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Advances in laboratory acoustic emission study

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Acoustic emission (AE) is an elastic wave radiated by rapid cracking in solids. As a technology of nondestructive inspection, AE has a long history of development and has been applied in numerous areas including material sciences, medical sciences and engineering fields. In stressed rocks, macroscopic fracturing is preceded by a very complex pervasive evolution of some pre-failure damage. Thus, studies focusing on both fracture dynamics and pre-failure damage are a subject of interest and can be inferred from AE statistics as the number of AE events is proportional to the number of growing cracks, and the AE amplitudes are proportional to the length of crack growth increments in the rock. In Earth science, since the similarity in size distribution of earthquakes and acoustic emissions (AE) was found in the 1960s, many laboratory studies have been motivated by the need to provide tools for the prediction of mining failures and natural earthquakes. This report aims to draw an outline of laboratory AE studies in the last 50 years, which have addressed seismological problems, with special focuses on some key issues associated with fault nucleation and growth in brittle rocks.

The AE technique, which monitors the spatiotemporal distribution of AE events, is applied to the analysis of the micro-cracking activity inside the sample space, and it can be performed under an artificially controlled pressure, which is very important for the simulation of underground conditions. During the last five decades, a great number of studies were done following developments in experimental technology, AE monitoring technology, and data processing methodology. Fifty years ago, only the hitting time of an AE could be recorded with a single sensor or a small number of sensors. The rock fracture test was performed under simple loading conditions. Later, the number of sensors that could be used in a study increased and thus allowed the determination of the hypocentre of an AE. Developments in transient memory technique in the 1970s through to the 1980s lead to the ability to make a digital multichannel recording of the full waveform of an AE. Hypocentre location was improved greatly by the use of more precise arrival times obtained through waveform analysis. In addition, it became possible to determine the mode of fracture, i.e., the focal mechanism solution of an AE source. In the present day, AE are usually monitored by 16-32 sensors with digital waveform recording at up to a 200 MHz sampling rate and up to a 16 bit A/D resolution. The dead time of a recording is sufficiently short and continuous recording is possible by use of very large amounts of memory. The waveform of most events can be captured with multiple channels, even for the period of dynamic failure in which the AE rate may reach several thousand a second. Rock fracture experiments can be performed under triaxial compression conditions with controlled fluid injection and pore pressure. AE hypocentres are determined with a location error of a few mms. A focal mechanism solution can be determined for individual events or a group of events. As demonstrated by very recent studies progress in laboratory AE study, particularly studies focusing faulting nucleation, is shedding more and more light on earthquake seismology.

By summarising recent results, it can be concluded that the fault nucleation behaviour, including critical size, duration time, and AE productivity, depend on the heterogeneity of the area of weakness of the fault compared with that of the host rock. If the fault is as strong as the host rock then the fracture makes no difference and the rock remains intact. Furthermore, a homogeneous fault or rock mass appears to fracture in unpredictable ways without a consistent trend in precursory statistics, while inhomogeneous faults fracture with clear precursors related to the nature of the heterogeneity.

Keywords: Acoustic emission (AE), Pre-failure damage, Rock fracture, Earthquake, Fault nucleation, Process zone