Pressure Stimulated Current – PSC – emitted from marble samples when subjected to stress of various rates up to fracture

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Abstract: - The change of a material structure can reasonably affect its electrical properties. Changing the thermodynamic equilibrium by applying stress on a geomaterial sample, current emission can be stimulated. This kind of emission can be detected experimentally. In the experiments described below various modes of stress change were applied. Stress was increasing with various stress rates, constants or not, until the fracture of the samples. During the experiments current emissions were studied. Results show that the stress rate influences the PSC values but the total charge released by this process does not seem to vary considerably for the various stress rates.

Key-Words: - Pressure Stimulated Current, Charge release, Stress, Rocks, Deformation, Marble, Damages, PSC.

1 Introduction

The attempt to mirror the mechanical status of geomaterials on electrical quantities has been seductive during the last thirty years. Some of these attempts have been made to study electric current and electromagnetic (EM) emissions during stress application on geomaterial samples [1-3]. This concept is documented and efforts focus on two main paths. Theoretical works have been introduced in order to model the underlying physical mechanisms that can generate transient electric and EM signals [4-9]; while concurrently several experiments have been performed to investigate in detail the characteristics of such electric emissions [10-17]. The proposed theoretical models implicate various stimulus for the currents generated after stress application on geomaterials. In years piezoelectric and electrokinetic effects have been studied theoretically [18,19] and experimentally [20-23] but the dominant theory concerns current production from crack opening process. This is best described by a summation of the underlying physical mechanisms called Moving Charged Dislocations (MCD) model [24-27].

An experimental technique has been proposed recently and concerns current emissions from geomaterials during stress application either with constant or time varying stress rate and it is known as Pressure Stimulated Current – PSC- technique [14-17].

Various types of samples have been used for the experiments performed to establish the proposed theoretical models. Some of them exhibit high quartz content favoring piezoelectric effect and others containing in their volume many connected pores implying that electrokinetic effect is present since their viscosity permits fluid transportation. Current emissions from materials exhibiting low quartz content and porosity can only be interpreted by MCD model.

In this work experimental results that connect the time-varying mechanical stress applied on marble samples to the emitted PSC are presented. Marble was used since it is a typical metamorphic geomaterial that can be characterised as quartz-free with extremely low porosity and water content, thus the influence of piezoelectric and electrokinetic effects was avoided. During the experiments stress was applied either with different but constant stress rates or with continuously decreasing stress rate up to the fracture of the samples. PSC measurements were conducted during stress application.

2 Material and experimental description.

The used samples were Pentelicon marble collected from an area near the ancient Dionyssos quarry. Pentelikon marble has a pure white colour and very good wear resistance. After its exposure to the atmosphere, a gold surface coating is created. It is mainly formed by calcite crystals dominating the 98% of its structure while the remaining are minerals like muscovite, sericite and chlorite. Its low porosity 0.4% with combination to the absorption coefficient (0.11%) and quartz (0.2%) ensure that piezoelectric and electrokinetic effect contributions to the total charge will be negligible.

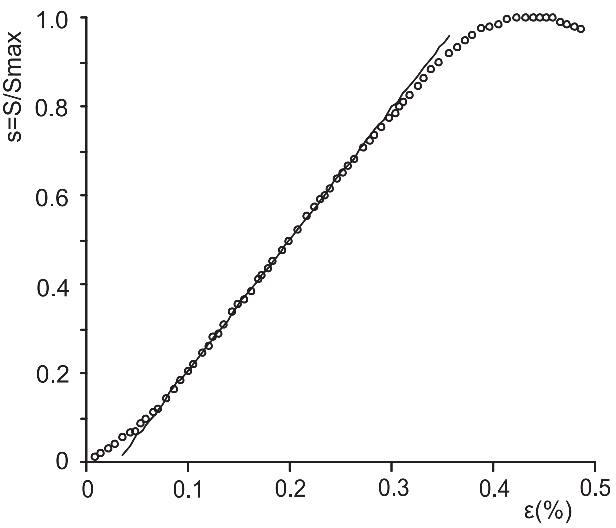

Fig. 1: Stress strain curve for marble samples on normalised stress axis.

