

The Correlation of Electric Emissions with Stress and Strain on Stressed Rock Samples

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ABSTRACT

Laboratory experiments on rock samples have shown electric signal emissions when the samples are subjected to temporal stress variation. These electric signals are attributed to the generation and propagation of microcracks that guide the sample to mechanical failure.

In this work such electric emissions will be demonstrated for marble samples subjected to stress at a rate 0.3MPa/s approximately. The emissions become intense when the relative compressional stress becomes approximately 70% of the ultimate stress while it reaches its maximum value for relative stress value 0.95. Consequently the emission diminishes. Based on the sample stress-strain diagrams the electric emissions are directly related to the deviation of the linearity in the stress- strain diagram. The emitted electric current is correlated to the deformation of the sample through the measured strain. These emissions are attributed to the movement of dislocations and cracks that cause electric polarization and consequently charge flow. The damage in the bulk of the sample increases with stress while there is a stress level beyond which damage increases rapidly as new cracks form and connect to the growing existing cracks until a failure plane is formed and the sample collapses.

KEYWORDS

Pressure Stimulated Currents, Electric current emissions, Crack opening, Marble fracture, Mechanical stress.

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1 INTRODUCTION

Laboratory investigations that show the existence of electric signal emissions during a full cycle of rock deformation have received considerable attention in recent years. These electric emissions have been attributed in the past at several potential sources like the quartz existence [Nitsan, 1977; Ogawa *et al.*, 1985; Eccles *et al.*, 2005], fluid movement causing electrokinetic effect [Eccles *et al.*, 2005; Ishido & Mizutani, 1981; Yoshida *et al.*, 1998], point defects [Varotsos & Alexopoulos, 1986] and electron emissions [Brady & Rowell, 1986; Enomoto & Hashimoto, 1990].

At the same time acoustic emissions (AE) have been studied when applying stress to rocks and it was shown that they are highly indicative of rock deformation and failure processes [Lavrov, 2005; Lockner *et al.*, 1991; Sammonds *et al.*, 1992].

When dealing with quartz free rocks with extremely low internal moisture and low porosity the piezoelectric and the electrokinetic effects are not considered as strong underlying physical mechanisms to support the existence of electric signal emissions. A model that is applicable for this case was proposed by Slifkin [Slifkin, 1993] and was further developed by [Vallianatos & Tzanis, 1999; Tzanis & Vallianatos, 2002] and explains electric signal emissions due to the dislocation and other defect movements that cause local polarization. This model is known as Moving Charged Dislocations (MCD) model.

Papers of experimental laboratory recordings and analyses of electric signals emitted under temporally varying uniaxial compressional stress upon rock samples like marble and amphibolite have been conducted [Anastasiadis *et al.*, 2004; Stavrakas *et al.*, 2004; Triantis *et al.*, 2007; Anastasiadis *et al.*, 2007a,b]. The electric current emitted during such temporal stress variation leading to a catastrophic process and to sample fracture has been rendered under the term “Pressure Stimulated Current” (PSC).

The technique applied in order to show up and record the above described signals is rendered under the term «PSC technique».

The Pressure Stimulated Currents are characterized by very low peak values (1pA up to 100pA) and they reveal from the background noise level when the applied stress on the sample leads to the non-linear deformation region (out of the limits of Hooke’s law) and specifically when the sample is led to the Crack Propagation Zone (CPZ). Intense PSC emissions are observed slightly before the fracture of the sample.

According to the MCD model the observed transient electric variation is related to the non-stationary accumulation of deformation. The expected emission of Pressure Stimulated Current (PSC), is proportional to the strain rate [Vallianatos *et al.*, 2004]. When a PSC emission $p_{sc}(t)$ is recorded during a process of a continuously increasing axial compressional stress it should obey the following law:

$$p_{sc}(t) \propto \frac{d\varepsilon(t)}{dt} \quad (1)$$

where $\varepsilon(t)$ is the temporal variation of the strain during the axial compressional stress variation $\sigma(t)$. According to the Eq. 1 the total charge Q , released during that process is given as:

$$Q(t) = \int_0^t p_{sc}(t) dt \propto \varepsilon(t) \quad (2)$$

During this work marble samples were subjected to constantly increasing compressional stress from early stress levels up to fracture. The stress rate was 0.3MPa/s. The PSC emissions were recorded

during all the experimental procedure. The emitted PSC is discussed with respect to the deformation and the applied compressional stress.

2 SAMPLES AND EXPERIMENTAL TECHNIQUE

In this section marble, which is the material under examination, is described. Rock materials and especially marble have been used in the past in constructions and therefore results concerning their strength may serve in many restoration works that are in progress as for example on the Parthenon temple of the Acropolis of Athens as well as on other civil engineering applications.

