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Orginal Article

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Comprehensive material activation of concrete structures

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Abstract: The investigation focuses on improving the mechanical properties of concrete by optimising its structural organisation through external activation using a modified electromagnetic field and internal activation with carefully selected fillers. The effectiveness of activating cement composites with fractal-matrix resonators has been demonstrated. The research examines the impact of both external and internal activation on structural changes, mechanical property indices, and the damage resistance of cement composites and concretes. It has been shown that comprehensive activation enables the control of binder setting time and concrete elasticity modulus while reducing the initial volumetric deformations of hardening systems. Additionally, it enhances crack resistance and increases concrete strength. Activation reduces initial volumetric deformations and thermal changes during hardening by 1.5-2 times, shortens the setting time by 30-90 minutes without affecting the final setting time, decreases specimen damage by up to 20%, and improves compressive strength by up to 20%. Furthermore, activation allows for precise regulation of the initial setting time within a range of 15 to 210 minutes and reduces the final setting time by 15 to 90 minutes, lowering damage from technological defects by up to 10% and increasing flexural strength by up to 40%. The increase in crack resistance and concrete strength is achieved through the internal and external introduction of optimal fillers, carefully selected based on their specific surface area and quantity, along with the application of fractal-matrix resonators.

Keywords: concrete, fillers, fractal matrix resonators, structure formation, damage

1. Introduction

Optimising the utilisation of mineral binders should be regarded as a crucial objective in the manufacturing of construction materials and products, particularly during periods of economic instability. This implies the improvement of qualitative indicators of construction materials while reducing their material intensity by lowering cement consumption. The generalised analysis made it possible to conclude that the solution to this complex problem is achievable through a more complete realisation of the potential of binding systems and materials based on them.

As the accumulated theoretical and practical experience shows, an effective method of revealing the possibilities of binding systems is their activation by various methods (chemical, thermal, electric, magnetic, mechanical, and their various combinations). Among the effective methods of activating structure formation processes is the method of changing external force permanent electromagnetic influences by using special fractal-matrix resonators. A less effective method of directed organisation of the structure of binding composites is the use of mineral fillers, rational in nature, quantity, and dispersibility. The joint use of matrix activators and rational fillers creates conditions for the regulation of structural changes and, accordingly, the properties of hardened and cured mortars and concretes based on mineral binders.

Thus, the combined effects associated with the transformation of external electromagnetic influences through special matrices and the use of rational fillers will enable the solution of important problems related to the economically justified use of cement, reducing the material intensity of building materials and products while maintaining the required quality parameters. In this context, enhancing the mechanical properties of concretes through deliberate structuring using external, internal, and combined activation of cement constituents during the early stage of setting is highly relevant. Altering the parameters of electromagnetic influences as an external factor, in combination with adjusting the parameters of fillers as an internal factor, should lead to a change in the initial structural organisation of cement-water compositions, which will affect their final structure and, consequently, the mechanical properties and crack resistance of the finished material (cement paste and concrete).

2. Purpose of research

Increasing the crack resistance and strength of concrete through the internal and external introduction of rational fillers (by selecting the optimal ratio of specific surface area to the amount of fillers) and the use of fractal matrix resonators.

3. Review of scientific sources and literature

The apparent activation energy of concrete reflects how concrete hydration processes respond to temperature variations and is crucial for evaluating concrete's compressive strength at early stages through the "equivalent age method." Typically, this parameter is determined using mechanical or calorimetric testing methods [1].

One of the parameters requiring accurate prediction of its effect on the structure is thermal expansion [2]. To achieve this, the Arrhenius equation can be applied, necessitating the determination of an activation energy value. In the case of cement materials, this value is typically derived from isothermal calorimetry or compressive strength data.

Article [3] presents the results of a study on the influence of a polymer–cement plaster coating on its fracture behaviour. It was found that, depending on the homogeneity of the structure and its characteristics, the number of cracks in the structure either decreases or increases, which leads to the occurrence of defects. The heterogeneity of the concrete mixture, as an open complex system, implies its organisation by the autopoiesis model. Paper [4] analyses the influence of the types of inhomogeneities that may be present in concrete on the formation of an integral concrete structure. For this purpose, the processes of organisation of concrete macro- and microstructures are modelled and predicted. Kaolin and metakaolin additives play a significant role in shaping both the micro- and macrostructures of concrete [5]. The formation processes of the microstructure of cement paste with additives follow a similar sequence, albeit with varying intensities.

All of these studies demonstrate the relevance of determining the bearing capacity of reinforced concrete structures that may contain concrete defects [6], and provide methods for determining their residual bearing capacity [7].

The study of alkali-activated cement made from construction waste is interesting and promising [8]. The cement underwent activation using an aqueous solution of sodium hydroxide and sodium silicate. Characterisation of the formulations involved compressive and flexural strength tests, X-ray diffraction, scanning electron microscopy, and water absorption tests. The findings suggest that the mechanical properties of the produced cement are significantly impacted by both the type of activated residue and the activator ratio.

In order to facilitate the commercial use of alkali-activated concrete, it is imperative to gain a deeper understanding of its durability characteristics [9]. The alkali-silica reaction presents a significant challenge, particularly due to the use of highly alkaline solutions during activation. Research has shown that the alkalinity of the pore solution rises in tandem with the concentration of the activating NaOH solution. Furthermore, this phenomenon is amplified at concentrations exceeding the optimum level, which is defined as the concentration yielding the highest compressive strength of the solution [10].

The study [11] outlines experimental findings on chemically activating Class F fly ash to address the issue of low early strength. A 40% replacement coefficient of Portland cement with fly ash was utilised in the experiments.

A separate topical area is the reduction of CO_2 emissions by increasing the efficiency of cement use or replacing it with more efficient types, such as geoplastic cement [12]. To this end, the nanostructure of geopolymer gels was studied to establish the relationship between gel microstructure and durability. As a result, the high performance of geoplastic concrete in accelerated strength tests was confirmed by its organised tortuous pore structure. Another promising and annually studied issue is the study of alkali-activated (slag) cement [13]. This study focused on developing alkali-activated (slag) cement using high-modulus soluble silicates. Concrete formulations based on this cement aimed to retain workability, achieve rapid and consistent strength development, and exhibit high strength properties.

The influence of the type of cement and aggregates on the thermomechanical behaviour of concrete mixtures was studied in [14]. The study established the significance of the concrete structure and highlighted that volumetric deformation during early hardening stages, along with potential cracking, results from the inherent thermal and mechanical properties of concrete. Another way to improve the mechanical properties and crack resistance is to add fibres and modifiers [15]. The amount and ratio of cement, silica, and polypropylene fibre were determined in [16]. The parameters of strength, water resistance, frost resistance, and density were investigated.

