UDC 620.179.17 **DOI 10.52928/2070-1683-2024-36-1-34-38**

MONITORING OF FIBROBLAST AT AN EARLY AGE BY THE METHOD OF ACOUSTIC EMISSION

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The article presents the main results of acoustic emission monitoring of concrete and fibro-concrete at an early age. The main characteristics of acoustic signals arising in a concrete mixture during the structuring of concrete with and without structural reinforcement are presented. In the course of the study, the influence of reinforcement on the processes of acoustic signal extraction during the formation of concrete samples was determined. The physico-chemical processes occurring inside the concrete mixture, associated with internal structural changes and, as a con-sequence, hydration stages, are interconnected with acoustic emission, which is sensitive to the capture of numerous elastic wave signals during the formation of the structure under various conditions.

Keywords: *fiber concrete, structuring, acoustic emission, concrete mix.*

Introduction. Monitoring the early stage of the material is important, as this stage largely determines the final properties of the hardened concrete. Concrete – an artificial construction conglomerate is a system of many atoms (elements) that develops over time. The structure of concrete is extremely complex, is in continuous change (dynamics) from the moment of bringing components of concrete in contact with water and until the loss of operational properties of the concrete structure. Since the properties of concrete and its behavior are determined by its structure, it is necessary to look for a change in its dynamics and, conversely, for every change in dynamics detected in it one should look for a transformation of the structure[1].

One of the most promising methods for studying structural changes in freshly prepared concrete is the acoustic emission (AE) method. This method of non-destructive control is based on the generation of elastic waves during structural changes of the material [1]. Sufficiently rapid physical processes of structural changes in a limited volume of material (plastic deformation, fracture, formation and growth of cracks, disruptions of dislocation clusters from attachment points, phase transformations, the origin of microdefects, friction, etc.) are accompanied by the emission of acoustic waves [2]. The AE method makes it possible to detect (and in many cases identify) nanostructural changes in solids, since it records single acts with an energy of up to 10–16 J [3]. The AE method registers acoustic signals emitted by the concrete structure itself during its formation. Studies by a number of authors[2,3] [4–6] have shown the possibility of using the AE method for monitoring freshly prepared concrete at the hardening stage. This method is preferable because it shows the sensitivity of capturing numerous elastic wave signals during the setting of the material. Using the AE method, it is possible to register the internal structural activity of concrete during its hardening[4]. In this paper, informative parameters of acoustic signals at the main stages of structuring concrete samples are highlighted.

Equipment and materials for experimental research. To measure the AE parameters, the AE system A-Line DDM–1, manufactured by INTERU-NIS-IT LLC, was used. AE equipment works only with electrical signals, therefore, piezoelectric converters are mainly used for receiving and emitting acoustic waves, transforming acoustic vibrations into electric voltage fluctuations and vice versa [3]. Therefore, in order to register and convert the energy of elastic mechanical waves into an electrical signal, bandpass converters manufactured by Don Measuring Systems LLC – GT200, with an operating frequency range from 130 to 200 kHz, were connected to the AE modules. The advantage of piezoelectric transducers is that they are highly sensitive to deformations and acoustic vibrations. The operation of these converters is based on the phenomenon of the piezoelectric effect. When some dielectrics are deformed, an asymmetric displacement of electric charges occurs and, as a result, un-compensated surface charges arise at the boundaries of the material. An electric field appears in the material, and an electric voltage appears at its boundaries [3]. For greater acoustic contact between the AE converter and the freshly

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prepared concrete mixture, a steel waveguide was used, shown in figure 1. The AE converter was installed on the waveguide through a contact lubricant and fixed with a magnetic holder. The waveguide, in turn, was immersed in concrete until the plate touched the composition.

