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Potential of acoustic emissions from three point bending tests as rock failure precursors

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ABSTRACT

Development of failure in brittle materials is associated with microcracks, which release energy in the form of elastic waves called acoustic emissions. This paper presents results from acoustic emission measurements obtained during three point bending tests on Nestos marble under laboratory conditions. Acoustic emission activity was monitored using piezoelectric acoustic emission sensors, and the potential for accurate prediction of rock damage based on acoustic emission data was investigated. Damage localization was determined based on acoustic emissions generated from the critically stressed region as scattered events at stresses below and close to the strength of the material.

1. Introduction

Non-destructive testing (NDT) has gained popularity in recent years due to commonly available sensors, devices and software tools. Although the majority of such testing still occurs under laboratory conditions, the ultimate goal is a direct field application, especially in the case of underground mining. NDT, if properly applied, may be used to directly provide material property values and characteristics that can be used to determine rock mass or soil mass behavior, with a direct impact to mine design [1].

Acoustic emissions (AE) are generally defined as the high-frequency transient elastic waves originating from the sudden release of energy at localized points within a loaded material [2]. The field of AE due to compressive, tensile or other types of loads is a promising research area due to its wide application. The accurate identification of failure precursors stemming from AE is still an open research topic [3].

Rock is a typically inhomogeneous and anisotropic material that contains several natural defects in various scales such as grain boundaries, microcracks, pores and joint inclusions [4,5]. Damage induced by microcracks is an essential mechanism in many brittle rocks subjected to stresses. Applied stresses induce microcrack growth and damage is distributed uniformly throughout the sample. Finally, the microcracks coalesce and the damage is localized to a shear band, leading to strain softening and macroscopic failure [6].

Large numbers of AE signals will be generated when a rock specimen is loaded to failure. Since AE signals are generated by propagation and expansion of microcracks, each AE signal contains plenty of information of the structure change taking place inside the rock.

Nondestructive testing in which mechanical, electrical or even electromagnetic signals are emitted by rocks or rock-like materials under axial or triaxial loads has been used by several researchers worldwide in an effort to determine this behavior [7,8].

In this work, in order to overcome the experimental difficulties and the developing shear stresses in direct tension tests and Brazilian tests, respectively, a series of three point bending (TPB) tests (flexular tests) were performed on prismatic beams of Nestos marble. The TPB test is considered as one of the most popular mechanical tests and is widely used for practical and scientific reasons. It is a relatively easy experimental test and a significant amount of data can be obtained during the test. The specimens were prepared by taking into account the orientation of marble anisotropy; the long axis of the beams was oriented parallel to the plane of transverse isotropy (rift plane specimens).

AE recordings during TPB tests on Nestos marble specimens are correlated with the indirect tensile stress of the material as well as the visual damage of the specimen. In addition, the locus of crack(s) initiation is evaluated with increasing AE in an effort to determine pre-failure characteristics.

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AE signals were captured using piezoelectric transducers, which were securely mounted on each specimen and calibrated prior to each test. Data acquisition and analysis was performed using a software package by Enviroacoustics, cited in *Enviroacoustics SA. Noesis, User's manual*, 2009.

This study is concentrated on the correlation between the AE signals and the tensile strength mobilized during the TPB tests. Special attention is given to the evolution of the crack(s) initiation locus (crack localization) as determined by a 2D and 3D location software.

2. Experiments and the acoustic emissions acquisition

2.1. Material

In order to investigate the evolution of AE activity under TPB tests, specimens consisting of Nestos marble were prepared and tested.

Nestos marble is quarried by surface mines in northern Greece and mainly used as a building material. It is composed of 93.4% calcite, 6% dolomite and 0.6% quartz. Its unit weight is 2.67 g/cm^3 and its absorption coefficient by weight is 0.09%. It is white color with a few thin parallel ash-green colored veins containing locally silver areas due to the existence of dolomite [9].

2.2. Specimen preparation and experimental setup

The specimens were prepared for the TPB tests according to the specifications published by the International Society of Rock Mechanics (ISRM). All specimens were prepared by cutting prismatic beams parallel to the plane of transverse isotropy (Fig. 1) (rift plane specimens) from a single Nestos marble cube in order to avoid large variations in the quality of the stone and ensure similar fracture loads.

