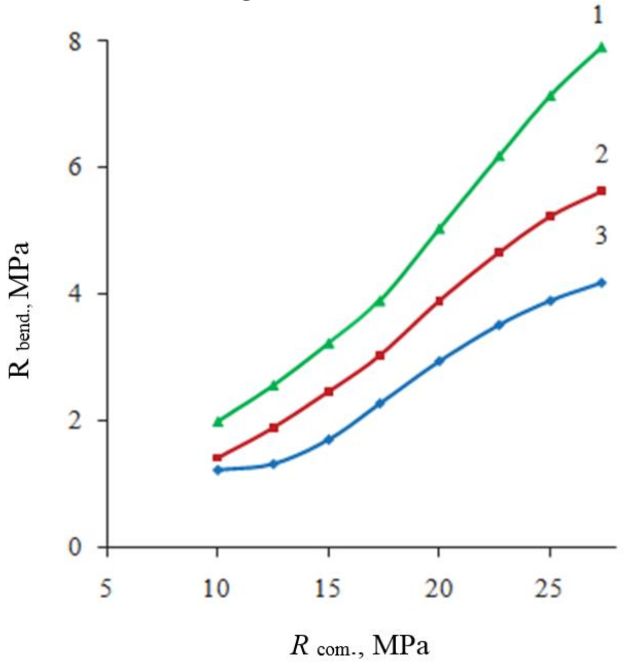

Figure 1. The dependence of the bending strength of concrete on its compressive strength: 1 – fine–grained ash concrete; 2 – fine-grained concrete based on metallurgical slags; 3 – ordinary concrete (control)

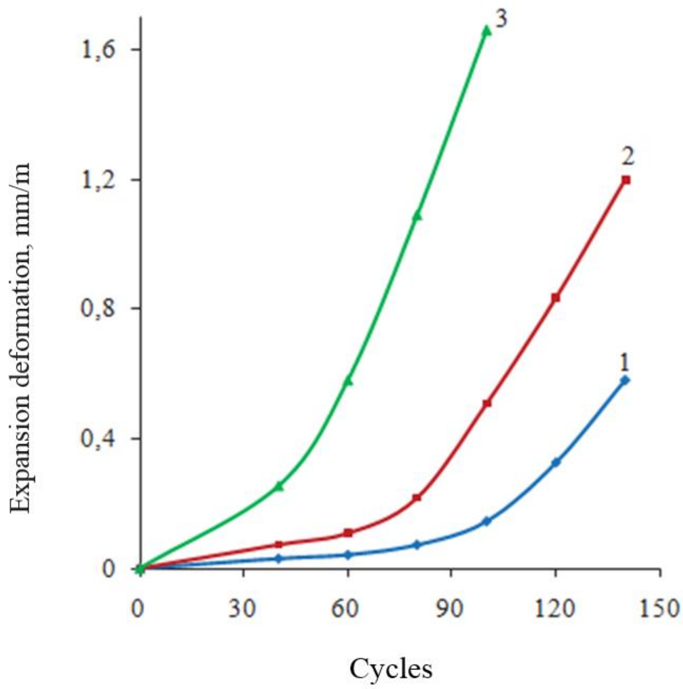

Figure 2. Kinetics of the development of linear deformations of concrete during cyclic tests in Na_2SO_4 solution: 1 – composition with the addition of metallurgical slag; 2 – composition with the addition of ash; 3 – control composition

The physicochemical character is due to the pozzolan properties that ash and slag waste and burnt rocks are able to exhibit. The result of the manifestation of pozzolan activity is the binding by mineral additives of free lime formed during the hydration of cement and the formation of a significant amount of cementing substances. At the same time, the contact layer has a more developed and less defective surface, more resistant to deformation manifestations and the effects of aggressive media [21].

Conclusion. Based on the results of the study , several main conclusions can be formulated:

1) the source of replenishment of the mineral resource base for the construction industry can be waste from mining and metallurgical enterprises, coal industry and thermal power engineering. A huge amount of ash and slag and metallurgical waste has accumulated in the dumps in the region. Accumulations of such waste in terms of quantity and quality of suitability for use are man-made deposits that are as valuable for the construction industry as they are dangerous for the environment and human health;

2) research and practical experience have proved that from technogenic raw materials (ash, metallurgical slag, ash and slag waste), with appropriate preparation, it is possible to obtain small aggregates of various sizes for the production of fine-grained concrete mortars;

3) the article shows the positive effect of ash and slag materials and metallurgical slags on the physical and mechanical properties of concrete, as well as the possibility arising from their use to significantly reduce cement consumption (up to 45%) without deterioration of the properties and quality of concrete give reason to recommend them for wide use in the technology of concrete mortars;

4) according to the obtained indicators of strength, frost resistance, abrasion resistance, corrosion resistance, resistance to alternating moistening and drying and other improved characteristics, these concretes can be recommended for the production of small-piece concrete products (curbs, artificial paving stones, paving slabs, side stones, facing slabs, concrete tiles,

etc.) and in road construction. The mobility of fine-grained concrete mortar allows it to be used for sealing seams and cracks in monolithic concrete and in the installation of reinforced cement structures, including large-sized ones;

5) the results obtained are recommended for introduction into the production of building materials, products and structures, and also contribute to solving environmental problems of the region associated with large volumes of man-made waste from mining, metallurgical and thermal power enterprises of the East Kazakhstan region.

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