ANNOTATION

of the dissertation work by
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on the topic: «Development of fine-grained concrete compositions using ash-and-slag waste from Ust-Kamenogorsk thermal power plant for additive technologies»
submitted for the degree of Doctor of Philosophy (PhD)
in the educational program 8D07302 – «Production of Building Materials, Products and Structures»

The relevance of the research topic is determined by the priority areas of science development in the Republic of Kazakhstan for 2024–2026, namely: «Ecology, Environment and Rational Use of Natural Resources» and «Energy, Advanced Materials and Manufacturing». In this context, the utilization of ash and slag waste generated by thermal power plants and the development of new construction materials based on these industrial by-products are of particular importance. At the same time, the advancement of additive technologies in construction requires the development of specialized concrete mixtures with tailored properties. Therefore, the development of fine-grained concrete compositions incorporating ash and slag waste for 3D printing represents a relevant scientific and practical task.

The purpose of the dissertation research is a comprehensive study of ash-and-slag waste from the Ust-Kamenogorsk thermal power plant used in fine-grained concrete for additive technologies (3D printing), with scientific substantiation of their optimal composition and application parameters.

To achieve this goal, the following objectives were set:

- to analyze the application of additive technologies in construction, the use of ash-and-slag waste from thermal power plants in the production of fine-grained concrete, including for additive technologies, as well as methods for designing its compositions;
- to study the formation and distribution features of ash-and-slag materials in the ash dump of the Ust-Kamenogorsk thermal power plant and assess the possibility of their use in cement composites;
- to develop and substantiate compositions of fine-grained concrete using ash-and-slag waste from the Ust-Kamenogorsk thermal power plant suitable for additive construction technologies (3D printing);
- to investigate the rheological, technological, physical, and mechanical properties of the developed concrete mixtures and concretes;
- to conduct experimental testing of the developed compositions under additive manufacturing (3D printing) conditions and evaluate the quality of the resulting concrete elements;
- to assess the operational properties of the developed concretes, perform modeling of their behavior, and determine the technical and economic efficiency of their application.

Research Methods. The study employed theoretical methods (analysis and generalization of domestic and international experience, modeling of concrete

properties), experimental methods (investigation of physical-mechanical and rheological characteristics of raw materials and concretes, mix design, and sample testing), instrumental methods (X-ray diffraction analysis and electron microscopy), as well as pilot-production methods (experimental 3D printing of samples and technical-economic efficiency assessment).

Scientific Novelty of the Research:

- it has been scientifically substantiated that the most effective active component is the ash from zone 4, characterized by the minimum bulk density (350–500 kg/m³) and the maximum glass phase content (75–93%). The studies confirmed that the predominance of amorphous aluminosilicates in this zone ensures high reactivity under mechanical activation conditions required to destroy inert aggregates and increase the specific surface area to 3000–4000 cm²/g;
- spherical ash particles with a fraction size of 0.16 mm reduce the internal friction of the mixture, ensuring stable extrusion at a cone penetration value (CPV) of 7.0–7.5 cm, and also densify the concrete structure by filling intergranular voids;
- it has been experimentally substantiated that the optimal characteristics of concrete are achieved using a mechanically activated binder obtained by joint grinding of 80% Portland cement and 20% ash (mainly from zone 4 of the ash dump). This method of component preparation provides compressive strength of 22.9 MPa and interlayer bond strength of 1,48 MPa;
- statistical-regression modeling of concrete properties was carried out. A mathematical model based on machine learning methods was developed (implemented in (R^2 = 0.87–0.95) mathematically confirm that 87–95% of the strength characteristics are determined specifically by the composition of the activated ash-cement binder;
- based on instrumental studies *Python* using the pandas and *NumPy libraries*). High values of the coefficient of determination (XRD, SEM), the formation of a high-density cement-ash matrix due to the pozzolanic reaction was proven, in which the amorphous silica of ash interacts with portlandite to form secondary calcium silicate hydrates (C–S–H). Numerical modeling in ANSYS confirmed that in the optimized composition (80/20), the equivalent stresses arising during the printing of small architectural forms do not exceed 2.51 MPa.

