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Acoustic and electromagnetic activity in impact destruction of the surface of dry and humid cement stone

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The energy yield of the acoustic and electromagnetic emissions (AE and EME, respectively) induced by the microcracking and distortion of the structure of cement stone CK M400 under a localized impact was evaluated. The experiments were conducted with samples both with dry and wet surfaces. The impact induced sweeps of AE and EME were associated with various processes of the material transformation, as follows the microplastic transformation of a material; the piezoeffect; the shift of double electric layers between grain boundaries and binder; the same, that is concerns the internal surface of natural (technological) microcavities in a cement stone; the static drain and annihilation of charges from collapsed grain walls following the passage of the shock wave.

Keywords: cement stone, surface, impact damage, acoustic emission, electromagnetic emissoion.

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1. Introduction

The surface of a construction cement rock (CR) in natural conditions is impacted by variable seasonal values of humidity and temperatures [1], which inevitably affect their mechanical properties. These parameters are directly related to each other, since the content of liquid water in CR surface layer directly depends on the temperature and hygroscopic parameters of the air. In this study, the experimental conditions were relevant for the use of concrete structures in a temperate continental close to marine climate in summer season [2].

When studying the nature of a mechanically induced degradation of CR structure at the microscopic level, emission methods are widely used: acoustics [3–6] and electromagnetic radiation [7–11]. Acoustic emission (AE) is used both to monitor the accumulation of cracks in order to assess the structural stability of construction sites, and to determine the impact strength of CR specimens by comparative analysis of the products' composition and properties [3]

Electromagnetic emission (EME) is mainly used in studies of the fracture mechanism as an indicator of various processes of transformation of the material structure under dynamic load. It is well known [8–15] that several EME generation mechanisms may occur under shock load on CR, including:

(A) electrical response to the impact on CR associated with the piezoelectric effect in quartz inclusions [8,10];

(B) occurrence of EME when a shock wave displaces double electric layers located at the boundaries of grains and filler [9,11,12];

(C) motion of charges in the CR pores when impacted by the shock wave [13];

(D) after the passage of a shock wave, EME occurs during the annihilation of induced opposite charges on the collapsing walls of microcracks [14,15].

In this study, the simultaneous registration of AE and EME was used to observe the generation and accumulation of microcracks under a localized impact on the dry or wet surface of CR specimens.

2. Specimens and equipment

CC M400 specimens were used as part of two groups prepared in various hygrometric conditions and air temperatures, which affect the nature of surface damage during impact. One of the groups, where the specimens surface may be considered conditionally wet, was previously soaked for 12 h at a temperature of 20 °C in a box with an air humidity of 70 %, while the other (conditionally dry) group was heated during the same time outdoors at a temperature of 80 °C.

The specimens $10\times10\times20$ mm in size were placed on a solid metal support coated with a layer of consistent grease. The impact was carried out by a pointed die made of hardened steel, on which a weight of 100 g dropped down from a height of 70 cm. Upon impact, a material damage occurred on the specimen surface in a spot with a diameter of $1-2\,\text{mm}^2$ with a well-reproducible morphology.

The system of AE registration was started at the moment when the weight touched the pointed die. PZT high-sensitivity ceramic piezoelectric transducer registered the AE time scans within $80-600$ kHz induced by microcracking in the CR material. Maximal EME signal was detected in 1–20 kHz and was accepted by Herz dipole.

Emission activity of both types was registered during 4 ms with time resolution of 40 ns. EME and AE signals were received at the input of the analog-to-digital converter ACK-3106 and in digital form were stored in a computer.

3. Results and discussion

3.1. Dry specimen

Figure 1 shows the AE and EME signal scans recorded during impact damage to the surface of the heat-treated specimen (drying).

AE time scan (Figure 1, *a*) includes two activity periods: sound emission ~ 2 ms long and further surge of another more powerful signal during ~ 1 ms. The initial period — the surge in AE output is explained by the destruction of the partitions between the pores due to the absence of plastic deformation in the dry material. The depletion of „weak points" is clearly manifested in a decrease in AE intensity after ~ 2 ms, after which the degradation of the material moves to another level — critical deformation is achieved, leading to the appearance of larger cracks with massive displacement of the filler grains and, accordingly, the second period of sound generation with a duration of ~ 1 ms, after which sporadic pulses of AE continue for some time.

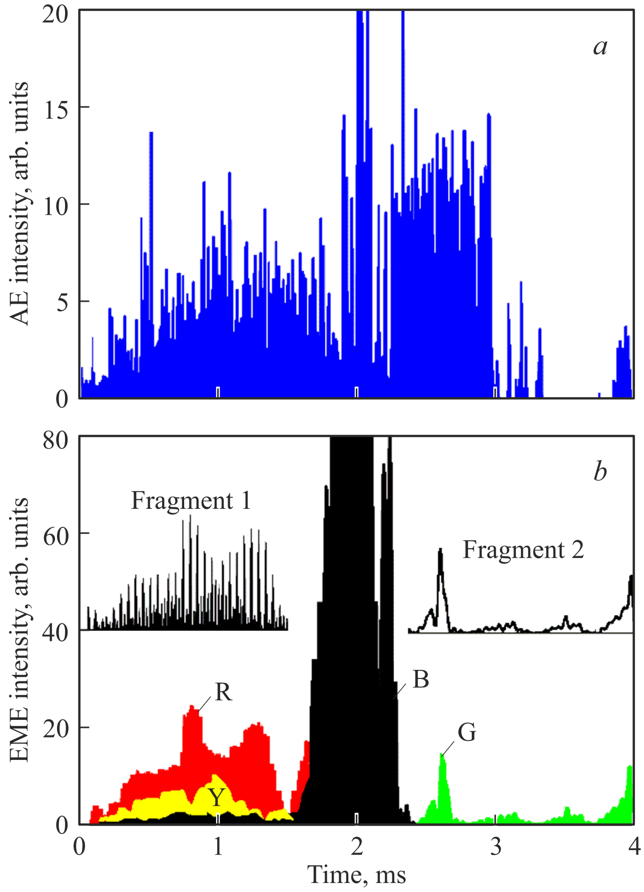

Figure 1. *a* — AE time scans excited by crack formation and *b* — shaded EME scans generated by the piezoelectric effect (black), mixing of double layers of charges (red), charge wandering in pores (yellow) and charge annihilation during crack relaxation (green) — for the dry specimen. The original fragments of the scans explain the identification of EME sources.

