2025 IEEE 6th KhPI Week on Advanced Technology

(KhPIWeek)

CONFERENCE PROCEEDINGS

October 06 - 10, 2025

Kharkiv, Ukraine

2025 IEEE 6th KhPI Week on Advanced Technology (KhPI Week)

IEEE Catalog Number: CFP25Z72-ART
ISBN: 979-8-3503-8909-8
ISSN: 3064-9560 (print), 3064-9579 (online)

Organizing Committee of 2025 IEEE KhPIWeek
Work phone: +38 (057) 707-66-34
E-mail: khpiweek@ieee.org.ua
National Technical University “Kharkiv Polytechnic Institute”
Kyrpychova Str. 2
61002, Kharkiv, Ukraine

ORGANIZERS

IEEE Ukraine Section EMB Society Chapter

IEEE Ukraine Section PE/IE/IA Societies Joint Chapter

IEEE Ukraine Section IE/PE/PEL Societies Joint Chapter

IEEE Ukraine Section NANO Council Chapter

Development and Research of Special Properties of Concrete Based on Alkaline Earth Elements

Olena Khrystych
Department of General and Inorganic Chemistry
National Technical University "Kharkiv Polytechnic Institute"
Kharkiv, Ukraine
khristichelena@gmail.com

Alla Korohodska
Department of General and Inorganic Chemistry
National Technical University "Kharkiv Polytechnic Institute"
Kharkiv, Ukraine
Alla.Korohodska@khpi.edu.ua

Halyna Shabanova
Department of Ceramics, Refractory Materials, Glass and Enamels Technology
National Technical University "Kharkiv Polytechnic Institute"
Kharkiv, Ukraine
Halyna.Shabanova@khpi.edu.ua

Maksim Kustov
Research Laboratory of Radiological, Chemical and Biological Safety
National University of Civil Protection of Ukraine
Kharkiv, Ukraine
kustov_m@nuczu.edu.ua

Mykhailo Khrystych
Department of Ceramics, Refractory Materials, Glass and Enamels Technology
National Technical University "Kharkiv Polytechnic Institute"
Kharkiv, Ukraine
Mykhailo.Khrystych@ihti.khpi.edu.ua

***Abstract*— The paper presents the results of experimental studies in the field of ferroelectric and piezoelectric materials. Theoretically, using the mathematical method of planning an experiment when constructing and studying composition-property diagrams, the optimal composition of aggregate for concrete based on alkaline earth aluminates was determined. To obtain concrete with high strength, density, and homogeneity, the optimal composition of concrete includes a three-fractional mixture of aggregate consisting of barium titanate. Concrete samples were experimentally obtained and its main electrophysical properties characterizing piezoelectric materials were determined: dielectric constant, dielectric loss, electrical resistance, and piezoelectric modulus. It has been proven that an increase in the content of aluminate cement in concrete leads to a decrease in the value of the concrete piezoelectric modulus. Therefore, for the manufacture of piezoelectric sensors, concrete compositions with the best performance characteristics were chosen, which have 30 % aluminate cement (composition: 40 % $BaAl_2O_4$ + 60 % $BaTiO_3$) and 70 % aggregate (barium titanate). The areas of application of the developed concretes as piezoelectric force pulse sensors characterized by a large surface and significant attenuation of their own resonant vibrations have been determined. Such sensing elements can be used in piezoelectric sensors for electrodynamic conversion of capacitors' electrical energy into a shock pulse for geophysical research in the study of mechanical processes in soils and in the field of seismology in the study of dynamic processes in buildings and structures.**

Keywords — concrete, oxide systems, alkaline earth aluminates, electrophysical properties, polarization, piezoelectric sensors

I. Introduction

The mineral exploration industry in various countries utilizes the technology of seismic wave generation by sources of powerful mechanical impact on the ground. The traditional technology uses explosives, which makes it dangerous and environmentally harmful. There is an alternative technology that uses pulsed seismic sources with different force-drive systems and different ways of impacting the ground. In pulse and vibration technologies of a number of industries as technical means, mechanical, pneumatic, hydraulic, electromechanical converters of reciprocating motion are used. At present the competitiveness of pulse electromechanical converters in comparison with devices of other types has significantly increased. The relevance of their application has increased due to the increase in energy efficiency, reliability and, especially, manufacturability of final products [1-3].