Marble is a geomaterial of known physical and chemical properties. The marble samples under examination were collected from Mt. Penteli (Dionysos) and are mainly composed of calcite (98%) and other minerals i.e. 0.5% of muscovite, 0.3% of sericite, 0.1% of chlorite, it also contains 0.2% of quartz (Kourkoulis et al. 1999). Its specific density is 2730 kg/m^3 , its apparent density is 2717 kg/m^3 and its porosity is very low, varying from 0.3% for pristine marble to 0.7% for marble that has suffered natural weathering and has been exposed to corrosive agents [Kleftakis et al., 2000].

The used samples were prismatic and the stress was applied in parallel axis to the long edge. The dimensions of the used specimens were 35mm x 35mm x 60mm and their fracture limit was 47MPa approximately.

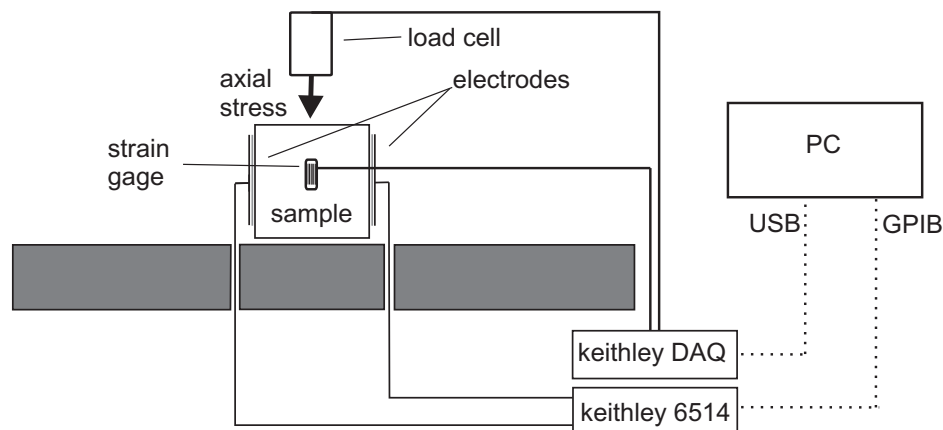


Figure 1. A schematic representation of the experimental set-up to conduct PSC experiments.

Figure 1 shows the schematic representation of the experimental PSC-techniques. The experiment was conducted in a Faraday shield to prevent from electric noise from affecting the measurements. The shield protects the mechanical parts that transfer the stress on the sample (i.e hydraulic stressing cylinder Enerpac-RC106, plates, sample underlay holder), the stress and strain sensors and the electrodes that measure the PSC.

The sample was placed on a steel anvil and thin Teflon plates were placed between the anvil and the stressing plates to provide electric insulation. The electrodes were attached to the marble sample, using conductive paste. Two gold plated electrodes were attached on the sample where the conductive paste was applied in a direction perpendicular to the axis of the applied axial compressive stress.

The stress sensor (load cell) is placed on the axis of stress and the strain sensor is placed in the free edges of the sample in a direction perpendicular to the stress (see Fig. 1).

Properly shielded Keithley cables that minimize electric noise lead through interfaces the PSC to the programmable electrometer placed outside the shield. PSC measurements were conducted using the programmable electrometer Keithley 6514. The communication of the Keithley electrometer and the PC that stored the measurements was achieved through a GPIB interface.

The stress was measured through a stress sensor ADW 15 that converts the applied stress to voltage. The strain was measured using Kyowa strain gauges attached on the Microlink-770, 120 Ω resistance bridge. The stress and the strain were directly recorded on the PC through a 8 differential channel, high sampling rate, and 500x maximum amplification, Keithley A/D converter. All the data were stored in a computer hard disk through the described interfaces at a sampling rate 3samples/s.

3 EXPERIMENTAL RESULTS – DISCUSSION

The applied compressional uniaxial stress was constantly increasing on the sample at a rate of 0.3MPa/s from very low stress levels up to fracture. Figure 2 (curve a) presents the temporal development of the emitted PSC. It becomes obvious that the PSC starts to show an excitation only after time $t=220$ s. It is significant to notice at the curve b of the same figure that time $t=220$ s corresponds to a strain value slightly higher than 0.004. This strain value corresponds to the stress-strain curve (Fig3. curve a) at the point where stress and strain are no more linearly related. It is known [Lavrov, 2005] that this value corresponds to the crack formation and propagation region, regarding the sample's mechanical behaviour. Since PSC emissions are mainly attributed to crack formation and propagation it is expected that when these mechanisms are activated they dominate the sample bulk and PSC excitation is expected to be observed.

Another significant observation is that despite the fact that the stress increases linearly the PSC values after time $t=270$ s approximately seem to grow fast following a corresponding change of the deformation. This is the point that the yielded strain changes much faster than the applied stress. In terms of cracking and damage mechanisms in general it can be stressed that this is the region where dynamic processes take place, macrocracks are created, the fracture plane is formed and the irreversible failure process initiates.