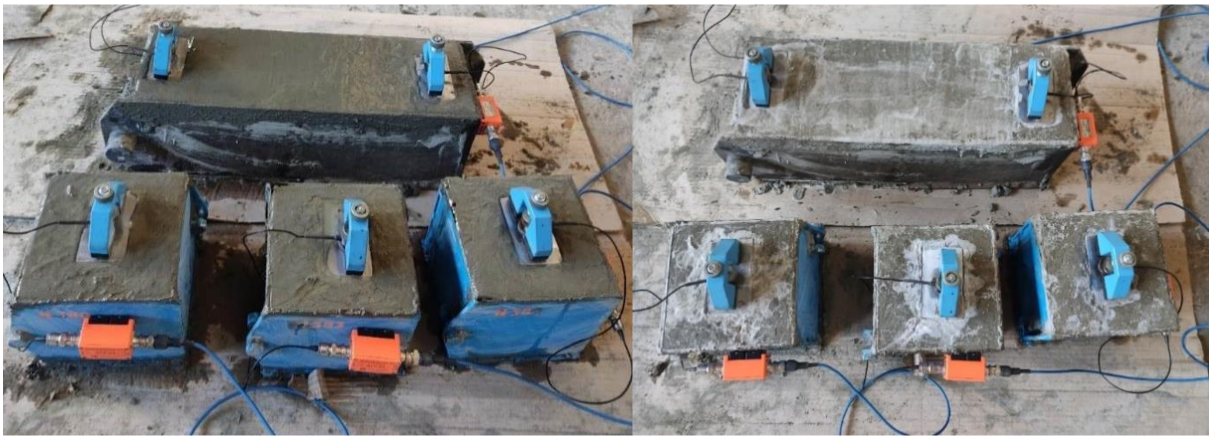
Figure 1. – Waveguide view

As the studied samples, a concrete mixture with an W/C ratio of 0,5 was used, which was poured into metal molds. Table 1 presents the materials of the studied samples. For dispersed reinforcement of concrete, metal (most often steel) and non-metallic (mineral, polymer, etc.) high- and low-modulus fibers of various lengths and cross-sections are used. Steel fiber is obtained by cutting low-carbon wire, foil or sheet steel, forming from melt, milling strips and slabs, as well as in the result of the turning process [7].

Table 1. – Characteristics of the materials used for the manufacture of the studied samples

Material	Basic information	Weight, kg
Binder	Portland Cement CEM I 42,5N (JSC "KRICHEVTSEMENTNOSHIFER"), with a specific surface area of 3615 cm^2/g, a normal density of NG = 26,5%	11
Sand	Quarry sand sifted fractions up to 5 mm	12
Crushed stone	Crushed stone fractions of 5–25 mm	26
Reinforcing material	Steel anchor fiber with a diameter of 1 mm and a length of 50 mm (RUE "Belarusian Metallurgical Plant")	40 kg per 1 m^3

Registration and analysis of parameters of acoustic emission signals of concrete structuring under natural hardening conditions was carried out continuously for three days from the moment of preparation of the concrete mixture. Part of the experimental setup is shown in figure 2.



a ***b***

Figure 2. – Conducting an experiment at the initial stages of structuring (*a*), on the third day of structuring samples (*b*)

Results and problematic. Acoustic emission signals propagating to the sample surface undergo significant changes due to the dispersion of the speed of sound, the transformation of wave types during diffraction, reflection, refraction, attenuation. The reason for the peculiarity of the laws of acoustic wave propagation in a concrete mixture is the variability of the acoustic resistance of the concrete components: cement stone; crushed stone or gravel; sand and pores filled with air and water [8]. The AE source in the sample emits spherical longitudinal and transverse waves. In this case, the high-frequency component of the signal undergoes attenuation, due to the directly proportional dependence of the attenuation coefficient in the material and the frequency. There are signals whose amplitude decreases with distance much slower than for a spherical wave. As a result, mainly this type of signals is registered[5]. The main task of AE control at the early stage of concrete hardening is the appearance of indicators that reflect the main periods of structuring associated with hydration processes, which will allow determining the disintegrating strength, predicting the strength of concrete, and monitoring the strength of concrete during the hardening process [8].

The properties of fiber concrete are determined by the type of fibers and concrete used, their quantitative ratio and depend on the state of contacts at the interface of phases, the introduction of fibers helps to improve the structure and properties of the initial concrete, increase its durability and durability. Reinforcement with steel fibers changes the properties of the material, as a result of the addition of steel fibers, a new composite is formed – steel fiber concrete [9].

The influence of reinforcing fibers at the early stage of hardening on AE signals can be traced in figure 3. In the first period of the structure formation of the background (the dissolution stage), there is a constant bombardment of free water molecules on the surface due to their Brownian motion, internal forces of interaction between particles arise, migration of water and gas bubbles is observed. AE activity in the first period is high and approximately the same in samples with and without fiber, the amplitude of the signals in the samples reaches a maximum value of 94 dB (figure 3, *a*). And in samples with dispersed reinforcement, additional surface tension forces of water arise on steel fibers, which is why the cumulative amplitude of the signals is higher – 21762 dB, than in concrete samples without fiber – 7527 dB (figure 3, *b*). The higher the AE activity within the first period and the higher the amplitude the mechanical movement of the mixture and its individual components[6].

