# Pressure Stimulated Current emissions on cement paste samples under repetitive stepwise compressional loadings

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***Abstract - The electric signals detection technique that is described here has been applied on several geomaterials in the past and on cement based materials lately. In this work cement paste samples were studied regarding electric signal emissions during axial stress application processes and specifically when subjected to repetitive loadings and unloadings in the in the range where crack opening and propagation processes are established. It was observed that the electric signal was emitted at two stages. Initially, current was emitted concurrently to the stress step and had a form of a spike and consequently gradually returned to its background level and a secondary current emission was recorded while the stress was maintained constant at the high level of each stress step.***

**Keywords:** Pressure Stimulated Current, electric current emissions, cement paste, uniaxial compressional stress.

## 1 Introduction

The study of the properties of cement products has attracted the scientific interest since they constitute the main structural materials. Several techniques have been applied in order to monitor the health of cement constructions. Some of them involve the electrical properties of cement. Since the health monitoring does not provide the flexibility to extract cement samples from the constructions Non-Destructive testing methods are the most suitable to be applied.
Many years now it is known that electric and electromagnetic (EE) signals can be observed when solids especially non-metallic materials, are mechanically stressed [1-5]. Micro and macrocracking processes are often accompanied by these signals. Several mechanisms for EE-generation have been discussed in literature like rapid movement of electric charges, separation of electric charges at crack formation and their recombination to form a miniature spark discharge, rapid movement of electric double layers under the action of the mechanical loading or piezoelectric phenomena [2, 6-9].
Previous works addressed processes of electrical emission in rock samples like marble and amhibolite [10-14]. The emitted current during the temporal stress variation that leads to catastrophic processes in the bulk of the samples and finally their fracture has been rendered under the term Pressure Stimulated Current (PSC). The technique applied in order to detect and record such electric emissions is mentioned as PSC technique. Relevant literature refer and show electric signal emissions with similar techniques regarding electrical emission in mortar under low compressive loading [15] and to the appearance of electrical current that increases nonlinearly with compressive stress [9].
During this work cement paste samples were subjected to stress adequate to lead them to the Crack Propagation Zone (CPZ). For the used samples this zone is estimated at around 11MPa. Consequently, repetitive mechanical loadings and unloadings were applied on the samples. Between each loading and unloading the stress level was maintained at its high value for relatively long time. The emitted PSC during this process was measured and it is presented and discussed here.

## 2 Experimental configuration

For the measurements a set of cement paste samples were prepared. The dimensions of the samples were 40mm x 40mm x 40mm. The rates of OPC (Ordinary Portland Cement) and water were 1:0.5. The drying time of the samples was 90 days. Conducting preliminary systematic tests the sample's average ultimate compressional strength was varying between 20MPa and 30MPa. Consequently samples prepared from the same mixture were used to conduct the experiments.
Figure 1 shows a representative relative compressional stress ( $\hat{\sigma}$ ) – strain ( $\varepsilon$ ) curve of the used samples. The relative compressional stress value is given as $\hat{\sigma} = \sigma / \sigma_{max}$ where $\sigma_{max}$ corresponds to the ultimate compressional strength of the sample. It is evident that it can be characterized by a linear material behavior at least up to stress of 80% (i.e.

$\hat{\sigma} = 0.8$ ) approximately of the ultimate compressional strength. When the relative compressional stress acquires value greater than 0.8 approximately, the material is driven to a range of non-linear deformation and eventually into the localized failure zone.

