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PREREQUISITES TO THE INTRODUCTION OF THE EFFECT OF MICROWAVE RADIATION ON THE PROPERTIES OF CEMENT-BASED SOLUTIONS AND CONCRETE

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ПЕРЕДУМОВИ ВПРОВАДЖЕННЯ ВПЛИВУ МІКРОХВИЛЬОВОГО ВИПРОМІНЮВАННЯ НА ВЛАСТИВОСТІ РОЗЧИНІВ І БЕТОНІВ НА ОСНОВІ ЦЕМЕНТУ

Purpose. The impact of conditions and parameters of microwave radiation on the change in the physical and mechanical properties of cement materials has been studied, particularly on the stability of their strength characteristics.

The methods. The following methods were used: analysis of modern scientific concepts of microwave radiation application in industrial purposes, considering the safety of its use; study of the impact of microwave heating on the kinetics of product properties; determination of the compressive strength limit of mortars and concretes; comparative analysis. The samples were cement-sand cubes with dimensions of 5×5×5 cm, produced according to standards, and cured until they achieved their design strength. When applying UHF radiation to the samples, it was considered that its influence at early stages could disrupt the hydration processes.

Findings. The results of the study on the impact of microwave radiation on the change in physical and mechanical properties of building mortars and concretes based on cement are presented. The parameters of microwave radiation that influence the physical and mechanical properties of cement-sand samples have been identified. The application of microwave radiation during the removal of water from the internal layers of the mortar mixture leads to an increase in the strength of cement mortars and concretes. The energy consumption when using UHF technologies is lower compared to thermal treatment.

The originality. Dependencies between the power and duration of UHF radiation and the strength characteristics of the samples have been established. Quantitative parameters of the radiation affecting the process of their destruction have been determined.

Practical implementation. The research conducted will expand the scientific basis for justifying the use of microwave radiation to influence the properties of cement mortars and concretes. The impact of UHF radiation can accelerate the hardening process of cement mixtures. This can be useful in conditions where rapid hardening of the material is required, such as in emergency construction work. However, the acceleration of the reaction may lead to a decrease in the quality of the final product if all parameters are not carefully controlled.

Keywords: *safety of UHF radiation use, parameters of microwave radiation, cement-sand cubes, physical and mechanical properties, strength.*

Introduction. For the first time, the ultra high-frequency (UHF) range of electromagnetic radiation was used in the late 1930s in radar systems for detecting enemy aircraft and ships. Today, a wide variety of devices operate using UHF energy. One of

the advantages of UHF heating is its high efficiency in converting UHF energy into heat within the volume of the heated objects. A promising area of UHF radiation use has become its thermomechanical impact on various natural minerals. UHF energy allows for selective mineral destruction with specific energy consumption many times lower than traditional methods of destruction (crushers, ball mills, etc.) [1].

Currently, UHF energy plays a significant role in many sectors of the economy. It is considered an energy-saving technology, which is why in recent years there has been a growing interest in the practical use of UHF energy for industrial purposes. The main areas of UHF energy application include:

– thawing frozen soils;

– loosening and crushing rocks;

– separating ores into components;

– complete extraction of metals from waste and sludges.

Microwave radiation has several advantages: – fast and contactless heating; – UHF energy is simply transferred to almost any part of the heated object, rather than heat;

– uniform heating; – enables virtually instantaneous cessation of thermal effects on the processed material; – microwave heating has a high efficiency in converting UHF energy into thermal energy, with the theoretical efficiency value being close to 100%; – high level of safety and automation.

It should be noted that the method of breaking solid structures using microwave radiation is being developed for use with rocks. However, the destructive effects of microwave radiation on construction materials, particularly on concrete and hardened mortars, have not been widely studied, and the combined effect of parameters such as radiation power, exposure duration, and the influence of moisture on their physical-mechanical properties has not been explored.

Several studies provide an overview of the application of powerful microwave electromagnetic field sources in the mining industry for loosening rocks, present the dielectric characteristics of minerals, discuss the mechanism of thermomechanical rock destruction by microwave fields, and describe the requirements for the loosening mode before grinding, along with the results of trial experiments. The research by Arzhannikov A.V., Bychenkova V.A., and others is somewhat fragmented, and they have formulated requirements for the microwave generator, determining the range of electrodynamic parameters within which the use of microwave radiation for concrete destruction is most effective [2].