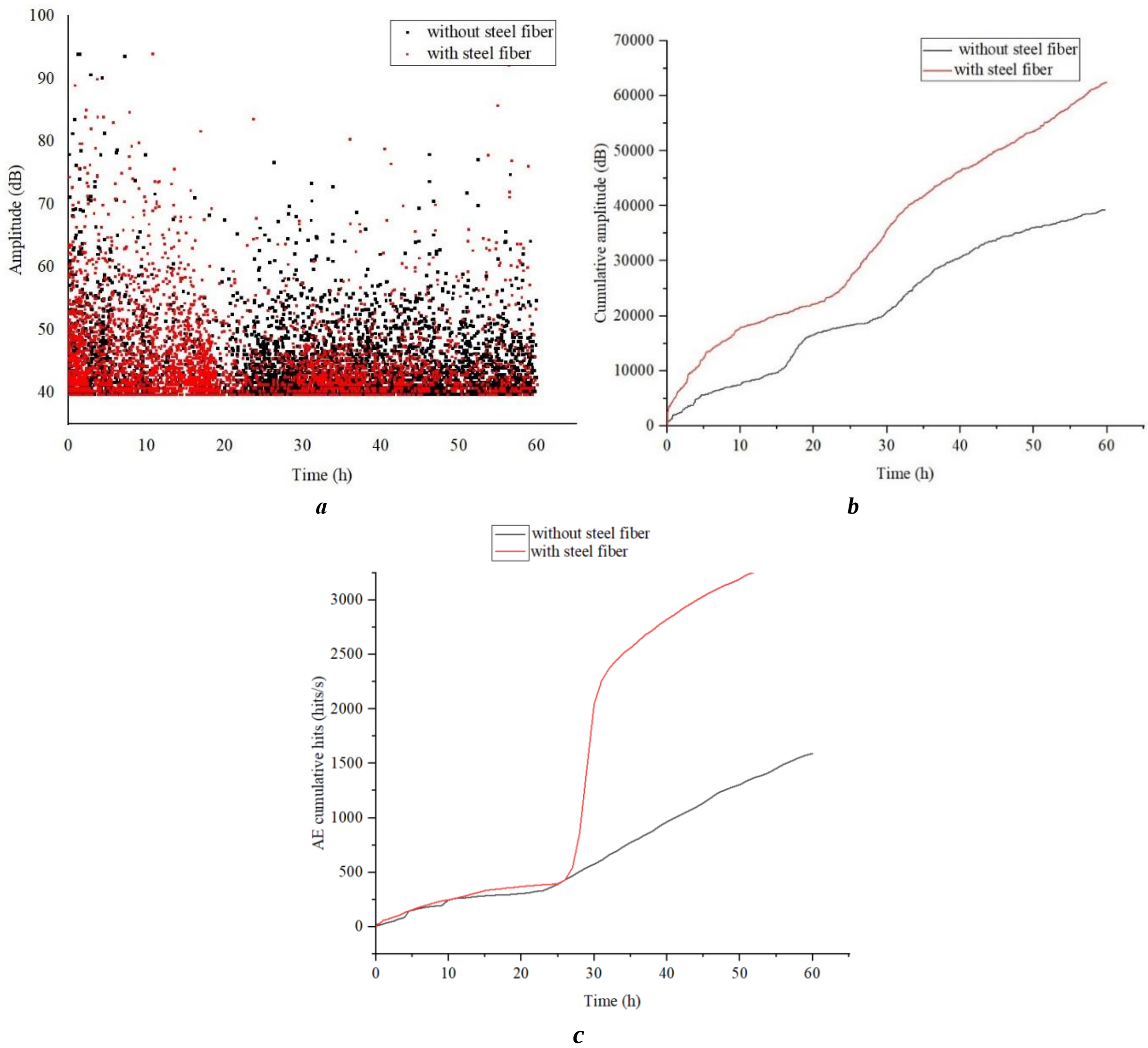


Figure 3. – Dependence of the amplitude of acoustic signals (*a*), cumulative amplitude (*b*) and AE cumulative hits (*c*) on the hardening time of the concrete mixture with and without reinforcing material

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[5] See footnote 1.
[6] See footnote 3.

