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Energy release produced by the accumulation of microcracks in impact damaged heated cement stone

© A.G. Kadomtsev, I.P. Shcherbakov, A.E. Chmel¶

Ioffe Institute,
St. Petersburg, Russia
¶ E-mail: chmel@mail.ioffe.ru

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The acoustic emission (AE) method was employed to observe the generation and accumulation of microcracks when locally hitting the surface of a heated cement stone CK M400 prepared with the aging. The experiments were carried out at temperatures of 20 °C, 200 °C and 400 °C. The last of these temperatures is ultimate for recovery of the mechanical properties of cement stone after a cycle of heating. The AE sweep amplitudes were analyzed and matched with the progressive processes of material transformation; those are the plastic deformation, fracture of interpore walls by heated vapor, accumulation of microcracks when exceeding the impact strength of the cement stone.

Keywords: cement stone, impact damage, acoustic emission, temperature effect.

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1. Introduction

Modern cement strength studies take into account only static characteristics that do not change rapidly over time [1,2]. However, vibration and even single impact loads of cement rock (CR) can lead to cracks formation. The impact resistance of concrete plummets with the temperature rise and when heated above 400 °C, concrete begins to loose its strength drastically and plastic deformations start growing [3] with a deviation from the nominal technical characteristics [4].

At natural climatic temperature, elastic deformations occur in the CR because of mechanical impact, which, when the elastic limit is reached, results in microcracking [5] and, under some sufficient load, in macroscopic degradation of the material structure. In the pores of concrete heated above the water boiling point, there is an additional effect: the vapor pressure rises to a critical limit and the pores of the walls start to rupture — thus, the micro-cracks are formed.

The conventional non-destructive method of detecting microcrack formation in CR is the method of acoustic emission (AE) [6–8], and in recent years new experimental techniques for its implementation have been on the rise [9–12]. In the present study, the method of AE was used to observe the generation and accumulation of microcracks under a combination of heating and localized impact on the surface of CR at temperatures 20 °C, 200 °C and 400 °C.

2. Specimens and equipment

The specimens of CR $10\times10\times40$ 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. The impact experiment was performed 3 times (each time on an undamaged surface at a distance of 8−10 mm from each other) at each temperature of the specimen. Upon impact, a localized material damage occurred on the sample surface in a spot with a diameter of $\sim$ 1 mm with a well-reproducible morphology.

The system of AE registration was started at the moment when the weight touched the firing pin. PZT high-sensitivity ceramic piezoelectric transducer installed on a side surface of the sample registered the time scans within 80−900 kHz of AE induced by microcracking in the CR material. AE generation was registered during 4 ms with time resolution of 40 ns. AE signals were coming to analog-digital converter ASK-3106 input and were saved in digital form on PC.

3. Results and discussion

Figures 1−3 shows time sweeps of shock-induced acoustic signals. The squares of the amplitude A^2 are proportional to the released energy ($E \propto A^2$). The time was counted from the moment the firing pin touched the specimen surface. At room temperature (Figure 1, a), AE activity in the first $\sim$ 1.8 ms was not registered, since microplastic deformations occur in the surface layer of concrete, which precede the appearance of cracks. When the plastic flow is exhausted, microcracks appear, stimulating AE generation for about 2 ms and decaying to 4 ms. Accordingly, the energy output of AE pulses (Figure 1, b) was recorded only after reaching the critical deformation of CR. With two repeated impacts, the emission pattern was reproduced by (not shown).