In turn, in the studies of H. Satish [3], the positive effect of low-energy microwave radiation (in the range of 150 W) on the formation of thermal cracks in the structure of basalt rock samples is noted. In his work, D. A. Jones [4] models the preliminary formation of thermal cracks in ore samples due to UHF radiation to facilitate their subsequent destruction. Pejman Nekoovaght [5, 6] indicates that microwaves penetrate the rock and create macro/micro-damages on the surface of the rocks due to the thermal expansion coefficient within the grains, which facilitates the destruction process. Comprehensive studies presented in work [7] are dedicated to the practical application of mechanical rock destruction using microwave radiation, and three-dimensional

modeling of the effect of microwave radiation on stresses in granite samples is also presented.

In work [8], it is shown that microwave treatment with microwave fields positively affects the properties of composite materials for thermal insulation based on liquid glass. The results presented in work [9] show that the use of UHF radiation in the fields of chemistry and construction materials plays an especially important role, alongside volumetric internal heating of the material, in the so-called non-thermal effect. The effect of UHF radiation on uncured concrete or mortar mixtures produces a completely different outcome. During the preparation of cement-based mortar, it is exposed to electromagnetic radiation after being mixed with water. While thermal treatment heats the upper layers of the material and the heat is subsequently transferred from the hotter layers to the cooler ones, microwave treatment causes internal heating of the concrete or mortar mixture. The mixture is irradiated with a high-frequency electromagnetic field, accompanied by heating. The use of UHF radiation is beneficial when removing water from the inner layers of the mortar mixture by affecting water molecules, which results in an increase in the strength of products based on cement mixtures.

A perspective direction for research is not only the problem of assessing the quality of ensuring the stability of the strength characteristics of materials [10, 11], but also the influence of microwave radiation conditions on the alteration of their physical properties. This work attempts to investigate the effect of radiation power and exposure duration on the process of destruction of cement-sand samples. This will provide a scientific basis for using UHF radiation not only for the destruction of concrete and other construction materials, but also for rocks.

Purpose. The main objective of this scientific work is to investigate the influence of UHF radiation conditions and parameters on the physical-mechanical properties of construction materials, particularly evaluating the stability of their strength characteristics. To achieve this goal, it is necessary to experimentally determine the effect of the duration and power of UHF radiation on the strength characteristics of cement-sand mortar samples.

Research methodology. One of the obstacles to the widespread implementation of UHF technologies, including in the construction industry, is the potential danger to humans from microwave radiation exposure. When using microwave heaters, it is necessary to follow regulatory documents, control the energy flux density, and the specific absorbed power per unit mass of the body. To reduce the impact of microwave radiation, existing sanitary and hygienic standards must be followed. The main ones are the sanitary rules and norms [12].

UHF radiation exposure can accelerate the hardening process of cement mixtures. This can be useful in situations where rapid hardening of the material is required, such as during emergency construction work. However, the acceleration of the reaction may lead to a decrease in the quality of the final product if all parameters are not carefully controlled.

For the experiment, a «Fairline» microwave oven was used, with the following radiation power range: minimum – 100 W, average – 500 W, maximum – 900 W, as well as a KL-200/R press from "Tecnotest". The samples were cement-sand cubes with

dimensions of 5×5×5 cm. They were prepared from the required amount of cement-sand mortar with a mix ratio of 1:3 (by weight) and a water-cement ratio (W/C) of 0.45. The components were measured using electronic scales. The cement and sand were mixed for 1 minute. Then, a hole was made in the center of the dry mixture, into which the required amount of water was added. The water was absorbed into the mixture for 30 seconds, after which the mixture was manually stirred with a round spatula for 8 minutes (according to standards, at least 5 minutes when mixing manually). The resulting mortar of normal consistency was used to fill the molds – the cubes. Each mold was then vibrated on a vibration table for 15 seconds. This recipe was used for the preparation of all cubes for the study. After curing for 24 hours, the cubes were removed from the molds and placed in a chamber with moist sawdust to gain standard strength. After 28 days of curing, the cubes were ready for the experiment [2].