The effect of the microsilica + C-3 additive on the kinetics of low-base calcium hydrosilicate formation was studied in [17]. The utilisation of mechanically activated general-purpose Portland cement alongside an organomineral additive (microsilica + C-3) was found to yield high-strength concrete, achieving compressive strengths of up to 120 MPa at 28 days.

Article [18] summarises the advantages and disadvantages of alkali-activated cement and concrete. It underscores the primary challenges: rapid setting, the possibility of an alkali–aggregate reaction, as well as the occurrence of efflorescence, shrinkage, microcracks, and changes in strength. Article [19] presents findings on the physical and chemical properties of thermally activated aluminosilicate material (ASM) and explores the characteristics of fresh and hardened concrete containing this material. Additionally, a study comparing the behaviour of fresh and hardened alkali-activated slag (AAS) and ordinary Portland cement (OPC) for concrete and evaluating the impact of mixing time was conducted [20]. Results indicated distinct differences in the setting of OPC and AAS concrete and in rheological outcomes, particularly when the slag was activated with water glass (WG). The choice of the alkaline activator emerged as a pivotal factor in the rheology of AAS concrete.

The study of the protective properties of concrete under neural activation is of practical importance and application [21]. In this case, neural radiation occurs, and the actual behaviour and change in properties under such exposure are studied.

4. Materials and methods

The objects of research are cement compositions and concrete based on them, activated by fractal-matrix resonators and fillers, their structure and complex mechanical properties, and rational technological solutions for their production.

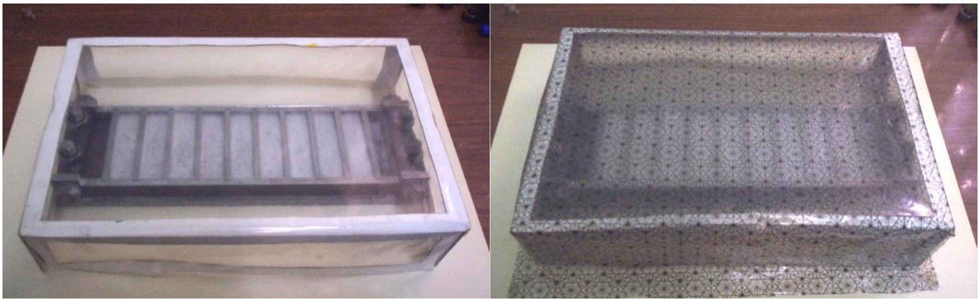
The focus of the study lies in investigating the processes involved in the organisation of structure and the development of properties within activated cement systems and the resulting concretes.

Research methods: The structural organisation of cement system models was estimated by the size and composition of cluster structures of dispersed phase particles; the manifestation and fixation of technological cracks and internal interface surfaces were carried out by special methods; sample damage was estimated using damage coefficients; volumetric deformations of hardening cement compositions were measured using special sensors. Periods of structure formation, temperature changes, and the physical and mechanical properties of cement compositions and concretes at different ages were studied using traditional methods according to current codes. Statistical processing of experimental results, calculation, and optimisation of compositions of activated binders and concretes were carried out using the apparatus of mathematical planning of experiments.

When conducting experiments in which cement-water compositions were the objects of research, Portland cement was used, made from clinker produced by Yugcement PJSC (a branch of Dickerhoff Cement Ukraine PJSC). The clinkers were pre-dried for 3 days, as in laboratory conditions it is important to control all variables, and removing moisture from clinker ensures a more accurate determination of its mass and composition, which helps to increase the reliability and repeatability of experimental results, at a temperature of T = 105±5ºC in a drying cabinet, followed by grinding in a laboratory ball mill to obtain cement without additives.

Cube samples measuring 10×10×10 cm and prism samples measuring 10×10×40 cm were subjected to experimental studies. The experimental specimens were produced in series of three specimens per series. The consistency of the concrete mixture was kept constant at S = 8...10 cm.

The alteration of external electromagnetic actions was carried out using fractal-matrix resonators, whose principle of operation is based on the ability to change the parameters of electromagnetic waves when they pass through a special pattern made on a polyethylene film using graphite-containing paints. During the research, the samples were placed in the action zone of the matrices (Fig. 1), after which their properties were determined in comparison with non-activated samples, which were covered with a transparent polyethylene film.



a) b)

Fig. 1. Provision of change of parameters of external electromagnetic fields during the action on hardening cement compositions: a) container with transparent polyethylene film; b) container with a film of fractal-matrix resonator. *Source*: own study

The overall principle for the production and activation of concrete is schematically presented in Fig. 2.

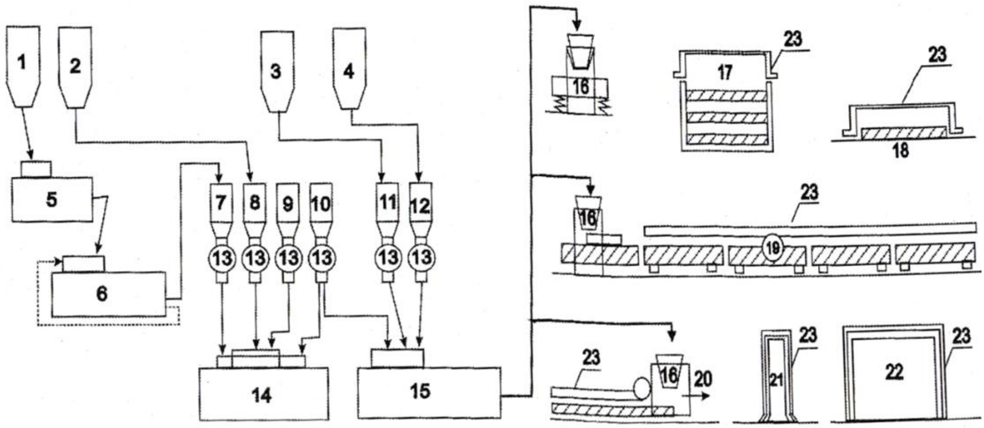


Fig. 2. Principal technological scheme of internal and external activation of reinforced concrete products: 1 – sand warehouse, 2 – cement warehouse, 3, 4 – warehouses of coarse and fine aggregate, 5 – drying drum, 6 – drum mill operating in a closed cycle, 7, 8, 9, 10, 11, 12 – bunkers for fillers, cement, chemical additives, water, fine and coarse aggregates, 13 – batchers, 14 – rotary high-speed mixer, 15 – forced concrete mixer, 16 – moulding stations, 17 – steaming chambers, 18 – individual products, 19 – pre-curing stations, 20 – continuous concrete paver, 21, 22 – individual products, 23 – fractal-matrix resonators. *Source*: own study

Damage of cement paste and concrete specimens was evaluated using the damage coefficient *Kp*, which was determined from the ratio $Kp = \Sigma Li/Li$, where ΣLi is the total length of fracture cracks (cm), and *Li* is the geodetic line connecting the points of destructive crack exit on opposite surfaces of the specimen. Process cracks and internal interfaces were manifested and fixed by applying special solutions, including tannins, to the surface of the specimens.