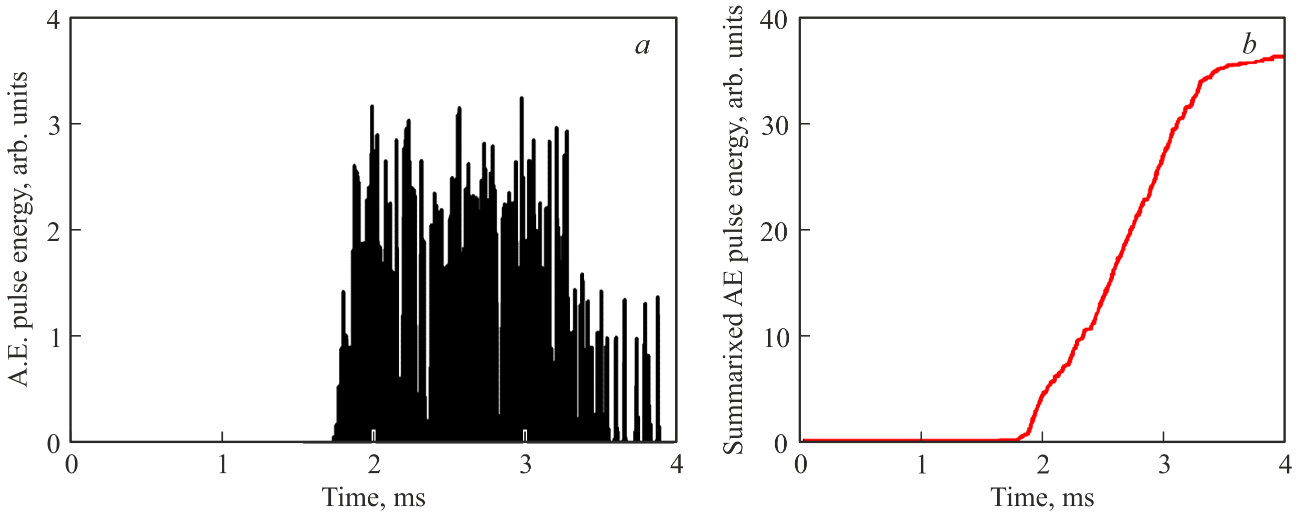

Figure 1. AE pulses sweep (a) and pulse energies accumulation curve (b) at a specimen temperature of 20 °C.

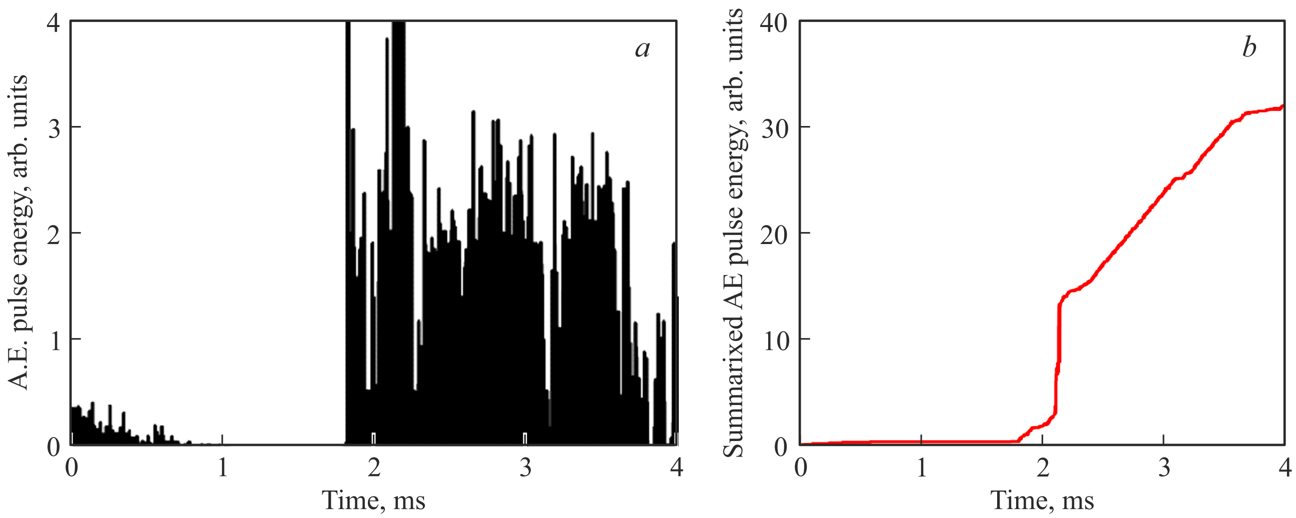

Figure 2. AE pulses sweep (a) and pulse energies accumulation curve (b) at a specimen temperature of 200 °C.

At the specimen temperature 200 °C (Figure 2, a), impact on the surface caused a slight emission spike associated with the destruction of the partitions between the pores due to increased vapor pressure. In this case, there was some accumulation of AE pulse energy during ~ 1 ms, that had been released before the critical deformation was reached with the formation of cracks (Figure 2, b). With successive impacts on CR heated to 200 °C, the AE emission pattern was also reproducible.

Finally, at a temperature of 400 °C (Figure 3, a), a weak AE signal associated with the pores aggregation in the heated specimen after the 1st impact continued until the mass release of microcracks, whereas at 2nd (Figure 3, c) and, in particular, at 3rd (Figure 3, d) repeated impacts the AE generation during the deformation stage skyrocketed. This indicates the effective propagation of impact waves in the specimen volume on a scale of several millimeters at a temperature of 400 °C. Each subsequent impact weakened the resistance to deformation of the CR structure in the area closest to the localization of the fracture site.

