Influence of microwave irradiation of cement mixtures on the strength of cement stone and concrete

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Abstract. The influence of microwave irradiation of mixtures on the strength of cement stone and concrete was studied. Created at NRNU MEPHI experimental installation for the investigation of microwave effects on imperfect dielectrics and semiconductor materials was the source of radiation. It is shown that on the twenty-eighth day after mixing, the strength of the cement stone increases by 1.2 times, and that of concrete by 2.2 times.

1. Catalytic action of microwave radiation

The article is devoted to research in the field of catalytic action of microwave radiation during hydration of inorganic materials. The possibility of improving the cement stone properties by means of microwave processing of cement mixtures has been investigated.

Processes based on microwave heating have many applications in the industry. The advantages of this heating are the features of electromagnetic radiation absorption. This is a volumetric uniform heating, the possibility of concentrating high power in small volumes and the possibility of its concentration in a certain place [1]. Microwave exposure saves energy, since power is released directly in the material being processed. NRNU MEPHI has extensive experience in the development of microwave installations: an installation for a two-stage processing of radioactive waste was developed [2], nanomaterials were obtained by microwave heating [3] etc.

Also, microwave radiation can play the role of a catalyst for chemical reactions. For example, it was shown that the short-term microwave exposure to polymers which does not cause temperature increasing leads to its properties modification that can be used for practical purposes [4]. Cement is a complex mixture of minerals. Chemical reactions that occur when cement is mixed with water, lead to the formation of a structure similar to polymeric materials.

Adsorption of water by mineral particles occurs during concrete curing due to electrostatic interaction between ions and water dipoles and van der Waals forces [5]. The smaller size of the adsorption layer leads to a stronger cement particle bonds and, ultimately, the strength of the cement stone. The microwave field interferes with adsorption of additional water layers, reducing the limiting cement water-retaining capacity. Also alternating electromagnetic field facilitates mixing and therefore more compact arrangement of the cement gel particles.
2. Experimental installation
The experimental installation for the investigation of microwave effects on imperfect dielectrics and semiconductor materials was created at NRNU MEPhI. The installation is shown in figure 1. Its main elements are a magnetron-type microwave generator with a continuous output power, a ferrite isolator, absorbing loads and a working chamber.

![Figure 1. Appearance of the installation.](image)

The installation uses a continuous generator with a power of 5 kW, based on the magnetron M-168 with an operating frequency (2450 ± 50) MHz. The generator consists of two units: a rectifier (1) forming a constant anode voltage of the magnetron and a generating unit (2). The positive quality of the magnetron is a low power level at which steady generation of microwaves begins (200 ... 300 W). This is very useful in carrying out the experiments.

Magnetron M-168 has a valid value of the standing wave ratio (VSWR) equal to 1.5. Such a VSWR value is difficult to provide in the experimental installation due to the uncertainty of the input resistance of the loaded working chamber. Therefore a ferrite isolator (3) is installed at the output of the generator to protect the magnetron from the action of the backward wave. So the magnetron is always matched to the waveguide.

A rectangular waveguide section was used as the working chamber. A circular below cutoff waveguide was installed on it (4). The microwave power not released in the test sample was dissipated in the absorbing load (5). The alundum container was placed on the bottom of the rectangular waveguide through the below cutoff waveguide.

3. Experiments
The container was loaded with a mixture of portland cement grade 45.5R, sand and water. In the first case the sample consisted of a water/cement mixture with a water-cement ratio of 0.4. In the second case the sample consisted of a mixture of sand and cement in a ratio of 3 to 1 with a water-cement ratio of 0.7. The container was filled with 50 cm³ of mixture. After microwave processing the mixture was poured into special molds.

A series of experiments on the processing of mixture samples was carried out. The experiments were carried out at a microwave generator power of 1.2 kW. The time of microwave exposure to the
samples ranged from 5 to 15 seconds. The mixture was poured into molds for subsequent testing on the seventh, fourteenth and twenty-eighth days from the moment of microwave processing. Investigation of the mechanical strength of concrete and cement stone was carried out using a hydraulic press. The cement stone obtained from the mixture processed with microwave irradiation showed an increase in strength compared to the unprocessed one by 1.2 times on the twenty-eighth day after mixing. The processed samples of the cement-sand mortar on the twenty-eighth day had strength of 2.2 times than the unprocessed samples. The best results were obtained with a microwave processing time of 10 seconds and a final temperature of the mixture of 50-55 °C. The results of the tests are shown in table 1. Rate of cement stone hardening is shown in figure 2.

Table 1. The results of the tests.

| Age of hardening (days) | Compressive strength (MPa) |
|-------------------------|---------------------------|
|                         | Cement stone              | Concrete              |
|                         | Unprocessed samples       | Processed samples     | Unprocessed samples | Processed samples |
| 7                       | 24.0                      | 32.0                  | 10.3                | 15.8             |
| 14                      | 38.5                      | 51.0                  | 10.8                | 27.5             |
| 28                      | 51.3                      | 61.2                  | 16.0                | 35.5             |

Figure 2. Rate of cement stone hardening: processed samples (2), unprocessed samples (1).

The obtained results give reason to believe that microwave processing of cement mixtures is a promising method to increase the mechanical strength of cement stone and concrete. This project is supported in part by the MEPhI 5/100 Program of the Russian Academic Excellence Project.

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