Results. Since the effect of microwave radiation involves the conversion of electromagnetic energy into thermal energy by interacting with water molecules through ultra-high-frequency radiation, it is advisable to use it for removing water from the inner layers of mortar or concrete mixtures. It is worth noting the low energy consumption when using UHF technologies compared to thermal treatment. Additionally, the drying process is accelerated when UHF technologies are applied.

The conduct of the research is regulated by the relevant standards [13, 14]. For the experiment, 24 cement-sand cubes were prepared. The experiment aimed to determine the impact of UHF radiation power and exposure duration on the change in strength characteristics of dry (at natural moisture content) samples and samples saturated with water. During the experiment, strength tests were conducted under uniaxial compression on both dry and water-saturated samples, which were previously exposed to UHF radiation (at minimum, medium, and maximum power levels) for a duration of 1 to 3 minutes. Six cubes (3 dry and 3 water-saturated) that were not exposed to UHF radiation served as control samples. Their strength was determined on a testing press. The results of three tests showed the average strength of the samples: -for dry samples – 37,2 N/mm²; for water-saturated samples – 30,5 N/mm².

In the next stage of the experiment, 9 cubes were taken, which were saturated with water for 2 hours. The water-saturated cubes were exposed to UHF radiation for 1, 2, and 3 minutes at minimum, medium, and maximum power levels. The results of the tests are presented in table 1.

Table 1

Strength of water-saturated samples

Time of exposure to UHF radiation	Strength of water-saturated samples, MPa (N/mm²)		
	Power 100 W	Power 500 W	Power 900 W
1 min	29,64 (2,78)*	28,53 (6,42)	26,16 (14,20)
2 min	27,65 (9,31)	27,11 (11,08)	22,92 (24,82)
3 min	26,5 (13,08)	17 (44,24)	16,12 (47,13)

* – the loss of strength in % relative to the control samples is indicated in brackets

The final stage of the experiment involved the use of the following 9 cement-sand cubes of natural moisture content. The samples were exposed to UHF radiation for 1, 2 and 3 min at minimum, average and maximum power. The test results are presented in table 2.

The analysis of the results showed that the treatment of samples with UHF radiation primarily affects the reduction of strength in water-saturated samples. This occurs because the water molecules within the structure of the mortar mixture begin to move actively (vibrating within individual clusters) when heated under the influence of microwave radiation. During this movement, micro-damages are formed.

Table 2

Strength of dry samples

Time of exposure to UHF radiation	Strength of dry samples, MPa (N/mm²)		
	Power 100 W	Power 500 W	Power 900 W
1 min	36,16 (2,7)*	36,08 (2,9)	32,23 (13,3)
2 min	34,65 (6,8)	32,05 (13,8)	28,33 (23,8)
3 min	33,91 (8,8)	27,7 (25,5)	27,33 (27,03)

* – the loss of strength in % relative to the control samples is indicated in brackets

The exposure of microwave radiation to cement-sand samples at natural moisture content (dry samples) leads to a decrease in their strength by 2,7% to 13% when exposed to microwave radiation in the range of 100 to 900 W for 1 minute, and by 8,8% to 27% when exposed to the same power ranges for 3 minutes (fig. 1). It should be noted that a promising direction for future research is the study of the inverse problem, namely, the application of UHF radiation during the dissolution of concrete or other mixtures in water, which, after hardening, would lead to an increase in the strength of the products.