The exploitation of electrodynamic transformations of capacitor electrical energy into shock pulse for geophysical research [4, 5] is associated with the need for constant determination of the shape and amplitude of the shock pulse, since these parameters determine the amplitude and spectrum of excited seismic oscillations.

Produced mono-polycrystalline piezoelectric sensors for measuring seismic signals do not meet the basic requirements for measuring dynamic processes in the operation of electrodynamic type installations. Because of the significant influence of the sensor's own resonant vibrations on the output signal under the impact of a shock pulse, as well as because of the very small size and fragility of mono- and polycrystalline sensors, it is not possible to measure uniformly distributed over a large area of force pulses of 10^6 N received from electrodynamic transducers.

To solve this problem, the authors considered the possibility of obtaining a material for manufacturing a piezoelectric sensor with a large intrinsic surface area based on cement compositions of aluminates of alkaline-earth elements.

Previously conducted by the authors theoretical studies in the ternary system BaO-Al_2O_3-TiO_2 and experimental work on obtaining cement combining strength and electrophysical properties, based on aluminates of alkaline earth elements [6], allowed to obtain a material that can be effectively used in the manufacture of special concretes with segmentoelectric and piezoelectric properties.

The research conducted by the authors makes it possible to obtain and effectively use concretes based on aluminates of alkaline earth elements in the production of piezoceramics, namely, piezosensors for seismic detection and engineering seismology in the study of dynamic processes in buildings and structures.

979-8-3503-8909-8/25/$31.00 ©2025 IEEE

II. The Purpose of the Work

The purpose of this work is to obtain and experimentally study the electrophysical properties of concrete based on alkali aluminates. It's planned to determine the rational composition of aggregate for the developed concrete. Investigation of the main parameters characterizing piezoelectric materials: dielectric constant, dielectric loss, electrical resistance, piezoelectric modulus. To study the possibilities of using the developed concretes as piezoelectric sensors, which are characterized by a large surface and significant attenuation of their own resonant vibrations.

III. Theoretical Information and Research Methods

In purpose of obtaining concrete of high strength, density and homogeneity, providing the necessary operational reliability of products we have made a selection of the optimal granulometric composition of aggregate, which has a significant impact on the above parameters.

During the experiments, alumino-titano-barium cement [7] of the composition was used as a binder: 40% $BaAl_2O_4$ + 60% $BaTiO_3$ in the amount of 20% of the weight of the mixture. Barium titanium obtained by synthesis at 1400 °C was used as aggregate.

Concrete specimens with a diameter of $15 \cdot 10^{-3}$ and were made by bilateral pressing of concrete mixtures at a pressure of 100 MPa.

The physical-&-mechanical properties of the elements were determined using standard methods: the open porosity and apparent density were determined according to DSTU ISO 5017:2014 [8] and the compressive strength limit was determined according to DSTU EN ISO 8895:2018 (EN ISO 8895:2006, IDT; ISO 8895:2004, IDT) [9].

According to the results of calculations and mathematical processing of experiments, the "composition-property" diagrams were constructed using the authors' method [10].

Experiment planning matrix and test results of physical and mechanical properties of concrete are shown in Table 1.

