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Changes in the Parameters of the Electromagnetic Response of Model Dielectric Samples with Air Cavity Defects under External Deterministic Acoustic Impact

The paper discusses the possibility of testing the air inclusions saturation in cement-sand samples using the acoustic-electrical transformations phenomenon in heterogeneous dielectric materials. An experiment technique is presented including contact external acoustic excitation and contactless registration of the electromagnetic response to such an impact. Methods of samples deterministic acoustic excitation by a ball impact and the experimental determination of the impact energy are described. The model samples size and composition are described, including air cavities in a polyethylene sheath. The experimental studies geometry is shown, indicating the direction of the samples acoustic excitation and the location of the electromagnetic receiving plates. It is shown that the defect-free samples and with air cavities, have different amplitude and frequency of the electromagnetic signals spectral components. The samples with air cavities have the average weight of the EMS spectrum changes towards lower frequencies. This frequency shift effectively reflects the concentration of air cavities defects in a cement-sand samples and this effect can be used when testing concrete products for the presence of air inclusions, and, accordingly, will allow determining the frost resistance of products.

Keywords: acoustic-elecrical transformations, acoustic excitation, electromagnetic signal, amplitude-frequency characteristics, dielectric structures, cement-sand mixture, defect, electrical double layer.

Introduction

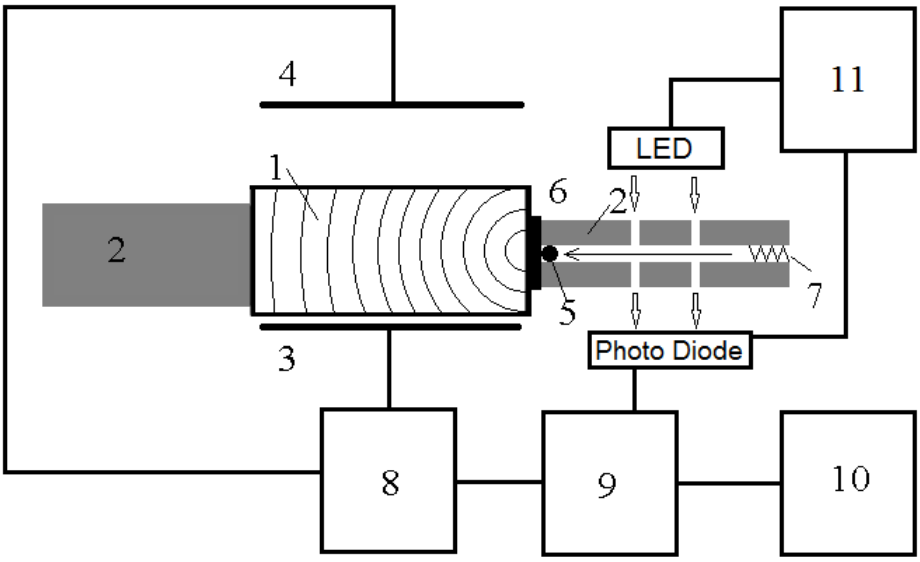
The reliability and durability of concrete products is always of great importance for the people safety, therefore, the determination of defects in such materials is an important task. Samples made from cement-sand mixture were used to simulate the impact of defects in the form of air cavities on the parameters of the electromagnetic response under external deterministic impact. It is known that preparation of such mixtures is followed by air entrainment, and air bubbles up to $10^{–3}$ meters have a beneficial effect on frost resistance and strength of concrete. However, this is not the most important characteristic for assessing its frost resistance. An important characteristic is the distance between air bubbles and their size. The larger the size of the air inclusions, the lower the strength of concrete or mortar under external loads. This is due to the fact that voids with the size exceeding $(5–7)\times10^{-3}$ meters serve as stress concentrators, which ultimately leads to concrete destruction [1]. The critical capillary length should not exceed 2×10^{-4} meters. A reduced length ensures concrete with high impermeability up to 16×10^{-4} m^2. This can be attained by entraining air into the concrete to form a system of numerous small bubbles where water can be squeezed out when frozen. Since the distance between the bubbles in the cement stone does not exceed the critical one, the destructive pressure will be higher, and the concrete will be frost-resistant.