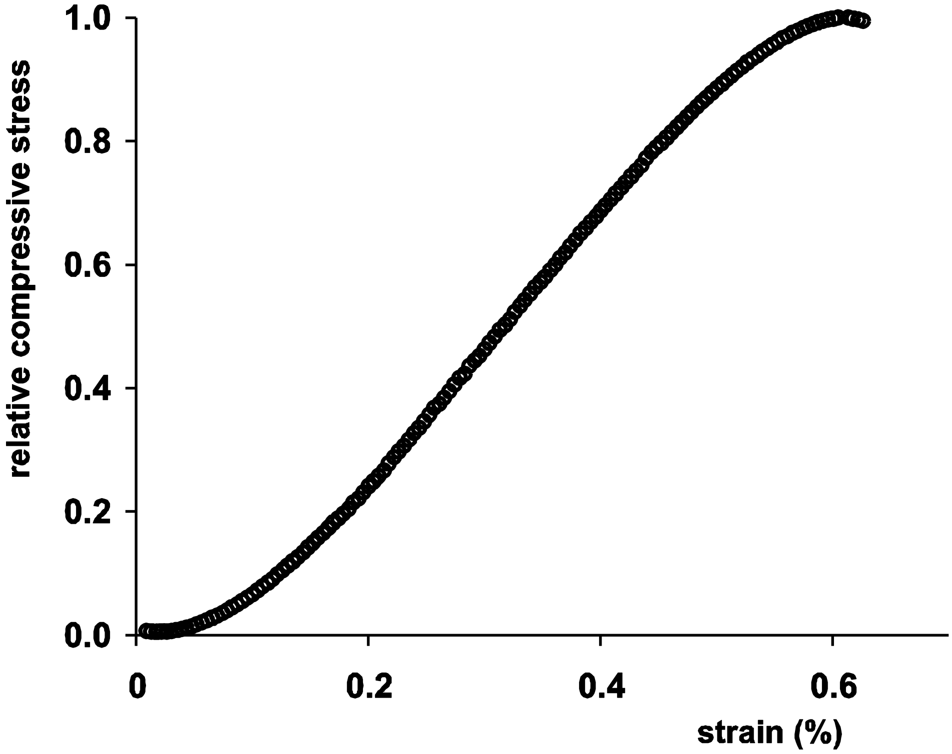


Figure 1: A representative curve that describes the relative compressive stress with respect to strain for the used samples.

Figure 2 shows the experimental installation. For the implementation of this experimental technique a pair of gold plated copper electrodes, were attached at the perpendicular axis of the stress. The measurements were achieved using a Keithley electrometer (model 6514). Electric measurements were stored in a computer hard disk through a GPIB interface while the load cell and the strain gages bridge were guided to an A/D Keithley DAQ. The stressing system comprised a uniaxial hydraulic load machine (Enerpac–RC106) that applied the load to the samples. The experiments were conducted in a Faraday shield to prevent from electric noise.

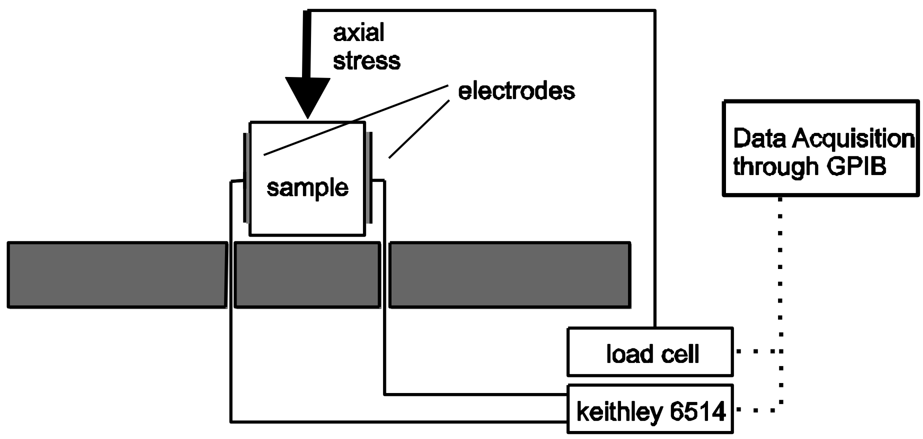


Figure 2: Schematic diagram of the experimental setup.