Fig. 2 presents the dimensions of a typical prismatic beam. The length of each specimen was $l = 200$ mm, while the span length was $l_s = 170$ mm. The cross section of each beam was 25 mm × 25 mm.

Load was applied using a 50 kN Triscan testing machine and a 50 kN load cell, with a displacement rate of 0.001 mm/s in displacement control mode. The specimens were placed in a TPB apparatus that was especially designed for this experiment (Fig. 3).

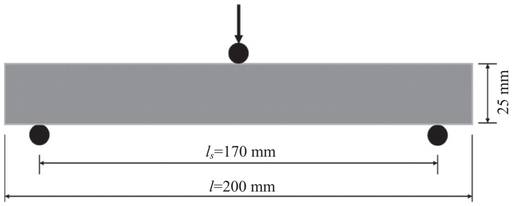

Fig. 2. Dimensions of a typical specimen subjected to TPB loading.

2.3. Description of the three point bending test

In the TPB test, a simply supported prismatic beam of rectangular cross section with span length l_s, width b and thickness h, is subjected to a concentrated and centrally applied force P (Fig. 4). Assuming that the material behaves linearly elastic, this geometry and loading ensures a linear stress state in the center plane of the specimen. According to this distribution, the expected failure mode is the splitting of the specimen in two halves across the plane of loading. For elastic materials, the maximum tensile stress ($\sigma_{\max}$) is a measure of the tensile strength [10]:

$$\sigma_{\max} = \frac{3Pl_s}{2bh^2} \tag{1}$$

where P is the applied load.

Assuming that the material fails in brittle mode after elastic loading, the maximum tensile stress at failure is a material property called bending tensile strength σ_t and is given by Eq. (2) [10].

$$\sigma_t = \frac{3P_f l_s}{2bh^2} \tag{2}$$

where P_f is the fracture load.

2.4. Monitoring of acoustic emissions

The AE activity is represented in a time series of detected signals: hits, events (single count for hits detected by different sensors into a predefined time window), amplitude (signal peak in dB) and other acoustic parameters. Interpretation of the recorded AE was performed using the advance software AE Win, cited in *Enviroacoustics SA. Noesis, User's manual*, 2009.

Acoustic emissions were detected through six miniature piezoelectric sensors (PICO sensors, 200 kHz–1 MHz, MISTRAS Group, SA) mounted on the sample's surface and recorded in an integrated multi-channel system by Physical Acoustics Corporation, cited in *Physical Acoustics Corporation, PCI-2 based AE system user's manual*, 2007. A pre-amplification of 40 dB was used in each channel and the sampling frequency of signals was 5 million samples per second. The threshold of detection was determined by switching on the loading apparatus and placing the specimen in contact with the load platens; the value determined to eliminate the background noise and provide as much information as possible was 39 dB. A hit definition time equal to 800 μs was used, with 200 μs peak definition time and 1000 μs hit lockout time. Before each test coupling of the sensors was tested using the pencil lead

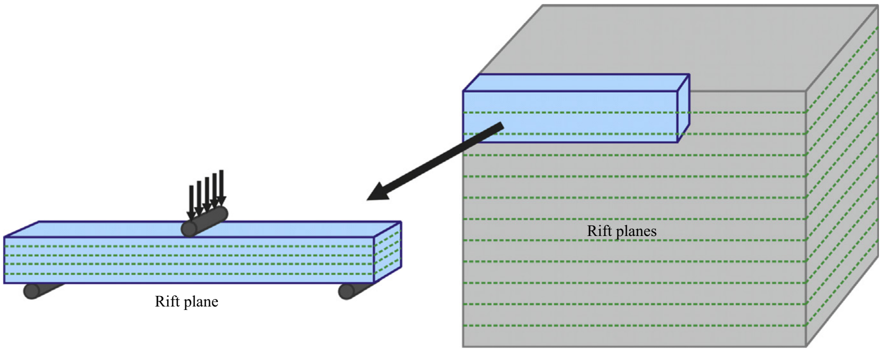

Fig. 1. Specimens were prepared by cutting prismatic beams parallel to the plane of transverse isotropy.