TABLE I. EXPERIMENT PLANNING MATRIX AND RESULTS OF EXPERIMENTS

Polynomial coefficients	Notations and physical meaning of factors				
	Fraction of aggregate, in USD per unit			Experimental data	
	X_1	X_2	X_3	Y_σ	Y_n
η_1	1	0	0	51,2	24,3
η_2	0	1	0	63,5	21,0
η_3	0	0	1	67,2	20,82
η_{12}	0,5	0,5	0	57,5	23,60
η_{13}	0,5	0	0,5	74,1	18,65
η_{23}	0	0,5	0,5	69,7	20,60
η_{123}	0,33	0,33	0,33	73,2	19,60
Control point	0,5	0,3	0,2	68,0	19,30

Fraction of aggregate: x_1 - fraction $(1{,}25\text{-}0{,}63)\cdot 10^{-3}$m; x_2 - fraction $(0{,}36\text{-}0{,}315)\cdot 10^{-3}$m; x_3 - fraction $(0{,}315\text{-}0{,}15)\cdot 10^{-3}$m.

We used an incomplete third order polynomial to describe the dependence of concrete properties on the quantitative ratio of aggregate fractions.

We calculated the coefficients of polynomials expressing the dependence of strength (Y_σ) and porosity (Y_n) on the granulometric composition of the aggregate. After substituting the found coefficients, the regression equations take the formula (1-2):

$$Y_\sigma = 51{,}2x_1 + 63{,}5x_2 + 67{,}2x_3 + 60{,}0x_1x_2 + 17{,}4x_2x_3 + 49{,}6x_1x_3 + 106{,}5x_1x_2x_3 \quad (1)$$

$$Y_n = 24{,}3x_1 + 21{,}0x_2 + 20{,}82x_3 + 3{,}8x_1x_2 - 15{,}64x_1x_3 - 1{,}04x_2x_3 - 27{,}24x_1x_2x_3 \quad (2)$$

The adequacy of the equations was checked using the Student's test and additional control experiments. According to the results of mathematical processing of the results of experiments, simplex-diagrams "composition-property" and projections of lines of equal level for the strength and for the porosity of concrete (Fig. 1) were constructed, which allowed to determine the optimal quantitative ratio of adjacent fractions of concrete aggregate.

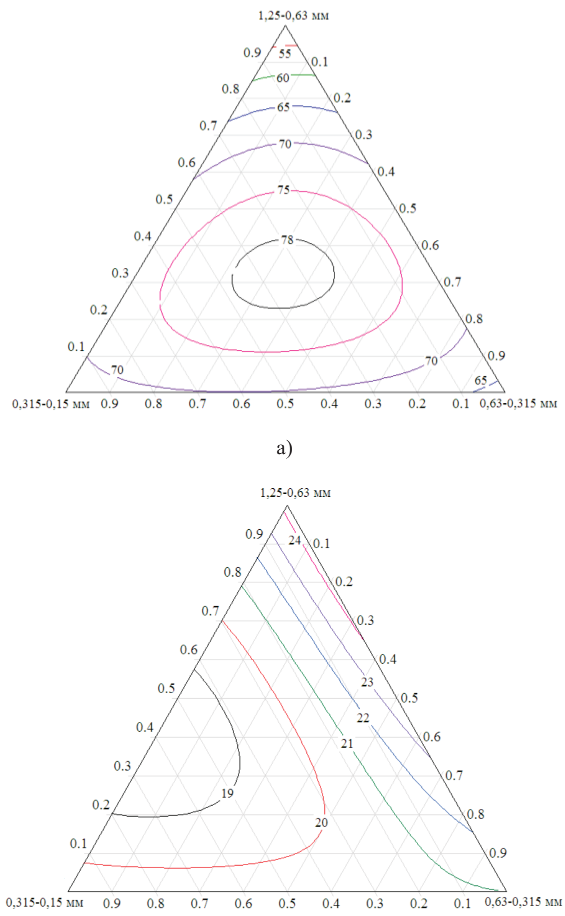

Fig. 1 - The "composition – property" diagram:

a) "composition–strength" concrete; b) "composition–porosity" concrete.

The optimum concrete composition includes a three-fraction aggregate mixture with the following quantitative grain ratio:

- 20...40% fraction $(1{,}25\text{-}0{,}63)\cdot 10^{-3}$ m;

- 10...30% fraction $(0{,}36\text{-}0{,}315)\cdot 10^{-3}$ m;
- 30...70% fraction $(0{,}315\text{-}0{,}15)\cdot 10^{-3}$ m.

