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Random and cooperative accumulation of intra- and intergranular defects in granite subject to high-temperature impact fracture

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Abstract

Acoustic emission (AE) from laboratory samples of coarse-grained granite hit by a dropped weight at temperatures from 20 to 500 ºC is recorded within a frequency range of 80 kHz–4 MHz. The time series of AE signals bear information on the size of primary defects, since the AE frequency is proportional to the growth rate of microcracks and inversely proportional to their lengths. According to AE data obtained in this study, impact fracture of granite produces cracks at grain boundaries at temperatures below 400 ºC and additional defects inside grains at 400 ºC and higher. The reason is that overheated water–vapor inclusions increase pressure in the grain interior, which affects the mechanic behavior of granite.

Keywords: granite; quartz; impact fracture; acoustic emission; temperature dependence

Introduction

Natural granitic rocks have various engineering applications, including geological disposal of radioactive wastes, underground coal gasification, and construction of tunnels or other utilities. Engineering structures of this kind may be subject to high temperatures reaching hundreds of degrees Celsius in the case of fire emergency (Ozguven and Ozcelik, 2014; Saiang, 2011) or to deformation by seismic or mine shocks, which poses high risks. Therefore, their thermal and mechanic stability is of crucial importance. Thermal and mechanical loads are frequently modeled in laboratory to study the behavior of rock samples associated with nucleation and growth of microscopic defects (Chen and Wang, 1980; Fredrich and Wong, 1986; Keshavarz et al., 2010; Menéndez et al., 1999; Meredith and Atkinson, 1985; Smirnov et al., 1995; Wang et al., 1989).

Incipient and propagating fracture generates elastic waves within acoustic frequencies from 10^4 to 10^7 Hz, which makes acoustic emission (AE) an efficient tool for monitoring the accumulation of defects in rocks, including granite (Lockner et al., 1992; Vinogradov, 1964). The time series of acoustic signals emitted from deforming samples bear information on the energy released during the formation of a single defect (crack) and on the defect size. AE intensity (square amplitude, A^2) is proportional to the released energy, which allows tracing the accumulation of defects. The respective approach was used to study crack propagation in granites under impact fracture at high temperatures (Shcherbakov and Chmel, 2014). On the other hand, the frequency of the generated acoustic signals is inversely proportional to the size of cracks and this information can be thus retrieved from AE spectra. In this study we analyze acoustic emission responses of heated granite samples to impact fracture, in order to estimate the size of microcracks and their location inside or between mineral grains. The results are checked against tests with samples of heated synthetic monolithic α-quartz (the strongest material in granite) in order to gain more insights into the origin of defects in quartz grains.

Methods and instruments

The laboratory tests were performed on samples of coarse (grain size of 3–5 mm) Rapakivi granite from Finland containing about 30 and 40% quartz and feldspar, respectively, as well as on hydrothermally synthesized crystalline quartz. The samples were cut out as $15 \times 20 \times 20$ mm blocks with polished faces. They were hit locally by a 100 g weight dropped from a height of 10 cm on a steel striker on the sample surface where the impacts produced irregular pits of about 0.5–~1.0 mm deep and 0.4–3 mm in diameter.

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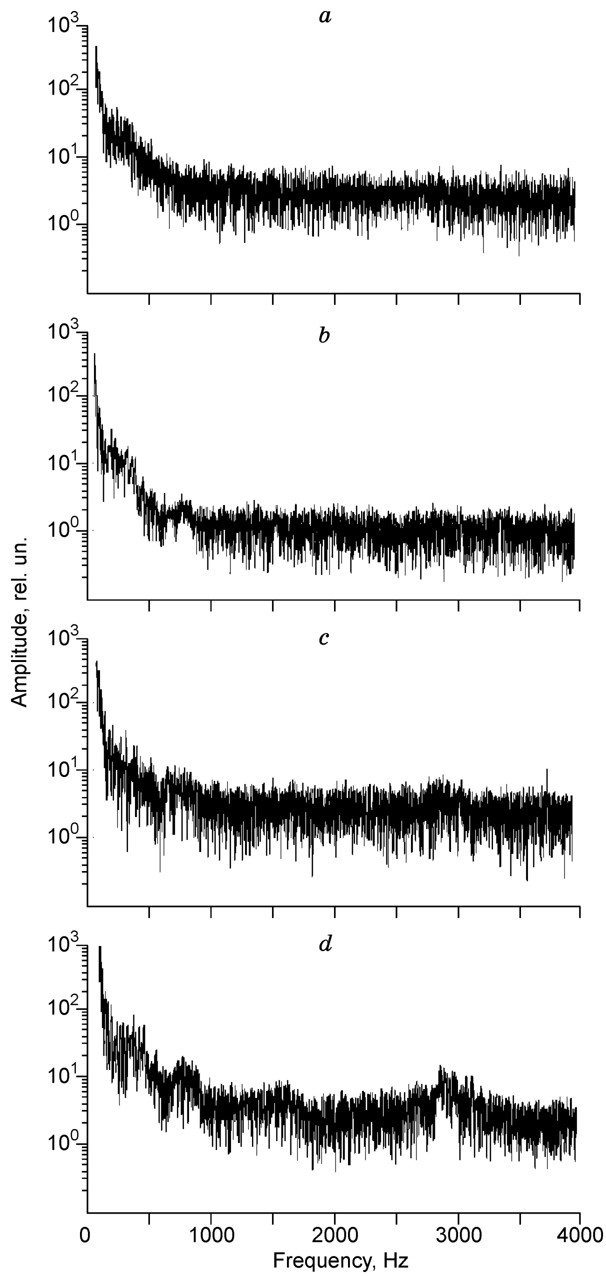

Fig. 1. Frequency dependence of AE intensity at different temperatures of samples: 20 ºC (*a*), 200 ºC (*b*), 400 ºC (*c*), 500 ºC (*d*).

Acoustic emission was monitored by a highly sensitive broadband transducer made from $Pb(Zr_xTi_{1-x})O_3$ ceramics fixed on the flat lateral surface of the pointed striker. The sensor placed on the striker instead of the hot sample surface was thus insulated, which reduced the background AE from thermally-induced cracks not related to the external mechanic loading.

Voltage values at the ADC output were saved to the PC memory. The AE signals of 4 MHz highest frequency were low-bandpass filtered at 80 kHz to eliminate the signals of primary elastic waves and parasitic oscillations of the sample and the test system. The tests were performed at temperatures of samples, placed on a base heated from 20 to 500 ºC, measured by a remote-sensing *CONDTROL IR-T4* infrared thermometer.

Results and discussion

The frequency-dependent AE intensity at different temperatures (Fig. 1) shows several peaks appearing with temperature increase: a single AE peak at ~ 270 kHz at room temperature; another peak at ~ 800 kHz upon heating to 200 ºC; one more small ~ 2.9 MHz peak at 400 ºC, which becomes predominant at 500 ºC and coexists with a lower peak at ~1.5 MHz.