The second stage of structuring (the setting period) is characterized by a long duration in samples with and without fiber. So the time interval of the second period for a concrete sample is 15 hours, and for a sample of fibroblast is 9 hours. By the end of the second period, the total pulse count for a sample with fiber was 2260 hits/s and the cumulative amplitude was 37689 dB, and in samples without fiber, the acoustic characteristics were 396 hits/s and 18132 dB, respectively (figure 3, *b*, *c*). In this period, i.e. in the period of stabilization of structural strength, there is a decrease in the recorded acoustic signals due to the high attenuation coefficient of the forming structure. This period is characterized by the appearance of flocculation forces of sur-face interaction, as well as the formation of a double electric Gemholtz layer, which affects the formation of the coagulation structure of the cement gel [10]. When structuring the concrete mixture with fiber inclusions, additional intermolecular and electrostatic forces arise, the internal friction forces of the matrix components increase, which leads to their limited movement in the presence of steel fibers, and therefore to a decrease in AE signals.

The main causes of attenuation of sound waves include scattering and absorption. Scattering is associated with the propagation of acoustic signals in a strictly non-homogeneous medium. Individual components media, for example, pores and foreign inclusions, have different densities and propagation speeds of incident rays, and as a consequence, different acoustic resistance (figure 4). Absorption, as mentioned above, is primarily directly related to the conversion of sound energy into heat. As a rule, the absorption is greater the faster the oscillations occur, that is, the higher the frequency of the sound wave. Therefore, absorption increases in proportion to the increase in frequency, that is, slower than scattering.

The shorter the duration of the second period, the more active the process of structuring takes place, which means that the design strength of the samples is higher. The strength for 28 days of the concrete sample was 49,5 MPa, and the fiber-concrete sample was 52,5 MPa.

The inclusion of reinforcing fibers leads to accelerated crystallization processes in the mineral part of the composite, therefore, in the third period (the period of crystallization) in a fiber-reinforced concrete sample, the activity of AE pulses and cumulative amplitude is higher than in samples with no dispersed reinforcement. By the end of the third period, the total pulse count for a sample with fiber was 32 pulses/s and the cumulative amplitude was 62432 dB, and in samples without fiber, the acoustic characteristics were 1591 pulses/s and 39276 dB, respectively. The higher the AE activity during this period, the higher the final strength of the material.

Conclusion. Variations in energy and power characteristics during the structuring of the material lead to changes in acoustic signals, therefore, the AE parameters in concrete samples with the addition of steel fiber differ from the AE parameters in the absence of dispersed reinforcement. This proves the sensitivity of the non-destructive passive control method, as an AE method that captures any changes in the structure. According to the change in AE parameters over time, three time intervals can be distinguished, characterized by varying degrees of AE intensity and the number of recorded pulses. It was found that each of the three time intervals corresponds to different periods of concrete structure formation. The analysis of acoustic emission parameters during the hardening of concrete mixtures allows us to identify characteristic periods of hydration, determine the kinetic parameters of hydration, and evaluate the effect of additives on the properties of concrete. The acoustic-emission method of concrete control at an early age will allow determining the decaying strength, predicting the strength of concrete, and monitoring the strength of concrete during the hardening process. The acoustic-emission control method will allow us to quickly determine the physical and mechanical properties of concrete, make adjustments when concreting structures and thereby ensure the reliability of structures and the safety of buildings and structures [11].

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Поступила 06.12.2023

МОНИТОРИНГ ФИБРОБЕТОНА В РАННЕМ ВОЗРАСТЕ МЕТОДОМ АКУСТИЧЕСКОЙ ЭМИССИИ

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В статье представлены основные результаты акустико-эмиссионного мониторинга бетона и фибробетона в раннем возрасте. Представлены основные характеристики акустических сигналов, возникающих в бетонной смеси при структурировании бетона с дисперсным армированием и без него. В ходе исследования было определено влияние армирования на процессы выделения акустического сигнала при формировании бетонных образцов. Физико-химические процессы, происходящие внутри бетонной смеси, связанные с внутренними структурными изменениями и, как следствие, этапами гидратации, взаимосвязаны с акустической эмиссией, которая чувствительна к захвату многочисленных сигналов упругих волн во время формирования структуры в различных условиях.

Ключевые слова: *фибробетон, структурирование, акустическая эмиссия, бетонная смесь*.