Mechanical properties and modulus of elasticity were determined in accordance with the requirements of current codes using verified measuring instruments [22].

Damage, crack resistance, strength, and initial modulus of elasticity of concrete specimens were determined after 28 days of curing under normal conditions.

5. Research results and analysis

Concrete can be considered a complex, dynamic, open system, which implies the presence of interacting subsystems. It is proposed to treat the concrete microstructure as a distinct subsystem, represented by cement-water compositions capable of spontaneously changing their structure. This structural evolution should be reflected in the changing properties of both the subsystem and the overall system. Experimental results on the property changes of hardening cement-water compositions of different formulations confirm the influence of external factors on system behaviour.

Cement compositions can be represented as coarse-dispersed lyophobic open systems with lyophilic interfaces. This representation implies that the initial structural organisation of such systems occurs as a result of their tendency to reach thermodynamic equilibrium by reducing the interfacial surface area. The general drive to minimise surface energy is realised through individual interparticle interactions. In dispersed systems of the selected subclass, unbalanced forces of interparticle interaction act on each particle. Under these forces, each particle assumes an equilibrium mechanical position, leading to the formation of discrete structural elements-clusters-within the dispersed system. Because the strength of interparticle interactions depends on the mass of the interacting particles and the distance between them, it is possible to control the initial distribution of particles into structural blocks by altering the dispersed composition and volume content of the particles. This has enabled the introduction of mineral fillers selected for their optimal dispersity, mineralogical composition, and quantity into cements. The use of such fillers allows for targeted modification of the properties of cement systems and materials based on them.

In addition to being viewed as dispersed systems, cement compositions can also be considered physical systems subject to external conditions. These external conditions are understood as physical fields, which represent a special form of energy that mediates the interaction of material particles. Among these fields is the electromagnetic field, characterised by two vector functions of coordinates: electric field strength *E* and magnetic induction *B*. Electromagnetic field perturbations are characterised by electromagnetic waves. The properties and propagation laws of these waves are described by Maxwell's equations. Reflection and refraction of electromagnetic waves occur at the interfaces between two media. Furthermore, during wave propagation in a medium, phenomena such as dispersion, diffraction, interference, absorption, scattering, refraction, and birefringence can occur. Wave dispersion and diffraction involve changes in electromagnetic wave parameters depending on the medium and obstacles encountered. The diffraction pattern is highly dependent on the relationship between the nature of the obstacles and the wavelength. Diffraction results in curvature of wave propagation in inhomogeneous media. Cement-water compositions, as physical systems, when exposed to zones of electromagnetic field perturbation, are expected to undergo changes in their internal organisational conditions. Since each particle of the dispersed phase (mono- or polymineral) is surrounded by its own electromagnetic field, changes in the parameters of external fields should alter the level of interparticle interactions, thereby affecting the structural parameters of the final material.

One of the essential characteristics of the hardening microstructure of concrete is its initial volumetric changes *(ΔV)*. This is because volumetric changes in the microstructure, already functioning as a matrix material, determine its interaction with aggregates, which significantly affects the properties of concrete as an integral system. The volumetric changes were monitored using special sensors that mimicked the behaviour of the matrix material in its interaction with aggregates. Experiments have shown that the use of matrices alters both the nature of development and the absolute values of volumetric changes.

Under the influence of internal, external, and comprehensive activation, there is an expansion of the range of structural aggregates at the level of binder particles (Fig. 3, Tab. 1).

Table 1. Model compositions. *Source*: own study

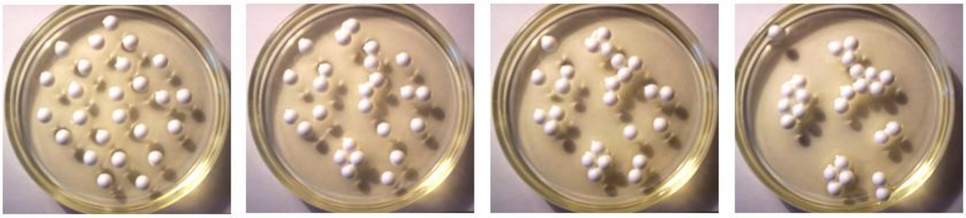
Model compositions	Structural parameters			
	L_{str}, [cm]	L_{str}, [cm]	S_{str}, [cm^2]	S_{str}, [cm^2]
	IA	*CA*	*IA*	*CA*
d_1 = 0.3 cm	2.9	3.3	1.7	2.0
d_3 = 0.9 cm	6.7	11.7	6.5	7.4
d_3/d_1 = 3	8.3	13.7	4.4	9.0

where: L_{str} – length of external boundaries of cluster structures, cm; S_{str} – area of cluster structures, cm²; IA – internal activation; CA – comprehensive activation.

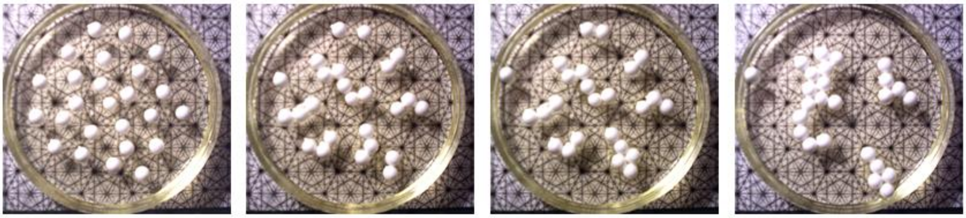
This alteration results in modifications to the parameters of the interfacial surface and the conditions of exchange reactions. The implementation of physicochemical processes and phenomena involved in the structure formation of cement compositions is accompanied by local and integral changes in the volume of the material, as well as thermal effects. Volumetric deformations occur at the interfaces, in the areas of inter-particle contacts, and in the free volume of the curing system. The kinetics of hydration processes in cement compositions depends on the geometric characteristics and composition of the substructures of dispersed particles. Therefore, by altering the magnitude and intensity of volumetric deformations, as well as the periods of structure formation in composites with different types of binders, it is possible to quantify the interdependence between the organisation of the initial microstructural inhomogeneities and the level of newly formed phase products.