Fig.1 shows the stress strain curve of the used marble samples. The stress is presented as normalised by the ultimate compressional strength (Smax) of the samples. For normalised stress values beyond s=0.7 approximately it becomes obvious that stress-strain relation deviates linearity. This is the point ($s \approx 0.7$) microcracking starts and consequently this is the value of the stress which implies PSC emission initiation. This process goes for normalised stress values beyond s=0.98 where fracture plane is defined [28].

Experimental setup has been detailed described in previous works and only essential details will be included here [16]. The experiment was conducted in a Faraday shield to protect the measuring system from external electric noise. The stress was applied by a loading unit (Enerpack RC-106) capable of applying a maximum force of 100kN and maximum displacement of 100 mm. The electrodes used to measure the PSC were attached in a perpendicular to the stress direction. For conducting electrical measurements a sensitive programmable electrometer (Keithley 617) with a current range from 0.1fA to 20 mA, has been used.

The experimental procedure can be described as follows: PSC measurements performed for the following samples and conditions. A marble sample with dimensions 69.6mm x 49.0mm x 149.1mm was subjected to uniaxial compressional stress with constant stress rate, 164kPa/s, and the ultimate compressional strength was 82MPa. A second sample, extracted from the same rock mass, with dimensions 69.8mm x 48.9mm x 148.8mm was subjected to constant stress rate 106kPa/s up to fracture which took place for stress value 85MPa. The rest of the samples were extracted from a second rock mass. They were of dimensions 50mm x 50mm x 60mm. One of these samples was subjected to constant stress rate 412kPa/s and the ultimate compressional strength found to be 58MPa. The last sample was initially subjected to stress rate 291kPa/s up to the stress value where s=0.6, the material is still in the elastic range where the stress and strain are linearly related, and then the stress rate varied, decreasingly, with respect to time. Finally, the sample failed for stress value 54MPa.

3 Experimental Results – Discussion

Fig. 2 shows the PSC emitted (curves, a2 and b2) during experiments with constantly increasing stress (curves, a1 and b1) respectively. Both PSC emissions initiate almost concurrently, for normalized stress values $s \approx 0.7$. The difference of the onset time of PSC emission can be attributed to the point that stress-strain deviates linearity ($s \approx 0.7$). Specifically, that point manifests the initiation of crack processes and has been proposed as PSC emission initiating point. Fig 2., curves a2 and b2, make clear that the emitted PSC from each sample exhibits different maximum value. The PSC maximum value is recorded for stress values close to fracture $s \approx 0.98$ and for curve a2 it is of the order of 410pA while for curve b2 of the order of 340pA.

The total charge was calculated in order to investigate if stress rate influences the total charge released from stress application process. The charge can be calculated by utilizing PSC curves that shows the temporal variation of the emitted current, *i(t)* according to:

$$Q = \int_{t_0}^{t_f} i(t)dt \qquad (1)$$

Eq. 1 was applied for the time window, from the moment PSC initiates, t_0, until the moment of fracture, t_f. According to Fig. 1 when $t=t_0$ the corresponding normalized stress equals to 0.7 approximately while for $t=t_f$ the normalized stress equals to 1. The total charge released during the first experiment was 21.9pC while for the second the corresponding charge released was 20.8pC. It is evident that the released charge during the two experiments is the same with good approximation.