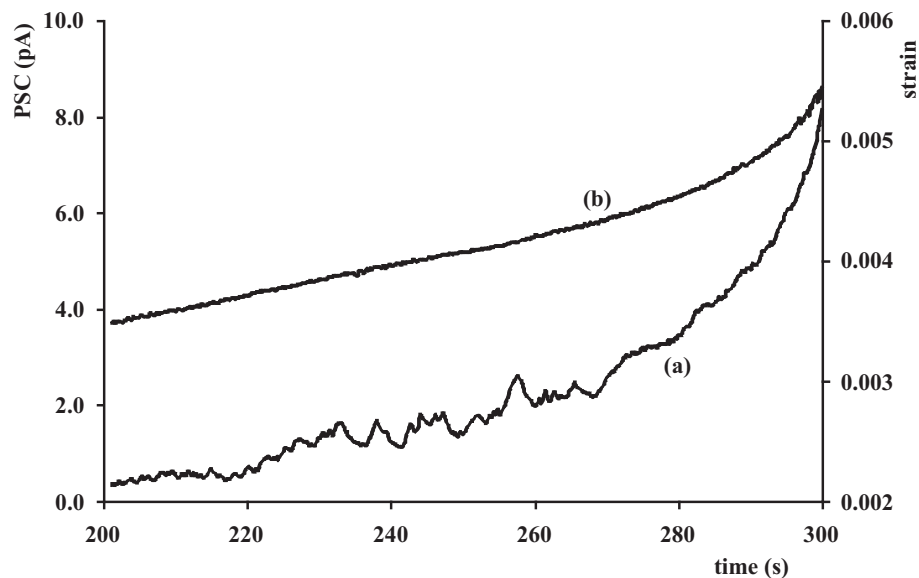


Figure 2. The temporal development of the emitted PSC (curve a) and the temporal development of the deformation while applying constantly increasing stress (curve b).

Studying the totally released charge with respect to deformation some significant results can be drawn. Figure 3, curve a, clearly shows that the stress and the strain are linearly related up to a stress value of the order of 40MPa approximately. Beyond that point the stress and the strain are no more linearly related to each other and the strain starts to grow faster than the applied stress. At a value of stress 47MPa approximately the failure of the sample occurs. Regarding the total released charge with

respect to the stress-strain curve of the marble samples it can be stressed that no significant charge is released when the stress and the strain are linearly related. For a strain value of the order of 0.004 it can be seen on the curve that the total released charge Q is of the order of 20 pC. When the stress increases further and stress and strain are no more linearly related the released charge increases linearly with the yielded strain. This process goes up to the vicinity of fracture for stress levels of the order of 46 MPa approximately which corresponds to the 98% of the ultimate compressional strength.

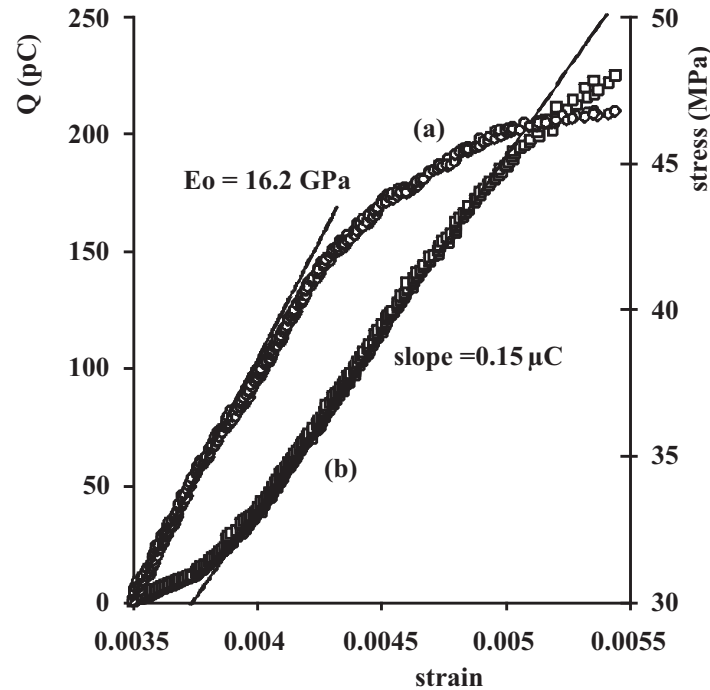


Figure 3. A representative stress strain curve of the used marble samples (curve a) in the same diagram with the totally released charge with respect to the strain (curve b).

4 CONCLUDING REMARKS

This work demonstrates that during a stressing process of marble samples the total released charge is linearly related to the deformation change in a good approximation. This linearity is valid from the point that both stress and strain are no more linearly related (see the stress-strain curve at about 60% of the ultimate compressional stress strength) up to the near fracture range (98% of the ultimate compressional stress strength of the sample).

When the released charge and the strain are no more linearly related this indicates the upcoming event of fracture.

After all these the PSC technique and specifically by the study of the totally released charge was proved to be a valuable tool in laboratory conditions that can detect the mechanical status of marble samples. The underlying mechanisms of the generation of the PSC are based on the Moving Charged Dislocation Model.

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