Scientific provisions submitted for defense:

- substantiation of the possibility of using ash-and-slag waste from the Ust-Kamenogorsk thermal power plant in fine-grained concrete intended for additive technologies;
- regularities of the influence of the composition and mineralogical characteristics of ash-and-slag components on the rheological properties, shape stability, and interlayer adhesion during 3D printing;
- developed compositions of fine-grained concrete using ash-and-slag waste, providing an optimal combination of strength and technological characteristics for additive construction;
- results of experimental and instrumental studies (XRD, SEM) confirming the effectiveness of ash-and-slag waste in forming the structure and durability of concrete.

Practical significance of the research:

- a scientifically substantiated composition of fine-grained concrete using ash-and-slag waste from the Ust-Kamenogorsk thermal power plant for additive technologies has been developed and recommended for application;
- patent of the Republic of Kazakhstan for Utility Model No. 10443 «Composition of Concrete Mixture for 3D-Printed Concrete» has been obtained;
- patent of the Republic of Kazakhstan for Utility Model No. 12067 «Raw mixture for 3D printing of concrete products based on ash-and-slag waste» has been obtained;
- certificate of state registration of copyright object No. 68369 dated March 5, 2026, was obtained for the methodology of selecting the composition of a concrete mixture for 3D printing, taking into account the mobility of the printed layer and shape stability;
- the developed composition of fine-grained concrete was implemented in the production of university landscaping elements using construction 3D printing technology, which is confirmed by an implementation act;
- the results of the dissertation research were introduced into the educational process of the educational programs 6B07305 – «Construction» and 6B07501 – «Standardization and Certification», which is confirmed by an implementation certificate.

The author's personal contribution consists in active participation in formulating the research objectives and tasks, as well as in preparing scientific publications, conference abstracts, and filing a patent application. Laboratory studies and testing were carried out independently by the author. In co-authored publications, the author made a significant contribution to conducting experimental research, processing and analyzing the obtained data, preparing article manuscripts, and developing recommendations for implementing the results in the university landscaping process and educational activities.

Degree of Reliability of the Research Results. The reliability of the obtained scientific results is confirmed by the use of modern research methods and compliance with the requirements of current regulatory and technical documents. Experimental studies were carried out in the accredited Laboratory of Construction Technologies and Materials at the «Center of Competence and Technology Transfer in Construction» (EKTU). Additional studies were conducted at the Polytechnic University of Madrid (Spain) during a scientific internship. The obtained results were validated through a set of laboratory and pilot experimental studies.

Approbation of the Research. The main results of the dissertation research have been published in the following journals and conference proceedings:

- «Optimization of a sustainable composition of fine-grained concrete for 3d printing with partial substitution of sand with fly ash and slag waste», Nanotechnologies in Construction Scientific Internet Journal, p. 296, June 2025, doi: 10.15828/2075-8545-2025-17-3-296-306;

- «Additive Manufacturing as an Alternative to Core Sampling in Concrete Strength Assessment», Applied Sciences, vol. 15, issue 14, p. 7737, July 2025, doi: 10.3390/app15147737;

- «Fine-Grained Concrete Based on Waste from Thermal Power Plants and Metallurgical Enterprises of the East Kazakhstan Region», Bulletin of Serikbayev EKTU, issue 1, pp. 313–323, December 2023, doi: 10.51885/1561-4212_2023_4_313;

- «Development of Composition of Fine-Grained Concrete Based on Ash-and-Slag Wastes for Additive Technology of Manufacturing Small Architectural Forms», Technobius, vol. 4, issue 4, p. 0069, November 2024, doi: 10.54355/tbus/4.4.2024.0069;

- International Scientific and Practical Conference «XVII Saginov Readings. Integration of Education, Science and Production», Part 3, pp. 260–261, presentation on the topic «Development of Concrete Mixtures for 3D Printing»;

- International Scientific and Practical Conference «XVI Saginov Readings. Integration of Education, Science and Production» (June 13–14, 2024), pp. 261–262, presentation on the topic «Possibility of Using Local Raw Materials for Fine-Grained Concrete Applied in 3D (Additive) Printers»;

- Patent of the Republic of Kazakhstan for Utility Model No. 10443 dated February 13, 2025, «Composition of Concrete Mixture for Creating 3D-Printed Concrete»;

- Patent of the Republic of Kazakhstan for Utility Model No. 12067 dated April 17, 2026, «Raw Mixture for 3D Printing of Concrete Products Based on Ash-and-Slag Waste»;

- Certificate of registration in the State Register of Copyright-Protected Objects No. 68369 dated March 5, 2026, «Methodology (algorithm) for selecting the composition of a concrete mixture for 3d printing considering the mobility and shape stability of the printed layer».