The results of the study showed the following: internal, external, and comprehensive activation lead to changes in the indicators of volumetric deformations (Fig. 4, Fig. 5) and the periods of structure formation of cement compositions under external electromagnetic influences (EEI) (Tab. 1).

This indicates the influence of the parameters of the initial substructures on the kinetics of the physicochemical processes of hydration in curing systems. The activation of composites based on mineral binders, through the selection of the proportions of dispersed phase particles by nature, size, or quantity, allows changing the magnitude and intensity of the *ΔV* flow by up to 2-7 times and adjustments to the setting time by up to 120 minutes. External activation, resulting from transformation by special matrices, causes a change in the volumetric deformation of cement systems by up to 25-58%, depending on the composition of the aggregates. The intensity of ΔV increases by up to 3.5 times, and the time of their manifestation extends by 30-90 minutes. Comprehensive activation, through the influence of fillers and fractal matrix resonators, results in a change in the magnitude and rate of deformation of up to 38% for cement compositions, with an increase in the periods of their organisation by up to 180 minutes.

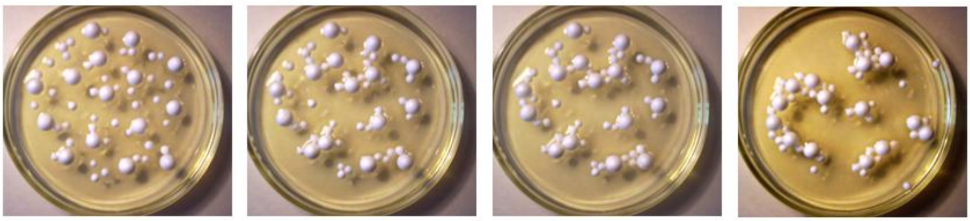


τ_1=0 min | τ_2=1 min | τ_3=2 min | **$\tau_к$=20 min**

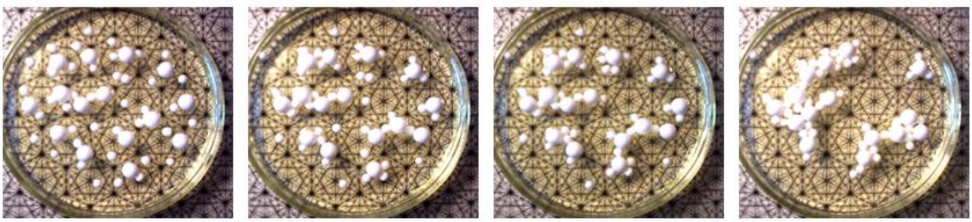


τ_1=0 min | τ_2=1 min | τ_3=2 min | **$\tau_к$=30 min**

a)



τ_1=0 min | τ_2=1 min | τ_3=2 min | **$\tau_к$=9,25 min**



τ_1=0 min | τ_2=1 min | τ_3=2 min | **$\tau_к$=13,5 min**

b)

Fig. 3. The kinetics of interparticle interactions at: a) d_3; b) d_3/d_1=3. *Source*: own study

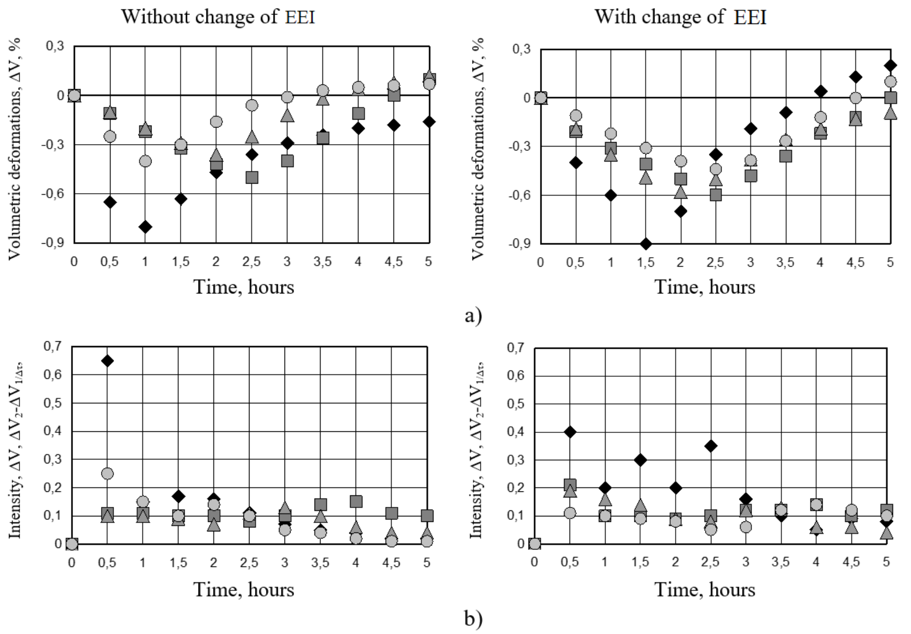


Fig. 4. The effect of dispersed phase particles on the magnitude (a) and kinetics (b) of volumetric deformations in cement–water compositions: ♦ - cement; ■ – cement + 5% CaSO4·2H2O; ▲ – cement + 30% quartz filler with Ssa= 300 m^2/kg. *Source*: own study. ● – cement + a mixture of dihydrate gypsum particles and filler