Further synthesis and research of concretes were carried out taking into account the optimal particle size distribution of aggregate.

IV. Discussion of the Results

The application of concrete based on aluminates of alkaline-earth elements for the fabrication of a piezoelectric sensor of force pulses requires studies of the electrophysical properties of promising materials.

Test samples were prepared from concrete mixtures at a pressure of 50...100 MPa in the form of disks of different sizes. The samples were hardened in air for 7 days, after which the surface of the sample was ground to obtain a minimum of roughness. Materials for electrodes were aluminum, copper, silver and suspensions of colloidal graphite in distilled water, aluminum and copper electrodes were deposited in vacuum, silver electrodes were obtained by burning paste, colloidal graphite was applied with a brush.

The results of tests of electrophysical properties of the investigated concrete (at pressing pressure P = 50 MPa) are shown in Table 2-3.

TABLE II. Electrophysical Properties of the Developed Concrete

No	Composition of concrete,%		Dielectric permittivity	
	Cement	Aggregate	At 50 Hz,	At 10^3 Hz
1	10	90	1517	755
2	20	80	1360	670
3	30	70	834	410

TABLE III. Electrophysical Properties of the Developed Concrete

No	Composition of concrete, %		Dielectric loss angle tangent		Specific volume electrical resistance, Ohm·cm
	Cement	Aggregate	At 50 Hz	At 10^3 Hz	
1	10	90	0,07	0,08-0,1	$6\cdot 10^9$
2	20	80	0,08	0,09-0,21	$4{,}4\cdot 10^9$
3	30	70	0,09	0,15-0,25	$6\cdot 10^9$

The research results presented in Table 2-3 show that the developed concrete has high dielectric constant at room temperature. The increase of alternating current frequency leads to a decrease in dielectric permittivity and an increase in the dissipation factor of the dielectric loss angle, which indicates the segmental behavior of the material. The presence of the increased value of the dissipation factor of concrete suggests that piezoelectric sensors with a significant value of attenuation of resonance oscillations can be made on the basis of concrete. In addition, concrete is favorably distinguished by the fact that it allows to create sensors with a large own surface, and this makes it possible to measure pressure pulses distributed over the surface in the study of mechanical processes in soils in the field of elastic deformations.

The investigated concrete is further imparted with piezoelectric properties by polarization with a constant voltage. Before the polarization process, concrete, like cement, is isotropic and does not possess piezoelectric properties. The polarization of concrete samples was carried out by the method described in [7]. The external electric field strength was 0.2...0.4 kV/mm.

The values of piezoelectric modulus ***d*** of different compositions of the obtained concrete are presented in Table 4. For comparison, the table shows the value of piezoelectric modulus ***d*** of ceramic barium titanate, which polarization we performed under conditions similar to the conditions of polarization of the developed concrete.

TABLE IV. Piezoelectric Modulus of Different Compositions of Developed Concrete

No	Composition of concrete. %		Piezomodule d · 10^{12}, K/n
	Cement	Aggregate	
1	10	90	1,0–1,2
2	20	80	0,9–1,0
3	30	70	0,87–0,9
4	Ceramic $BaTiO_3$		1,0–1,4

Comparative analysis of the data in Table 2 shows that the piezomodulus value of concrete based on aluminates of alkaline earth elements is insignificantly different from the piezomodulus value of ceramic barium titanate. Increasing the content of aluminate cement in the concrete composition leads to a decrease in the piezomodulus value of concrete. This decrease in the piezomodulus of concrete is explained by the fact that with the increase in the amount of aluminate cement introduced into the concrete composition, the content of barium aluminate in concrete increases, which does not exhibit piezoelectric properties.

Based on the obtained data, it can be concluded that concrete based on aluminates of alkaline earth elements is a promising material for the manufacture of sensitive elements characterized by large own surface and significant attenuation of natural resonance oscillations. Such sensitive elements can be used in sensors designed to measure pulse shock accelerations distributed over a large area.