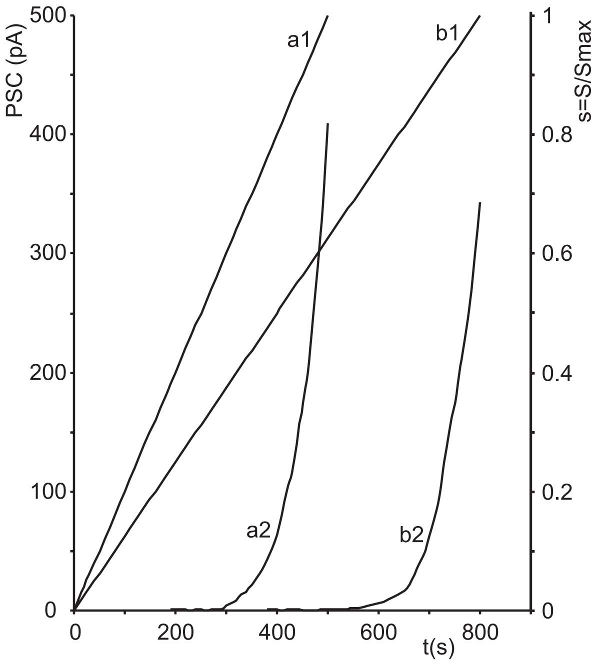

Fig. 2: (a1,b1) The temporal development of the normalized stress for the conducted experiments when the stress rate was constant, (a2,b2) the corresponding PSCs emitted.

Fig. 3 shows stress temporal variation (curves a1 and b1) as well as the PSC emitted (curves a2 and b2) during the corresponding stress change. Both PSC emissions initiate for stress values of the order of s=0.7 where stress-strain curve deviates linearity. The maximum value of the emitted PSC for the curve a2 is of the order of 150pA and for the curve b2 the, maximum PSC emitted, is much lower than the latter and of the order of 30pA. Both maximums are achieved for normalized stress values of $s \approx 0.98$. Despite the major difference of the maximums of the two curves the total charge released is approximately the same. Specifically, for curve a2, 2.8pC and for curve b2, 2.9pC.

The difference between the charge released during the experiments described from Fig 2 and those of Fig.3 can be attributed to the large difference of the dimensions of the samples. This dimensions difference is mirrored in the space that is available for microcrack generation and propagation in the body of the samples.

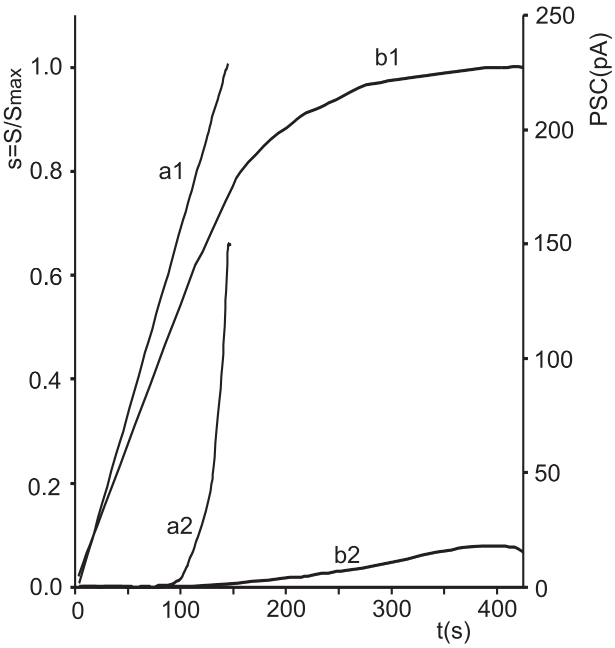

Fig. 3: (a1,b1) The temporal development of the normalized stress for the conducted experiments when the deformation rate was constant, (a2,b2) the corresponding PSCs emitted.

If we accept that the electric charge released during a fracture process is proportional to the energy required to activate each single crack, then one could proceed to the notion of a relationship associating the released charge and the sample mass i.e. the released charge during a fracture process is related to the mass of the compressed sample. The associated quantities are not proportional due to the way that stress is distributed within a sample, which depends on the shape as well as on the application region of the sample. An important factor in crack generation and consequently in charge release is crack branching which also depends on crack propagation and microcrack evolution; All these parameters are affected by the relative dimension analogies as well as by the absolute magnitudes of them.

4 Conclusions

In the above described experiments it was observed that samples of approximately same masses respond to compressional stress emitting approximately equal electric charge. This happens irrespectively of the stress rate and of the form of the emitted PSC. Even if the stress rate varies at our will during the experiment, the released charge is not affected. It was also observed that large samples release large charge amounts and small samples release small charge amounts respectively.

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