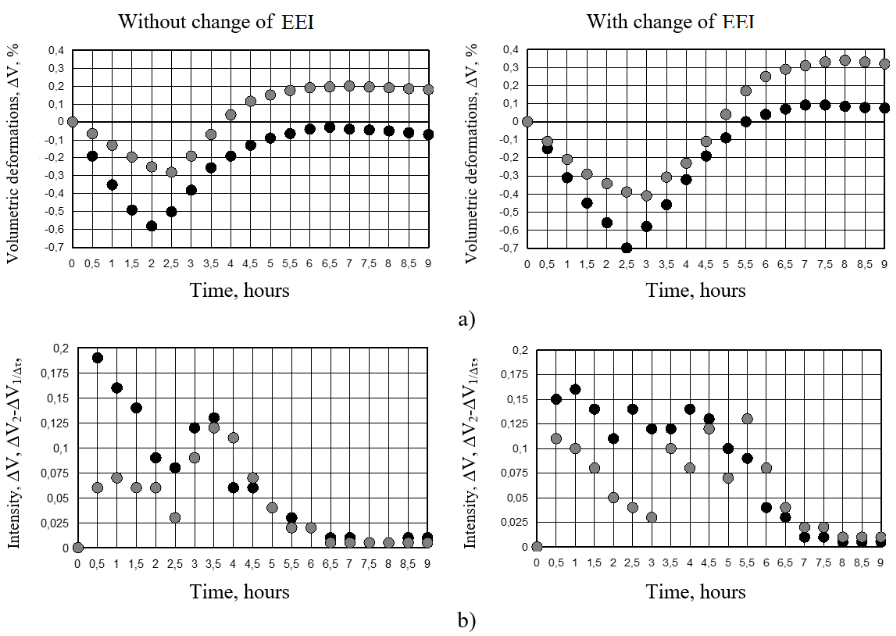
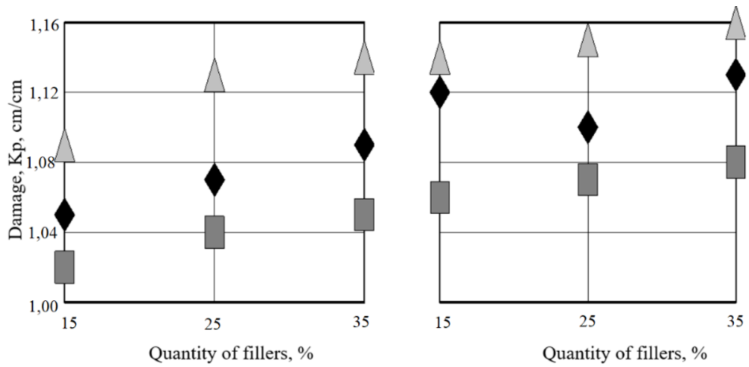


Fig. 5. The influence of changes in external electromagnetic influences (EEI) on the magnitude (a) and kinetics (b) of volumetric deformations in cement–water compositions: ● – cement + 30% filler of S_{sa} =100 m^2/kg; ● – cement + 30% filler of S_{sa} =500 m^2/kg. *Source*: own study

Cement compositions are characterised by a blocky structure, which implies damage to the cured materials by initial cracks and internal interfaces (IIS). Crack initiation and IIS occur as a result of the opening and expansion of intercluster interfaces under the influence of volumetric strain gradients. Therefore, the targeted formation of substructures at the level of binder particles, and consequently of interblock interfaces, allows for the regulation of deformation processes to obtain materials with a specified length of differently oriented cracks and stresses. The damage to building composites with different types of binders should determine their fracture toughness, understood as the material's ability to resist the development of major cracks arising from mechanical and other impacts. The relationship between the cluster structure of cement paste, the intensity of physicochemical processes, and the manifestation of deformations causes the development of cracks and fractures to vary under different conditions of structure formation and hardening of materials. Therefore, studies were conducted to determine the effect of internal, external, and comprehensive activation on changes in technological damage and crack resistance of cement compositions.

The integral technological damage of the cured samples was assessed by the damage coefficient *Kp* and determined on halves of beams measuring 40×40×160 mm after 28 days of curing under normal conditions (Fig. 6).



a) b)

Fig. 6. The coefficient of technological damage of cement–water compositions during internal and external activation: a) without change of EEI; b) with change of EEI. ♦ – S_1=100 m^2/kg; ■ – S_2=300 m^2/kg; ▲ – S_3=500 m^2/kg; N=25±10% – the amount of fillers by volume of binder. *Source*: own study

The results of the study of cement compositions showed that the damage to the material increases from *Kp* = 1.02 to *Kp* = 1.16 when using fillers of different compositions and changing external conditions. The variation in the parameters of external electromagnetic fields induced by specialised matrices leads to an increase in damage values, a characteristic observed across all the compositions considered. The technological damage of materials with different types of binders hereditarily depends on the initial conditions of cluster formation. The directed, interdependent organisation of the final structure allows for the production of materials that are resistant to the development of fracture cracks.

The crack resistance was evaluated using the stress intensity coefficients K_{Ic}^{e}, K_{Ic}^{c}. Cracking was initiated by two recommended methods: by embedding a metal plate in the sample during its formation (K_{Ic}^{e}) and by cutting an already hardened sample (K_{Ic}^{c}).

For the internal activation of cement-water compositions, aggregates with a specific surface area S_{sa}=300 m^2/kg in the amount of N=0.1% and finely ground gypsum stone with S_{sa}=300 m^2/kg in the amount of N=0.2% were used. The specific surface area of cement (ground clinker without additives) was also S_{sa}=300 m^2/kg.

The values of the stress intensity coefficients for cement paste that did not contain fractions of dihydrate gypsum and quartz fillers were as follows: K_{1c}^{e} = 26.3 MPa m$^{1/2}$, K_{1c}^{c} = 29.2 MPa m$^{1/2}$ (Fig. 7, Tab. 2, Tab. 3).

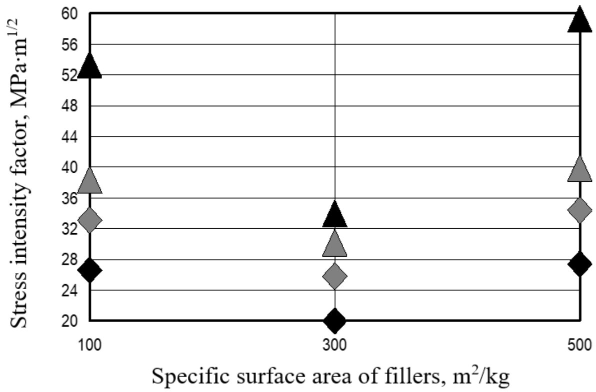


Fig.7. Crack resistance of activated cement compositions. *Source*: own study. ◊ – crack obtained by the method of embedding during forming, K_{1c}^{e}; Δ – crack obtained by cutting the sample K_{1c}^{c}, ♦, ▲– cement + 10% fillers +1% CaSO4·2H2O; ♦, ▲ – cement + 30% fillers +1% CaSO4·2H2O

Table 2. The influence of activation factors on the crack resistance of cement-water compositions. *Source*: own study

Composition of C/W	Coefficients of stress intensity: Crack obtained by the method of embedding during the formation of the sample, K_{1c}^{e}, MPa·m$^{1/2}$		Crack obtained by the method of cutting the sample, K_{1c}^{c}, MPa·m$^{1/2}$		Coefficient of technological influence $K_t=K_{1c}^{c} / K_{1c}^{e}$	
	N=10%	N=30%	N=10%	N=30%	N=10%	N=30%
Cement + fillers S_{sa}=100m^2/kg	0.26	0.33	0.53	0.38	2.04	1.15
Cement + fillers S_{sa}=300m^2/kg	0.20	0.27	0.34	0.30	1.70	1.11
Cement + fillers S_{sa}=500m^2/kg	0.27	0.34	0.59	0.40	2.18	1.17

The adopted methods of internal, external, and comprehensive activation provided a targeted organisation of the structure of cement compositions, achieving specific indicators of technological damage and crack resistance in the final materials. To maximise the values of K_p and K_{1c}, it is necessary to establish initial conditions for structure formation that promote an increase in the structural diversity of systems with different types of binders (through the introduction of polymineral and polydisperse fillers). Changes in the damage coefficient allow the assessment of the impact of formulation and technological factors on the structure of construction composites. Depending on the qualitative and quantitative compositions of aggregates, the damage to cement paste can vary from 7% to 13%. The crack resistance of cement-water compositions as a result of internal activation increases by 23-49% with monodisperse aggregates and by 40-58% with polydisperse aggregates. At the same time, the influence of formulation factors on the fracture toughness of cement samples increases from K_t=1.11 to K_t=2.18.