It is known that the action of piezoelectric sensors is based on the direct piezo effect, when the pressure applied to the crystal faces is converted into electric charges. When a piezo element is placed between an inert mass and the flat coils of an electrodynamic transducer, it will be affected by the force pulses generated by the flow of electric current through the coils [11-14]. Due to the desire of the inertial element to keep the state of rest, the piezo element deforms from the inertial force acting on it according to formula (3):

$$F = m \cdot a \tag{3}$$

Where *m* is the mass of the inertial element; *a* is the transmitted acceleration.

In the case of the longitudinal piezoelectric effect, the amount of electricity arising on the faces of the crystal during its compression will be expressed by the equality (4):

$$Q = d \cdot S \cdot p \tag{4}$$

Where *Q* is the resulting charge; *d* is the piezoelectric modulus; *S* is the area of the plate subjected to compression; *p* is the pressure.

A characteristic feature of the pressure pulse sensor for geophysical devices is the low-frequency range of recorded oscillations. Necessity to reduce the influence on the output signal of the sensor of its own resonance oscillations under the influence of shock pulses. Realization of the conditions for obtaining from the sensor a large Q at a significant value of damping of resonant oscillations can be achieved by using as a sensor material a concrete with piezoelectric properties on the basis of aluminates of alkaline-earth elements.

Further, the authors worked on the creation of a piezoelectric sensor with large own surface for measuring uniformly distributed force pulses of up to 106 and in electrodynamic type installations.

As a material for manufacturing of the piezoelectric sensor we used the developed concrete of the following composition: cement (40% $BaAl_2O_4$ + 60% $BaTiO_3$) - 30%; aggregate (barium titanate) - 70%. Structurally, the piezoelectric sensor is a disk with a diameter of 0.5 m and a height of 0,04 m. In the center of the disk there is a through hole with a diameter of 0,05 m for the guide rod.

The concrete mixture, prepared as a mass, was placed and tamped into a special mold made of 6 mm thick organic glass. The concrete was cured in the mold for 1 day, after which the sample was removed from the mold. Electrodes from colloidal graphite suspension were applied to the horizontal planes of the sensor and the sensor was kept in air under normal conditions for 6 days, then copper foil leads were glued to the graphite electrodes using electrically conductive glue. The empty weight of the sensor is ~ 32 kg. Polarization of the sensor was carried out under normal conditions by a constant electric field of 1 kV/cm.

Tests of a piezoelectric sensor with a large surface were carried out at the shock installation with an electrodynamic energy converter. The sensor was placed between flat coils (coil diameter 0,5 m), electrodynamic converter of electrical energy of capacitors into shock pulse. Parameters of the shock pulse: $F_{max} = 10^4$-10^5 m; $\tau = 10$ ms. The output signal of the transducer was registered by a memorizing oscilloscope. During the tests, the output signal parameters obtained from the sensor differed from the calculated ones by no more than 5-7%.

It was determined that due to the large diameter of the sensor (compared to the size of commercially available sensors) and high mechanical strength of the material used, it is possible to measure force pulses of 10^6 m evenly distributed over the area.

V. CONCLUSIONS

Based on the results of synthesis and studies of electrophysical properties of concrete based on aluminates of alkaline earth elements, we can draw conclusions about the rational composition of concrete, samples of which consist of 30% aluminate cement (40% $BaAl_2O_4$ + 60% $BaTiO_3$) and 70% aggregate (barium titanate). We have experimentally determined the main indicators for the studied samples of the developed concrete: high dielectric permittivity at room temperature up to 1517; increased value of the dissipation factor 0.7 - 0.9; dielectric resistivity - 6-10^9 Ohm·cm, piezomodul - 0.87-0.9 · 1012 K/n. As a result of the work it was determined that the developed concrete based on aluminates of alkaline-earth elements is a promising material for the manufacture of sensitive elements characterized by large own surface and significant attenuation of natural resonance oscillations. Such sensitive elements can be used in sensors designed to measure pulse shock accelerations distributed over a large area.