The sample under test was slowly loaded up to a value of 50% approximately of the ultimate compressional stress strength. Consequently a stress increase was applied at a relatively high rate and the stress maintained its high value for 10min. Afterwards the stress was removed until the level of the 50% of the ultimate stress strength. This procedure was repeated three times. Consequently, the stress was further increased in the vicinity of fracture and after some time the sample collapsed without further increasing the stress. During all this process the emitted PSC was recorded.

# 3 Results and discussion

Figure 3 shows the temporal variation of the three repetitive mechanical loadings and the corresponding emitted PSC. Specifically, the upper plot (a) corresponds to the applied compressional stress and is graded in MPa while the three lower (b,c and d) are graded in pA and correspond to the emitted PSC during the three repetitive loadings. Two kinds of PSC emissions can be seen in Figure 3. Specifically, a primary current that is emitted concurrently to the stress increase, from the lower to the higher level, that restores relatively fast and a secondary emission that takes place while the stress is maintained practically constant. It is obvious that both the PSC emissions during each loading become lower.

Primary PSC emission is attributed to the crack formation and propagation processes that are directly mapped into corresponding deformation changes. The reduction of the peak value of the PSC can be attributed to the electric emission memory effect that has already been discussed and interpreted in previous works that refer to PSC emissions from rock samples like marble [14,16] and amphibolite [13].

Figure 3 also shows the secondary PSC emissions that take place after stabilizing the stress at the corresponding high level of its stress increase. The stress level that was maintained after each stress step was 16.5MPa approximately. It becomes obvious that despite the fact that there is no stress variation a significant PSC is emitted. This can be attributed to the fatigue of the sample due to the opening of new crack formations or propagation of the existing ones since the material is already in the Crack Propagation Zone (CPZ).