4. Conclusion

The application of the acoustic emission method to analyze the structural degradation of CR under a combination of impact load and heating to „critical" temperature 400 °C made it possible to differentiate the processes separated in time: elastic plastic deformation, destruction of pore walls and accumulation of microcracks during global destruction of the structure when the impact strength of the material is exceeded. For CR at 400 °C, an increase in the total energy of microcrack release during the pore walls destruction upon repeated impact on the specimens was demonstrated,

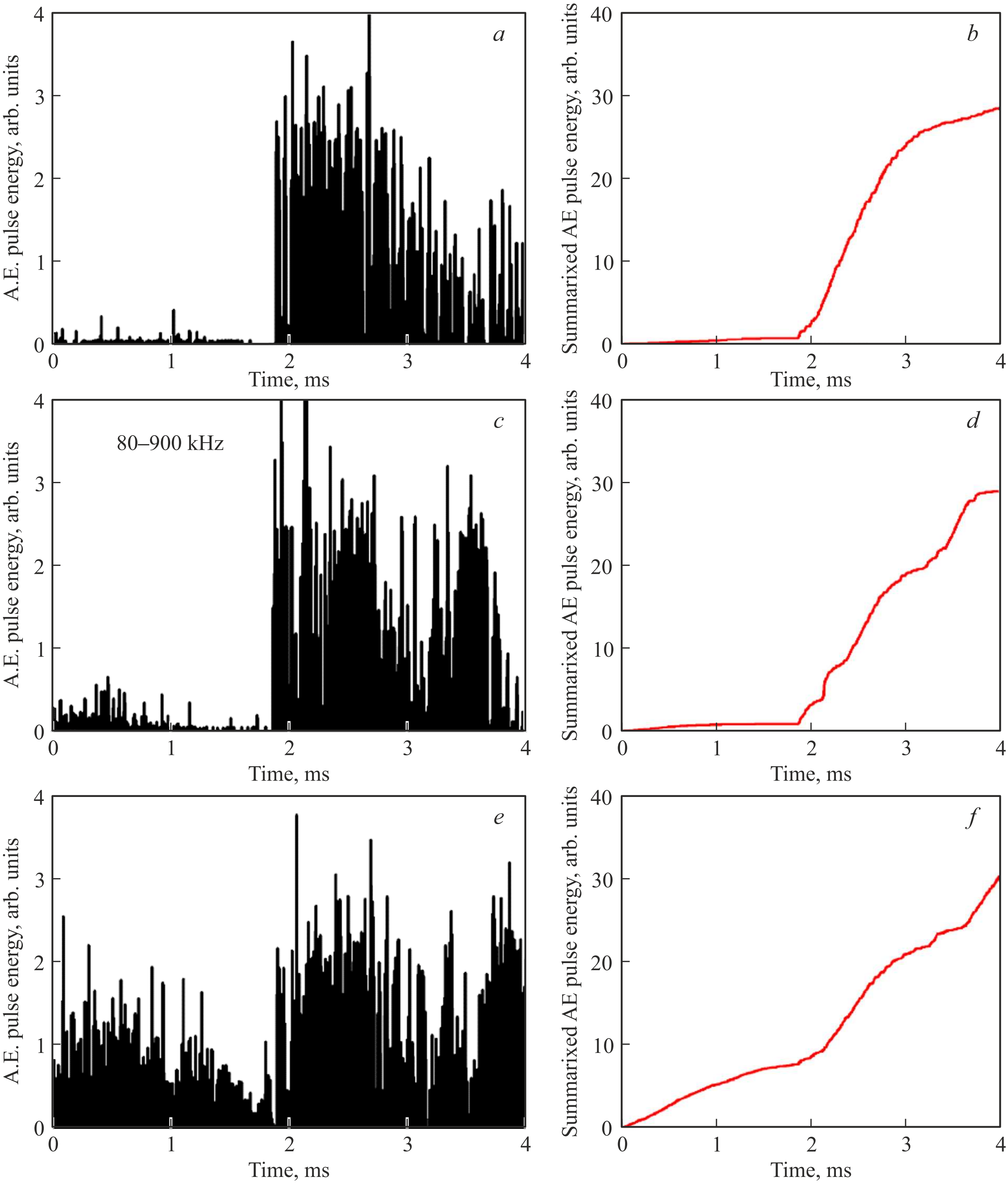

Figure 3. AE pulses sweeps at the temperature of specimen 20 °C after the first (*a*), second (*b*) and third (*c*) impacts and pulse energies accumulation curves of the first (*d*), second (*e*) and third (*f*) impacts.

i. e., existence of memory of the previous decrease in the continuity of the material was proved.

Conflict of interest

The authors declare that they have no conflict of interest.

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