Therefore, the experimental and theoretical studies show that concrete based on aluminates of alkaline-earth elements is a promising material for the production of piezoelectric sensors. Such devices can be used in seismic exploration for measuring seismic signals excited on the Earth's surface by impact installations, as well as in seismology for studying dynamic processes in buildings and structures.

REFERENCES

[1] M.M. Rezinkina., O.L. Rezinkin, and R.P. Mygushchenko, “Electrical Physical Properties of Nanostructured Ferroelectrics in Pulsed Power Electric Fields,” *J. Nano- Electron. Phys.*, vol. 10(2), pp. 02008, 2018. DOI: 10.21272/jnep.10(2).02008

[2] Y.K. Fetisov, A.A. Bush, K.E. Kamentsev, A.Y. Ostashchenko, and G. Srinivasan, “Ferrite-Piezoelectric Multilayers for Magnetic Field Sensors,” *IEEE Sensors J.,* vol. 6(4), pp. 935-938, 2006.

[3] G.V. Lisachuk, *Functional Ceramics. Ceramic Materials Protecting Against Electromagnetic Radiation: A Monograph.* Kharkiv, Ukraine: Planeta-Print , 2013.

[4] V.V. Korobiychuk, V.G. Kravets, V.V. Boyko., V.V. Vapnichna, and C.I. Bashynskyi. *Rock Fracture and Industrial Seismicity: A Handbook.* Kyiv, Ukraine: Igor Sikorsky Kyiv Polytechnic Institute, 2020.

[5] Yu. Striletskyi, V. Rovinskyi, and O. Yevchuk “Method of studying corrosion processes of metal electrodes by surface voltage fluctuations,” *East.-Eur. J. Adv. Technol.*, vol. 3, no. 9, pp. 24–29, 2016.

[6] G.N. Shabanova, S.M. Logvinkov, A.M. Korogodska, E.V. Khrystych, M.Y Ivashchenko., and O.V. Kostyrkin, *Barium-Containing Refractory Materials for Special Purposes: A Monograph*. Kharkiv, Ukraine: FLP Brovin A. V., 2018.

[7] O. Khrystych, A. Korohodska, H. Shabanova, and M. Kustov, "Special properties of composite materials of alkaline earth element oxide compounds," *in Proc. 2024 IEEE 5th KhPI Week on Advanced Technology (KhPIWeek)*, Kharkiv, Ukraine, 2024, pp. 1-4.

[8] DSTU ISO 5017:2014, *Products are Fireproof, Dense, Molded. Method for Determining Apparent Density, Open Porosity and Total Porosity*, 2015.

[9] DSTU EN ISO 8895:2018, *Molded Fire-Resistant Heat-Insulating Products. Determination of Strength Limit During Compression (EN ISO 8895:2006, IDT; ISO 8895:2004, IDT)*, 2019.

[10] Sh. Kumar, and S.V. Barai, *Concrete Fracture Models and Applications*. Berlin, Germany: Springer-Verlag, 2011.

[11] V.S. Samyukthaa, R.P. Suvarna, and T.S. Raob, “Synthesis and dielectric properties of ceramic material,” *Int. J. Eng. Res. Technol. (IJERT)*, vol. 5, no 05, pp. 245-249, 2016

[12] Y.M. Poplavko, and Y.I. Yakymenko, *Piezoelectrics: A Handbook.* Kyiv, Ukraine: NTUU “KPI”, 2013.

[13] J. Akedo, “Room temperature impact consolidation (RTIC) of fine ceramic powder by aerosol deposition method and applications to microdevices,” *J. Thermal Spray Technol.*, vol. 17, no. 2, pp. 181-198, 2008.

[14] O.L. Rezinkin, and V.V. Vytrishko, “Methodology of experimental investigation of the properties of segmentoelectrics in pulsed electric fields,” *Visnik NTU "KhPI"*, vol. 13. pp. 37-42, 2008.