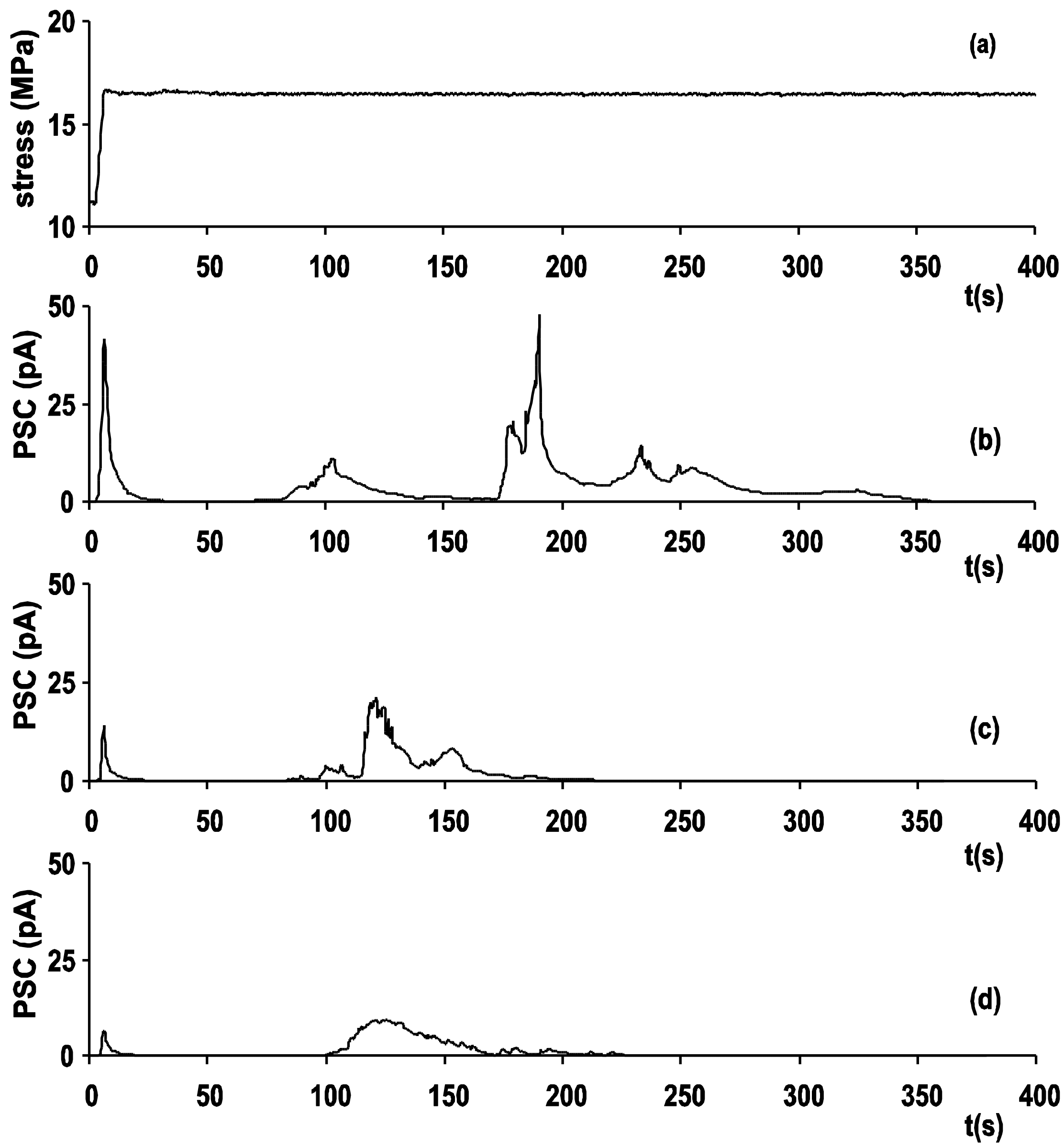

Figure 3: Plot of a representative stress step (curve a) repeated three times and the corresponding primary and secondary PSC emissions during the first stress step (curve b) the second (curve c) and the third (curve d) respectively.

Figure 4 describes the last stress step (curve a) that was performed from 16.5MPa up to 21MPa approximately. The sample suffered this loading for 5min and consequently it collapsed due to fatigue. During this compressional stress step a significant PSC emission was observed and lasted until the sample failed. During this final stress step the primary PSC emission cannot be distinguished from the secondary and they seem to overlap. The fact that the duration of the emissions is long (from the stress change until fracture) and has high magnitude in combination with the fact that the primary emission never restored are factors that promise the fracture of the sample at the time $t_f$=270s (see Fig. 4a). Another observation is that before the sample fracture the secondary emission has a brush-like form introducing the upcoming fracture. This prior-to-fracture PSC emission (curve b) is put in contrast to the PSC emission of the first stress step (curve c) in order for the changes in the form of the emitted PSC slightly before fracture to become clear. The deformation, after a compressional stress application with a step like form, continues to vary (hysteresis). This phenomenon becomes more intense as the sample reaches the ultimate stress strength. Since the secondary PSC emissions are attributed to this phenomenon it is expected to be more intense as the sample reaches failure limits.