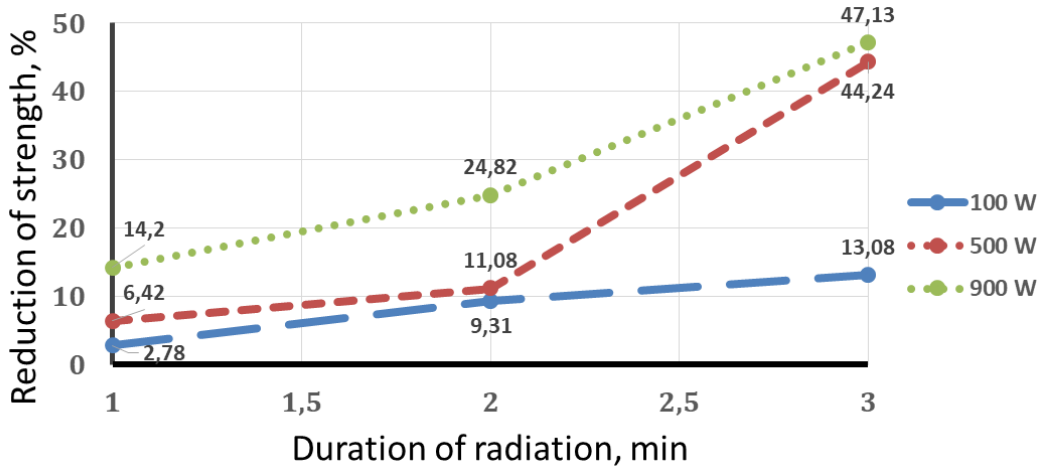

Fig. 1. Reduction in strength of dry samples in % depending on the duration of radiation

The greatest impact of UHF radiation on the reduction of sample strength (at a radiation power of 900 W and exposure duration of 3 minutes) is observed when the samples are pre-soaked – up to 47% compared to a 27% reduction in strength in dry samples (fig. 2).

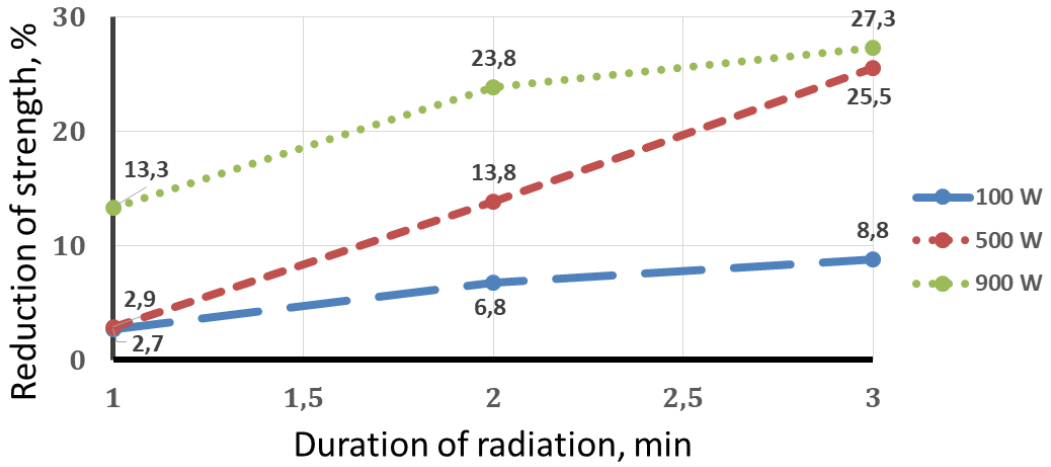

Fig. 2. Reduction in the strength of wet samples in % depending on the duration of radiation

The most destructive effects of UHF radiation on cement-sand samples were observed at power levels ranging from 500 to 900 W for durations of 2 to 3 minutes.

Scientific novelty and practical significance. When applying microwave radiation to the samples, it was taken into account that, at early stages of curing, hydration reactions occur according to Baykov's theory. If microwave radiation is applied at these early stages, water will be removed from the material volume of the samples, and the hydration processes will be disrupted, leading to cracking and a loss of strength.

The research found that the most significant impact of UHF radiation on the formation of artificial cracks and micro-damages in cement-sand samples occurs when they are pre-saturated with water and exposed to radiation power levels between 500 and 900 W for 3 minutes.

With shorter exposure times, the strength loss in cement-sand samples is somewhat lower compared to the control samples. However, it should be noted that the control sample of water-saturated cement-sand mortar (or, essentially, fine-grained concrete) only had 82% of the strength of the dry sample.