Table 3. Physical and technical properties of activated cement–water compositions with polydisperse fillers. *Source*: own study

Compound of cement-water compositions	Quantity of fillers	Amount of dihydrate gypsum,	Bending tensile strength, R_f,	Compressive strength, R_c,	Compressive strength, R_c^e, halves of samples at K_{1c}^e	Compressive strength, R_c^c, halves of samples at K_{1c}^c	Coefficient of technological influence $K_t = R_c^c/R_c^e$
	[%]	[%]	[MPa]	[MPa]	[MPa]	[MPa]	[-]
$50\%S_1+50\%S_2$	10	3	10.0	79.6	68.8	75.0	1.09
$50\%S_1+50\%S_3$	10	5	10.3	80.4	80.0	80.3	1.0
$50\%S_1+50\%S_3$	20	3	12.2	80.6	66.9	75.6	1.13
$33\%S_1+33\%S_2+33\%S_3$	20	1	6.6	74.4	59.6	74.0	1.24
$50\%S_1+50\%S_2$	30	1	8.9	79.9	60.0	78.6	1.31
$50\%S_2+50\%S_3$	30	1	7.5	66.9	54.6	63.4	1.16
Cement	-	-	6.9	66.0	56.8	59.4	1.04

The influence of internal and external activation factors provides favourable conditions for the development of the structure of cement composites, which is reflected in their curing behaviour and the properties of the cured materials. This is confirmed by differences in the values of volumetric deformations, setting times, and technological damage of building composites across various aggregate compositions and parameters of external influences. Changes in the value of integral damage reflect the result of structural transformation in activated self-organising systems, due to the formation of specific sets of initial cracks and internal interfaces. Different sets of cracks and internal interface defects (IIDs) determine the individuality of structures and, to a large extent, the behaviour of materials under load, including mechanical loading. The performance of composite materials is a function of their structural potential. It can be assumed that the range of quantitative values for the mechanical characteristics of composites based on mineral binders depends on the diversity of their structures. The strength and deformation properties of cement composites were assessed by modifying the initial conditions of structure formation under internal, external, and comprehensive activation (Tab. 2, Tab. 3, Fig. 8).

The studies have shown that the results obtained can serve as a basis for addressing the improvement of mechanical properties and reduction of material consumption in cement composites. With specific aggregate compositions and the use of special matrix resonators, it is possible to reduce the consumption of the cement component by up to 35% without compromising the strength characteristics of the building composite materials. The introduction of mono- and polydisperse aggregates into the binder composition makes it possible to increase the compressive and bending tensile strength of cement paste by up to 18-43%.

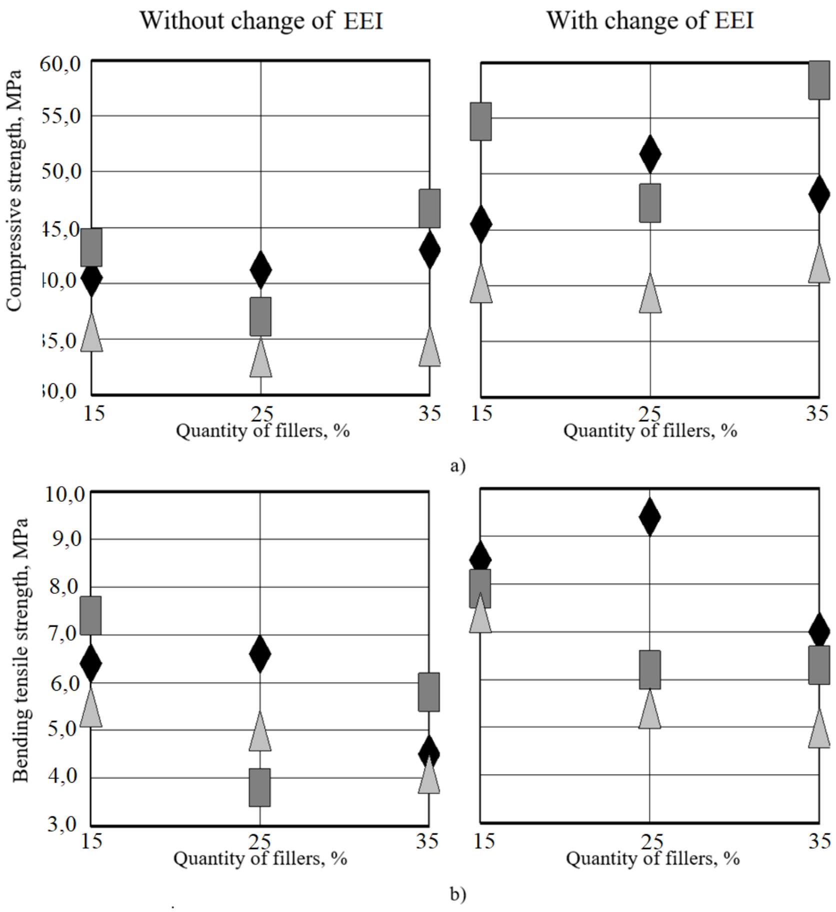


Fig. 8. Mechanical properties of cement paste during internal and external activation: a) – compressive strength, MPa; b) – tensile strength in bending, MPa. *Source*: own study.
♦ – S_1=100 m^2/kg; ■ – S_2=300 m^2/kg; ▲ – S_3=500 m^2/kg

External activation contributes to an increase in R_c and R_f by up to 22% and 30%, respectively. Changes in the quantitative and qualitative composition of aggregates make it possible to obtain materials that differ in strength by 18-48%. Comprehensive activation of cement compositions causes an increase in the R_f value by up to 2.2 times and in the *R*c value by up to 39%. The hereditary influence of formulation factors on the physical and mechanical properties of cement paste is confirmed by the wide range of quantitative indicators of the coefficient of technological influence.