However, non-destructive methods for testing air entrainment into concrete or cement stone are required. Non-destructive direct methods are used to measure the tensile strength of the glued steel disc separation, or partial separation of the product edges. The most interesting non-destructive indirect methods are ultrasound examination, impact excitation, and rebound and plastic deformation. In practice, these testing methods lack accuracy and mobility [2–5].

The phenomenon of mechanoelectric transformations in heterogeneous dielectric materials, including acoustic-electrical transformations, can be used to test the saturation of concrete or cement stone with air inclusions [6–14]. The principle of the proposed method lies in the fact that the research object is subjected to mechanical impact, and acoustic waves appear in the sample, which propagate along the sample. As a result of the deformation of the piezo-inclusions and double electrical layers in the concrete sample by acoustic waves, an electromagnetic response arises. Previous performed studies analyzed the main mechanisms of mechanoelectric transformations in heterogeneous dielectric structures. As a result, relationships were revealed between the parameters of the electromagnetic signal arising during quasi-elastic impact excitation of materials and their porosity, strength of the contact between components in composite materials, stress-strain state, imperfection and strength, which indicates the potential of mechanoelectric transformations used to test the defectiveness and strength of engineering structures.

Methods and materials

The studies were conducted using a laboratory complex for recording the electromagnetic response of heterogeneous materials under acoustic deterministic impact. The block diagram of the complex is shown in Figure 1.



1 — sample, 2 — clamps, 3 — measuring electrode, 4 — compensation electrode,5 — ball, 6 — substrate, 7 — spring, 8 — differential amplifier,9 — data input-output board, 10- computer, 11 — power supply

Figure 1. Block diagram of the laboratory complex for recording the electromagnetic response of heterogeneous materials under deterministic acoustic impact

Sample1 was fixed between clamps 2; metal substrate 6 was placed on the sample surface at the impact point, which was in acoustic contact with the sample through a thin layer of mineral oil. Pulsed mechanical excitation of the samples was initiated with metal ball 5 using spring-loaded device 7. The impact energy was measured with respect to the speed of the ball's flight between two optical pairs of LEDs and PDs installed at a certain distance in clamp 2 with a flying hole. The substrate and the ball were made of steel of similar hardness. Battery 11 was used for power supply of the light and photodiodes. This excitation system enabled a point deterministic single impact. A differential transducer was used to record the EMC signal arising from pulsed acoustic excitation of the samples.

The input of electromagnetic sensor 8 consisted of two flat metal plates 3 and 4. Plate 3 (measuring) was placed at a distance of $10^{–3}$ meters from the sample surface, and plate4 (compensation) was installed at a distance of $2 \times 10^{–2}$ meters from the sample. The measuring plate received both a useful signal and the signal of remote electromagnetic interference. Since the compensation plate is placed at the distance from the source of the useful signal and received only distant electromagnetic interference, the level of distant interference at the differential sensor output significantly decreased, and the signal-to-noise ratio increased. The signals from the differential electromagnetic sensor were fed to the inputs of the preamplifiers and were recorded using multifunctional input-output board 9 to digitize the time realization of the electrical signal and perform fast Fourier transform. Computer 10 was used to record the results of EMC measurements and the spectrum.

The dimensions of the samples made from cement-sand mixture were $(50x50x100)\times10^{–9}$ m^3. An external deterministic acoustic pulse was excited by the ball impact towards the greater plane in the center. During the tests, smaller faces of the samples were placed in the clamps, and the impact device was fixed in the cell using special clamps. In this experimental geometry, attenuation of acoustic waves formed in the sample upon its impact excitation was determined by the characteristics of the sample only.