The EME time scan (Figure 1, *b*) has a more complex structure, including 4 independent components representing the mechanisms of occurrence of electromagnetic signals mentioned above (A–D). The most intense emission should be attributed to the piezoelectric effect (curve B in the Figure), which is insignificant at the stage of destruction of the pore walls (up to about 1 ms), but when a critical deformation is reached, it skyrockets to a peak value and then declines rapidly.

Along with the electrical signal caused by the piezoelectric effect, two EME scans (R, Y) with different generation frequencies (Fragment 1) occur under the action of a compression shock wave. We explain the lower frequency scan (R) by the occurrence of EME when a shock wave displaces double electric layers located at the boundaries of grains and filler, and the higher frequency scan (Y) — by the motion of charges in the fine pores.

Finally, when the shock wave goes away it causes „collapse" of cracks with the flow of relaxing pairs of charges (curve G, Fragment 2).

3.2. Wet specimen

Figure 2 shows the time scans of AE and EME signals excited by the passage of a shock wave in a specimen with its surface moisturized by exposure in a box filled with humid air. AE generation (Figure 2, *a*) is not observed until approximately 1.5 ms. The reason for the absence of an acoustic signal is the high microplasticity of the wet surface, which prevents the appearance of cracks. As the limiting deformation of the structure approaches, an AE signal appears, which quickly reaches approximately the same intensity as when hitting a „dry" specimen, and the final stage of the scan is identical to that shown in Figure, *a*.

EME activity in the wet specimen in terms of quality is equivalent to that for the dry specimen (Figure 2, *b*). Yet, unlike the damaged dry specimen, in the wet specimen, the interaction of double electric layers between grains and filler (curve R in the figure) is observed not only at the stage of microplastic flow, but also at the final stage of relaxation of impact-induced cracks. This result can be explained by the greater mobility of CR components in wet material.

4. Conclusion

In this study, though a complex procedure of using acoustic and electromagnetic emissions the main processes of evolution of the structure of CR, specimens dry or moistened surface layer during a localized impact were

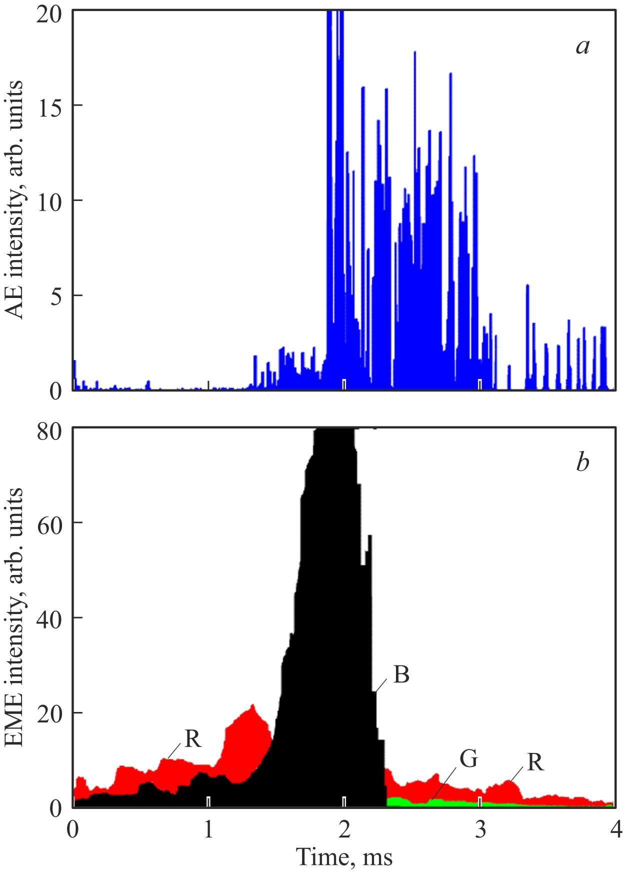

Figure 2. Same for the wet specimen. See the scans contours in Figure 1.

observed. The AE method shows the role of moisture-induced microplasticity during the initial impact from the drop weight, which prevents the destruction of structural bonds of the material. However, the massive accumulation of cracks after depletion of the plastic flow was, in fact, identical in time and intensity in dry and wet specimens.

When EME method was used, either simultaneous or sequential activity of all the main processes causing an electrical response under mechanical impact on CR was observed:
(a) piezoelectric effect in the quartz inclusions; (b) displacement of electric layers located at the boundaries of grains and filler due to the action of elastic wave; (c) motion of charges in the CR pores when impacted by the shock wave; (d) annihilation of induced opposite charges on the collapsing walls of microcracks after the shock wave has passed.

A repeated specimens drying and humidification cycle showed reproducibility of the mechanical response characteristic of the brittle or plastic surface structure of CR, respectively.

Conflict of interest

The authors declare no conflict of interest.

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