Thus, the use of rational fillers and modifications to the parameters of external electromagnetic influences minimise initial volumetric deformations, leading to reduced damage in cement paste and improved mechanical properties. This suggests that internal and external activation should contribute to such structural organisation that the mechanical properties of concretes – as systems organised according to the "structure-in-structure" principle – should improve. The effect of comprehensive activation on damage and mechanical properties of concrete was studied.

The amount of quartz filler was assumed to be 25% of the cement mass, with a specific surface area of S_{sa}=100 m^2/kg. The composition of the concrete mixture was calculated to obtain concrete of class C16/20 (without quartz filler).

Analysis of the results (Tab. 4, Tab. 5) revealed that curing under the influence of fractal-matrix resonators (external activation) led to a 20% increase in the compressive strength of concrete without filler. The introduction of rational fillers made it possible to obtain concretes whose strength was comparable to that of concretes based on additive-free cement. It was found that the compressive strength of activated concrete increased by 12% to 30% after 360 days of storage under normal conditions, depending on the initial composition. This suggests that the main trends in strength development over time are preserved.

Table 4. Characteristics of the composition of the dry mixture of samples for research. *Source*: own study

Code of the samples	Type of activation	Material consumption, kg/m^3			
		Fillers	Cement	Sand	Crushed stone
1-1W	Without	-	380	684	1187
1-2W	Without	-	380	649.4	1187
2-3I	Inner	82.5	247.5	684	1182
3-4C	Comprehensive activation	82.5	247.5	684	1187
2-5I	Inner	95	285	649.4	1127
3-6C	Comprehensive activation	95	285	649.4	1127

Table 5. Physical and mechanical characteristics of test samples. *Source*: own study

Code of the samples	Compressive strength R_b, MPa, at age, days		Modulus of elasticity E, MPa×10^3, at age, days		K_p, cm/cm^2
	28	360	28	360	
1-1W	25.1	29.6	26.3	29.3	0.340
1-2W	31.5	36.1	30.2	36.1	0.380
2-3I	24.7	28.4	26.5	28.6	0.306
3-4C	32.2	36.1	32.1	37.3	0.255
2-5I	30.7	35.2	32.9	38.6	0.37
3-6C	35.7	36.3	35.4	42.2	0.31

The use of quartz fillers up to 25% by weight made it possible to obtain concretes with strength values corresponding to classes C20/25 and C25/30, taking into account the recalculation of concrete mix compositions. External activation resulted in an increase in the compressive strength of these concretes by 23% and 14%, respectively. Thus, the application of comprehensive activation methods enabled the production of concrete of class C25/30 instead of C20/25, and class C30/35, without altering the concrete mix composition.

For concrete of the specified classes, the use of rational fillers without the influence of external electromagnetic effects contributed to a reduction in sample material damage by an average of 10%. Comprehensive activation led to an average 24% decrease in the damage coefficient of the investigated concretes, resulting in an increase in the elastic modulus of the specimens by up to 20%.

It was found that, in order to achieve positive effects, moulded products should be exposed to external electromagnetic influences for at least 30 minutes. After 3 hours of hardening, no positive effects of the fractal matrix resonators on the structural formation and resultant properties of the material were observed.

The developed technological schemes for internal and comprehensive activation in the production of reinforced concrete structures are based on a combination of experimental and theoretical studies. Technological schemes were developed for the production of reinforced concrete structures both in factory conditions and on construction sites. In factory conditions, the use of rational aggregates in concrete mix preparation is envisaged. Various methods for fixing film matrices to individual moulds, technological equipment, and in the form of spatial structures (caps, covers, pallets, etc.) are proposed. Their application does not require the installation of auxiliary process equipment, is easy to implement, and is technologically safe.

An analysis of modern frame-monolithic construction showed the widespread use of reusable formwork in the concreting of horizontal surfaces and vertical elements (columns, diaphragms, lift shafts, etc.). Given that concrete mix is supplied individually for each construction project, it is not rational to provide generalised recommendations for the use of internal activation methods. Therefore, it was decided to apply the external activation method separately by using film matrices. The design of reusable formwork allows for the permanent installation of film matrices in a technically appropriate manner for each case (e.g. attached installation of frame holders). Additionally, it is recommended to cover the surface of freshly moulded concrete with matrix frames, which, apart from activation, also address concrete curing requirements. Comprehensive activation enabled the recalculation of concrete compositions, making it possible to reduce cement consumption by up to 11% while maintaining the required strength of the products.

6. Conclusions

The findings from both experimental and theoretical investigations indicate that the properties of concrete can be enhanced by altering the conditions of its structural organisation through comprehensive activation, which involves both external and internal methods. Modifying the parameters of the external electromagnetic field as a constant factor, facilitated by specialised fractal matrix resonators, results in adjustments to the conditions for organising the concrete microstructure. The use of rational aggregates as an internal activation factor, together with the activating effect of an external factor, enables control over the structure formation of hardening systems. This leads to a reduction in damage and an improvement in the mechanical properties of concrete. External activation of cement-based composites results in a reduction in the magnitude of initial deformations and alters the temperature profile of hardening systems by a factor of 1.5 to 2. It was found that the initial setting time of activated compositions is reduced by 30 to 90 minutes, without changing the final setting time. Damage to activated samples of various compositions is reduced by up to 20%, resulting in an increase in compressive strength of up to 20%. External and internal activation allows for the adjustment of the start of curing time within a range of 15 to 210 minutes. At the same time, depending on the initial composition, the time to reach the end of hardening can be shortened by 15 to 90 minutes. Damage due to processing defects in activated samples is reduced by up to 10%. Reduced damage in activated samples contributes to an increase in tensile strength in bending of up to 40%. Compressive strength as a result of comprehensive activation can increase by up to 34% after 28 days of curing under normal laboratory conditions. Altering the specific surface area of fillers, while maintaining a constant quantity, can lead to changes in compressive strength of up to 35%. Through comprehensive activation, the consumption of the clinker component can be reduced by up to 25%, while still achieving equally strong samples. This opens up the possibility of addressing the issue of reducing material consumption in cement-based materials. External and internal activation can reduce the damage factor of concrete by up to 24%, increase compressive strength by up to 28%, and raise the elastic modulus by up to 20%. The use of comprehensive activation enables the introduction of up to 25% rational aggregates without reducing the strength and elastic modulus of C20/25 and C30/35 class concrete. It was concluded that, depending on the initial composition, the compressive strength of activated concrete increased by 20% after 360 days of storage, confirming that key trends in strength development over time are preserved. The comprehensive results of experimental and theoretical studies made it possible to develop technological schemes for the production of activated concrete and related products, adapted to existing technological lines in the industrial production of precast concrete products and to the conditions of monolithic construction. In the industrial production method, the use of comprehensive activation is recommended.