Results and discussion

In order to search for possible criteria to assess the dynamics of changes in imperfection, the nature of changes in patterns of mechanoelectric transformations was analyzed on physical models with artificial defects. Testing was performed on models with internal air cavities. To create internal air cavities, air-filled polyethylene balls with a diameter of 10^{-2} meters were used. The model samples were made from cement-sand mixture containing 1, 5, 20 and 50 air inclusions. Defects of this type simulate internal air cavities that can arise when preparing cement-sand mixture. In the experiment, they act as scattering centers for acoustic waves formed in the sample upon excitation by the ball impact. However, in contrast to real cavities, these models exhibit a polyethylene layer at the interface of the cement-sand matrix, which should form double electric layers during cement structure formation [9]. These samples were used to measure electromagnetic signals and their amplitude-frequency parameters at equal pulsed acoustic excitation. Figure 2 shows previously measured and re-obtained spectral characteristics of electromagnetic signals for model samples with a different number of air cavities. As can be seen, a slight increase in the number of air cavities leads to an insignificantly increased value of the main spectral maximum at a frequency of about 11 kHz, followed by its decreased amplitude and increased number of air inclusions.

In addition, the EMC spectrum is found to change as well. Due to the fact that air inclusions are located at different distances from the acoustic excitation source during model sample fabrication, additional spectral bands appear in the exciting acoustic pulse as a result of reflection from the surfaces of air inclusions in accordance with the laws of linear acoustics [15]. Acoustic-electrical transformations cause additional EMC spectrum ranges at the interface of inclusions. The initial increase in the amplitude of maximum is due increased non-overlapped electrical double layers, which does not compensate for their charge state. Further increase in the number of air inclusions causes strong attenuation of the acoustic pulse, compensation of charges on the walls of neighboring inclusions and, consequently, decrease in the EMS amplitude due to acoustic-electrical transformations. In addition, there is a steady shift of the EMS spectrum to the low-frequency region.

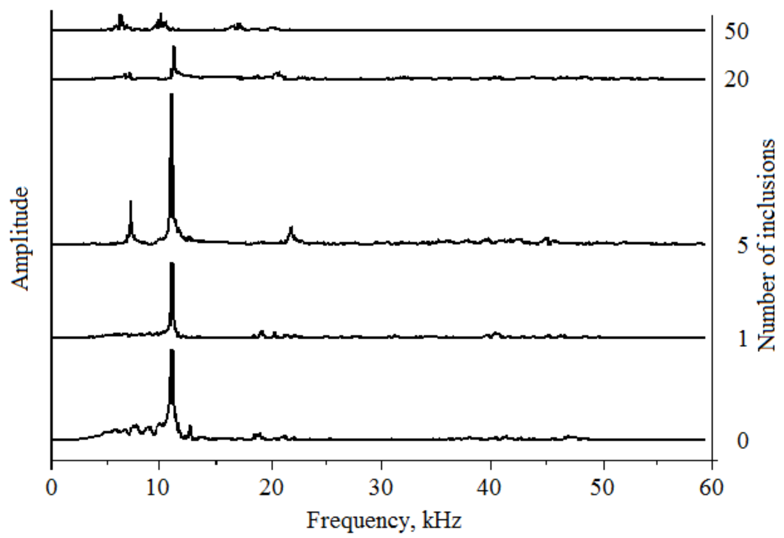


Figure 2. Changes in spectral characteristics of the electromagnetic signal caused by the concentration of internal air cavities

Conclusion

The purpose of the research presented in this paper is to study the possibility of testing the air inclusions saturation in cement-sand products using the phenomenon of acoustic-electrical transformations in heterogeneous dielectric materials. Acoustic-electric transformation is a consequence of the interaction of an acoustic wave caused by mechanical impact on the test object with piezoelectric inclusions and double electric layers in the heterogeneous dielectric material. For the purpose of the research, cement-sand samples with different concentrations of air inclusions were made and electro-magnetic responses were measured.

The study of the parameters of electromagnetic signals during deterministic acoustic excitation of model samples made from cement-sand mixture with a varying number of air inclusions showed that an increased number of air inclusions change both the amplitude of the spectral components and the EMS spectrum compared with defect-free samples. In this case, the average weight of the EMS spectrum changes towards lower frequencies. This frequency shift indicates the concentration of defects in the form of air inclusions in samples made from cement-sand mixture and can be used to test concrete products for air inclusions and determine the frost resistance of products.