Pre-wetting the cement-sand mortar before subsequent microwave radiation helps create micro-damages in the concrete body, which, in turn, simplifies the destruction process.

Conclusions. When using UHF heating, heat generation occurs directly within the material itself, making this type of heating more efficient and easily controllable, which allows its use in energy-intensive technologies for the production of building materials. UHF radiation is an effective tool for energy resource conservation in modern manufacturing technologies.

The recommended parameters for processing cement-sand mortar samples to facilitate their destruction are as follows:

– Pre-saturation of concrete with water;

– UHF radiation power of 900 W for optimal results;

– Exposure duration of 2–3 minutes.

In the absence of the possibility to saturate the concrete with water, the effect of microwave radiation at a power of 900 W with the same duration (2–3 minutes) will be 62–65% lower (the strength of dry samples is 27 MPa compared to 17 MPa for wet samples).

The conducted research is promising for solving such an urgent problem as the cleaning and «rehabilitation» of buildings contaminated with radioactive waste. The basis of this cleaning method lies in the following processes: 1) chipping on the free surface under the influence of a shock wave generated by local heating of the surface layer of the solid body by powerful UHF radiation; 2) brittle destruction of the near-surface layer due to shear deformation caused by the strong anisotropy of the stressed state. Undoubtedly, the advantages of the cleaning method using powerful pulsed UHF radiation flows include remote control of the process, ensuring no direct contact of personnel with radioactive contamination, the relative safety of the electromagnetic radiation used in the technology, and finally, the possibility of creating a mobile installation. In connection with the above, determining the characteristic UHF radiation parameters for the destruction of the surface layer of concrete used in nuclear power plants is of interest.

The use of UHF radiation may also be applicable in the technology of manufacturing concrete, mortars, and mixtures, as well as in the processing and cementation of liquid and solid radioactive waste, particularly in their burial.

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АНОТАЦІЯ

Мета. Досліджено вплив умов та параметрів мікрохвильового випромінювання на зміну фізико-механічних властивостей цементних матеріалів, зокрема на стабільність їх характеристик міцності.

Методика. Були використані такі методи: аналіз сучасних наукових концепцій використання мікрохвильового випромінювання у промислових цілях з урахуванням безпеки його застосування, дослідження впливу микрохвильового нагріву на кінетику властивостей виробів; визначення межі міцності розчинів і бетонів на стиск; порівняльний аналіз. Зразки - цементно-піщані кубики розміром 5×5×5 см, виготовлені згідно нормативів, витримані до набуття ними марочної міцності. При застосуванні НВЧ-випромінювання на зразки було враховано, що його вплив на ранніх термінах може призвести до порушення процесів гідратації.

Результати. Наведено результати дослідження впливу мікрохвильового випромінювання на зміну фізико-механічних властивостей будівельних розчинів та бетонів на основі цементу. Встановлено параметри мікрохвильового випромінювання, що дають змогу впливати на фізико-механічні властивості цементно-піщаних зразків. Застосування мікрохвильового випромінювання при видаленні води з внутрішніх шарів розчинної суміші призводить до підвищення міцності цементних розчинів і бетонів, енерговитрати при застосуванні НВЧ технологій нижче порівняно з тепловою обробкою.

Наукова новизна. Встановлено залежності між потужністю та тривалістю НВЧ-випромінювання та міцнісними характеристиками зразків, визначені кількісні параметри випромінювання, які впливають на процес їх руйнування.

Практична значимість. Проведені дослідження дозволять розширити наукову базу для обґрунтування застосування мікрохвильового випромінювання для спрямованого впливу на властивості цементних розчинів та бетонів. Вплив НВЧ-випромінювання може прискорити процес твердіння цементних сумішей. Це може бути корисно в умовах, де потрібне швидке твердіння матеріалу, наприклад, при екстрених будівельних роботах. Однак, прискорення реакції може призвести до зниження якості кінцевого продукту, якщо не контролювати всі параметри.

Ключові слова: *безпека використання мікрохвильового випромінювання, параметри мікрохвильового випромінювання, цементно-піщані кубики, фізико-механічні властивості, міцність.*