References

[1] D'aloia L., Chanvillard G. “Determining the “apparent” activation energy of concrete: Ea – numerical simulations of the heat of hydration of cement”, *Cement and Concrete Research*, vol. 32, no. 8, (2002), 1277-1289. https://doi.org/10.1016/S0008-8846(02)00791-3

[2] Poole J. L., Riding K. A., Folliard K. J., Juenger M. C., Schindler A. K. “Methods for calculating activation energy for Portland cement”, *ACI Materials Journal*, vol. 104, no. 1, (2007), 303-311. https://krex.k-state.edu/handle/2097/4495

[3] Paruta V., Gnyp O., Lavrenyuk L., Grynyova I. “The influence of the structure on the destruction mechanism of polymer-cement plaster coating”, *Key Engineering Materials*, vol 864, (2020), 93-100. https://doi.org/10.4028/www.scientific.net/KEM.864.93

[4] Vyrovoy V. M., Korobko O. O., Sukhanov V. G., Posternak O. O. “Concrete as a self-organizing system”, *Materials Science and Engineering*, vol. 708, no. 1, (2019), 012115. https://doi.org/10.1088/1757-899X/708/1/012115

[5] Krivenko P., Petropavlovskyi O., Kovalchuk O. ”A comparative study on the influence of metakaolin and kaolin additives on properties and structure of the alkali-activated slag cement and concrete”, *Eastern-European Journal of Enterprise Technologies*, vol. 1, no. 6, (2018), 33-39. https://doi.org/10.15587/1729-4061.2018.119624

[6] Lobodanov M., Blikharskyy Z., Vegera P., Shnal T., Karpushyn,A. “Bearing capacity of reinforced concrete beams with damages in the compressed area obtained before the workload of 50–70%”, *Lecture Notes in Civil Engineering*, vol. 290, (2022), 245-252. https://doi.org/10.1007/978-3-031-14141-6_24

[7] Kos Z., Klymenko Y., Crnoja A., Grynyova I. “Calculation model for estimation of residual bearing capacity of damaged reinforced concrete slender columns”, *Applied Sciences*, vol. 12, no. 15, (2022), 7430. https://doi.org/10.3390/app12157430

[8] Cardoza A., Colorado H. A. “Alkali-activated cement manufactured by the alkaline activation of demolition and construction waste using brick and concrete wastes”, *Open Ceramics*, vol. 16, (2023), 100438. https://doi.org/10.1016/j.oceram.2023.100438

[9] Williamson T., Juenger M. C. “The role of activating solution concentration on alkali–silica reaction in alkali-activated fly ash concrete”, *Cement and Concrete Research*, vol. 83, (2016), 124-130. https://doi.org/10.1016/j.cemconres.2016.02.008

[10] Fernandez-Jimenez A. M., Palomo A., Lopez-Hombrados C. “Engineering properties of alkali-activated fly ash concrete”, *ACI Materials Journal*, vol. 103, no. 2, (2006), 106. https://doi.org/10.14359/15261

[11] Hefni Y., Abd El Zaher Y., Wahab M. A. “Influence of activation of fly ash on the mechanical properties of concrete”, *Construction and Building Materials*, vol. 172, (2018), 728-734. https://doi.org/10.1016/j.conbuildmat.2018.04.021

[12] Van Deventer J. S., Provis J. L., Duxson, P. “Technical and commercial progress in the adoption of geopolymer cement”, *Minerals Engineering*, vol. 29, (2012), 89-104. https://doi.org/10.1016/j.mineng.2011.09.009

[13] Krivenko P., Petropavlovskii O., Vozniuk H., Lakusta S. “The development of alkali-activated cement mixtures for fast rehabilitation and strengthening of concrete structures”, *Procedia Engineering*, vol. 195, (2017), 142-146. https://doi.org/10.1016/j.proeng.2017.04.536

[14] Klemczak B., Batog M., Giergiczny Z., Żmij A. “Complex effect of concrete composition on the thermo-mechanical behaviour of mass concrete”, *Materials*, vol. 11, no. 11, (2018), 2207. https://doi.org/10.3390/ma11112207

[15] Kroviakov S., Shestakova L. “Influence of basalt fiber and air-entraining admixture on the properties of rigid concrete pavement”, *Revista Romana de Materiale*, vol. 53, no. 2, (2023), 170-175. URL https://solacolu.chim.upb.ro/pg170-175.pdf

[16] Kroviakov S., Mishutin A., Pishev O. “Management of the properties of shipbuilding expanded clay lightweight concrete”, *International Journal of Engineering & Technology*, vol. 7, no. 3.2, (2018), 245-249. https://doi.org/10.14419/ijet.v7i3.2.14412

[17] Ksonshkevych L., Krantovska O., Petrov M., Synii S., Uhl A., “A. Investigation of the structure of cement stone, obtaining and optimization of high-strength concrete on mechanically activated binder”, *MATEC Web of Conferences*, vol. 230, (2018). 03010. https://doi.org/10.1051/matecconf/201823003010

[18] Wang S. D., Pu X. C., Scrivener K. L., Pratt P. L. “Alkali-activated slag cement and concrete: a review of properties and problems”, *Advances in Cement Research*, vol. 7, no. 27, (1995), 93-102. https://doi.org/10.1680/adcr.1995.7.27.93

[19] Zhang M. H., Malhotra V. M. “Characteristics of a thermally activated alumino-silicate pozzolanic material and its use in concrete”, *Cement and Concrete Research*, vol. 25, no. 8, (1995), 1713-1725. https://doi.org/10.1016/0008-8846(95)00167-0

[20] Puertas F., González-Fonteboa B., González-Taboada I., Alonso M. D. M., Torres-Carrasco M., Rojo G., Martínez-Abella F. “Alkali-activated slag concrete: Fresh and hardened behaviour”, *Cement and concrete composites*, vol. 85, (2018), 22-31. https://doi.org/10.1016/j.cemconcomp.2017.10.003

[21] Hajdú D., Dian E., Gméling K., Klinkby E., Cooper-Jensen C. P., Osán J., Zagyvai P. “Experimental study of concrete activation compared to MCNP simulations for safety of neutron sources”, *Applied Radiation and Isotopes*, vol. 171, (2021), 109644. https://doi.org/10.1016/j.apradiso.2021.109644

[22] Kazmirchuk N., Korobko O., Semenova S., Rozhniuk O. “Role of activation in formation of polymer composite properties”, *Key Engineering Materials*, vol. 864, (2020), 191-197. https://doi.org/10.4028/www.scientific.net/KEM.864.191