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Сыртқы детерминирленген акустикалық әсер ету кезінде ауа қуыстарынан ақаулары бар модельдік диэлектрлік үлгілердің электромагниттік реакция параметрлерінің өзгеруі

Мақалада гетерогенді диэлектрлік материалдардағы акустикалық-электрлік қайта құру құбылысын қолдана отырып, цемент-құм қоспасынан жасалған үлгілердің ауа қосылыстарымен қанықтылығын сынау мүмкіндігі қарастырылды. Эксперимент әдісі, оның ішінде сыртқы акустикалық қозу және осындай әсерге электромагниттік реакцияны контактісіз тіркеу ұсынылған. Шариктің соққысымен үлгілердің детерминирленген акустикалық қозуы және энергияны эксперименттік анықтау әдістері және полиэтилен қабығындағы ауа қуыстарының әр түрлі санын қамтитын модельдік үлгілердің өлшемдері мен құрамы сипатталған. Үлгілердің акустикалық қозу бағытын және дабыл мен сыртқы электромагниттік шудың арақатынасының максималды мәнін қамтамасыз ететін электромагниттік дабылдардың қабылдау тақталарының орналасуын көрсете отырып, эксперименттік зерттеулердің жүргізу геометриясы көрсетілген. Ақаусыз үлгімен салыстырғанда, олардағы ауа қуыстарының саны артқан кезде спектрлік компоненттердің амплитудасы да, электромагниттік дабылдар спектрі де өзгеретіні көрсетілген. Осы жағдайда ЭМД спектрінің орташа салмағы төменгі жиілік аймағына өзгереді. Бұл жиіліктің жылжуы цемент-құм қоспасының үлгілеріндегі ауа қуыстары түріндегі ақаулардың концентрациясын тиімді көрсетеді және бетон өнімдерін ауа қосылыстарының болуына сынау кезінде қолдануға болады және сәйкесінше өнімдердің аязға төзімділігін анықтауға мүмкіндік береді. Мақалада келтірілген зерттеу нәтижелері ауа қуыстары түріндегі ақаулардың концентрациясының өзгеруі электромагниттік реакцияның сынақ спектрлік компоненттерінің ығысуымен жақсы бақыланатынын көрсетті.

Кілт сөздер: акустикалық-электрлік түрлендірулер, акустикалық қозу, электромагниттік реакция, амплитудалық-жиіліктік сипаттама, диэлектрлік құрылымдар, цемент-құм ерітіндісі, ақау, қос электр қабаты.

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Изменения параметров электромагнитного отклика модельных диэлектрических образцов с дефектами из воздушных полостей при внешнем детерминированном акустическом воздействии

В статье обсуждена возможность тестирования насыщенности воздушными включениями образцов из цементно-песчаной смеси, используя явление акустико-электрических преобразований в гетерогенных диэлектрических материалах. Представлена методика проведения эксперимента, включающая контактное внешнее акустическое возбуждение и бесконтактную регистрацию электромагнитного отклика на такое воздействие. Описаны способы детерминированного акустического возбуждения образцов ударом шарика и экспериментального определения энергии, а также размеры и состав модельных образцов, включающих различное количество воздушных полостей в полиэтиленовой оболочке. Показана геометрия проведения экспериментальных исследований с указанием направления акустического возбуждения образцов и расположения принимающих пластин электромагнитных сигналов, обеспечивающих максимальное значение соотношения сигнала и внешнего электромагнитного шума. Показано, что, по сравнению с бездефектным образцом, при увеличении количества воздушных полостей в них изменяется как амплитуда спектральных составляющих, так и спектр электромагнитных сигналов. При этом средний вес спектра ЭМС смещается в область более низких частот, которая эффективно отображает концентрацию дефектов в виде воздушных полостей в образцах цементно-песчаной смеси и может быть применена при тестировании бетонных изделий на присутствие воздушных включений, и, соответственно, позволит определить морозостойкость изделий. Результаты проведенных исследований показали, что изменение концентрации дефектов в виде воздушных полостей наилучшим образом отслеживается смещением тестовых спектральных составляющих электромагнитного отклика.

Ключевые слова: акустико-электрические преобразования, акустическое возбуждение, электромагнитный отклик, амплитудно-частотная характеристика, диэлектрические структуры, цементно-песчанный раствор, дефект, двойной электрический слой.

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