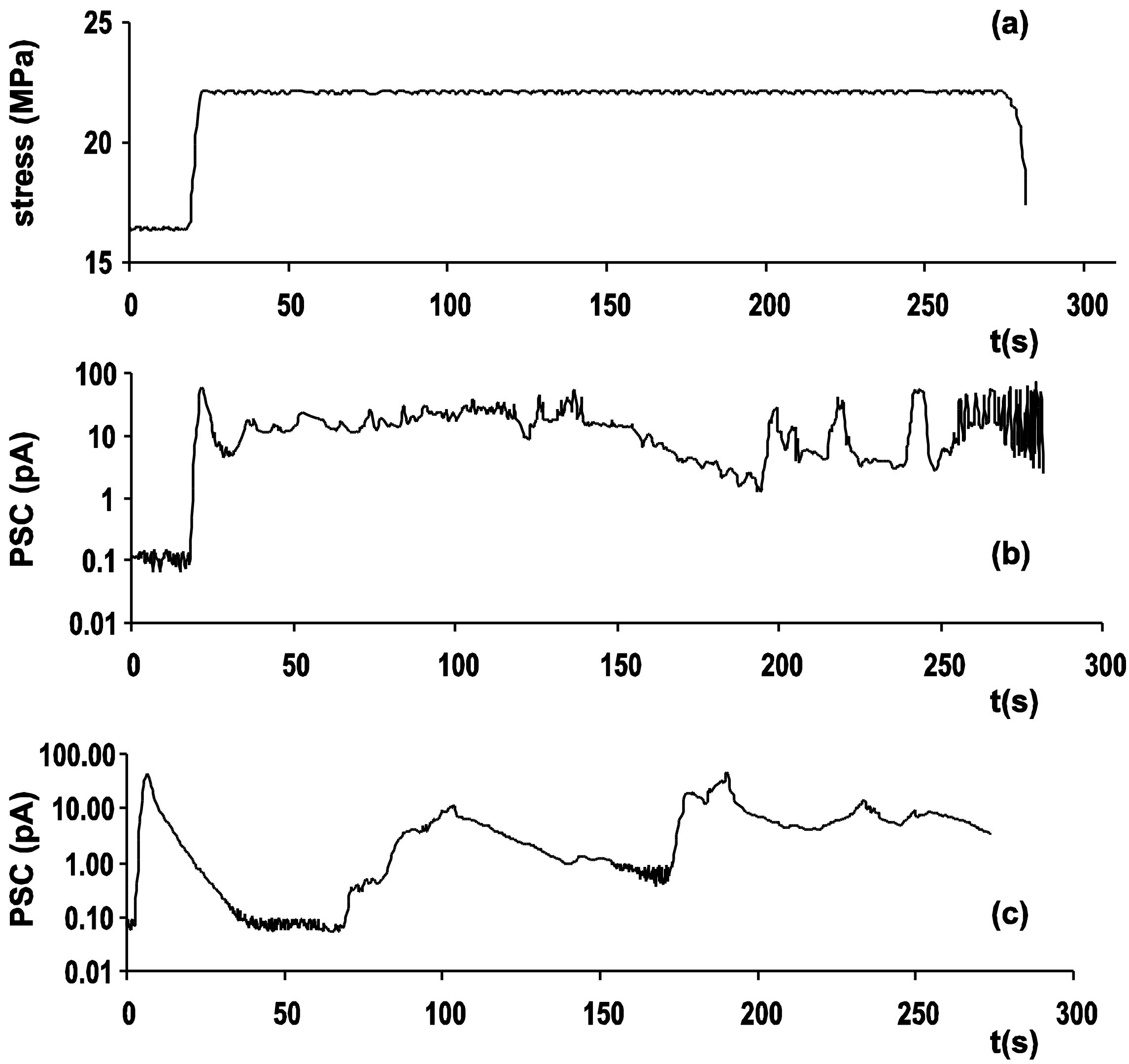


Figure 4: a) The final stress step in the vicinity of fracture and b) the corresponding emitted PSC, c) the PSC emission during the initial stress step at lower stress level in order to observe the time window between the primary and the secondary PSC emissions.

# 4 Concluding remarks

Cement paste samples were studied using the PSC technique. The recorded PSC was separated to a primary emission detected during the stress increase and a secondary one recorded while the stress was maintained constant at the higher level of each stress step. The PSC emissions are attributed to the crack formation and propagation processes and the consequent deformation and under this theoretical background the experimental results were discussed. The primary PSC emission was attributed to the concurrent-to-stress variation deformation and the secondary emission was attributed to the deformation hysteresis mechanisms. Another experimental observation was the lower value the PSC reached after each stress application and this result was put in contrast to similar previous results recorded and discussed for geomaterials like marble and amphibolite. Concluding it can be stressed that the PSC technique and the qualitative characteristics of the emissions observed can become a significant factor to monitor the health of cement paste using a non destructive method.

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