Pressure stimulated electrical emissions from cement mortar used as failure predictors

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Abstract The electrical signals emitted during the application of uniaxial compressive mechanical stress upon cement mortar specimens are observed and discussed in this paper. This work discusses the electrical signals that are detected when the specimens are excited by a stepwise uniaxial stress increase from a low level ($\sigma_L$) to a higher level ($\sigma_H$) at a fast or slow rate and consequently remain at a high pressure regime for a long time. When maintaining constant mechanical stress for a long time, creep phenomena are evident in the specimen and the corresponding electrical emissions are recorded and analyzed. The characteristics of the electrical signal give clear information regarding the breaking stress ($\sigma_F$) of the material. The electrical emission recordings are of great interest when the applied $\sigma_H$ is located in the vicinity of the failure stress; the emitted electrical current increases greatly due to the sequential formation and propagation of cracks that occurs in this stress region. Thus, by correlating the strain rate variations to the electrical emissions this methodology can be used to predict failure due to compressive stress in cement mortars.

Keywords Laboratory testing · Microcracks · Electrical signal monitoring

Abbreviations
PSC Pressure stimulated currents
CBM Cement based materials
LRSS Low rate step stress
ARSS Abrupt rate step stress
FVS Failure vicinity stress

1 Introduction

Laboratory experiments using various techniques for the detection of electrical emissions when non-metal solids suffer mechanical stresses have been reported by a number of researchers (Brady and Rowell 1986; Enomoto and Hashimoto 1990; Hadjicontis and Mavromatou 1994; Sun et al. 2002; Eccles et al. 2005; Aydin et al. 2009). The emitted electrical signals are the outcome of a number of processes of micro-and macro-crack development. Several mechanisms for the emission of electrical signals have been discussed in the literature (Brady and Rowell 1986; Varotsos and Alexopoulos 1986; Yoshida et al. 1998; Takeuchi and Nagahama 2001; Vallianatos et al. 2004; Sun et al. 2004). Typical mechanisms cited are the fast movement of...
electrical loads, the electric charge separation when a microcrack is produced, and piezoelectric phenomena.

Electrical signals have been recorded in various modes when uniaxial compressive stress is applied upon rock samples like marble (Stavarakas et al. 2003; Anastasiadis et al. 2004; Stavarakas et al. 2004; Triantis et al. 2006a; Anastasiadis et al. 2007a,b) and amphibolite (Triantis et al. 2007) as well as on cement mortar specimens, more recently (Kyriazopoulos et al. 2011). Weak electrical currents measured with a sensitive electrometer correspond to the detected signal. These currents are collected by a pair of gold plated electrodes mounted collaterally on the stressed specimen. This technique has been called as the Pressure Stimulated Currents (PSC) technique (Anastasiadis et al. 2004). The term Pressure Stimulated Currents was first used in the literature to describe the emission of a transient (polarization or depolarization) electrical signal, as a result of a gradual variation of the pressure on a solid containing electric dipoles due to defects (Varotsos et al. 1998). It became evident from the first PSC experiments that the procedure of crack formation and development is accompanied by electric polarization (Vallianatos et al. 2004; Stavarakas et al. 2003). Preliminary laboratory experiments show a linear correlation between electrical charge and strain on marble specimens (Triantis et al. 2008) as well as a linear relationship between the values of the electrical current and the strain rate on cement based materials (Kyriazopoulos et al. 2011). Recent experiments where electrical signal emissions are recorded using the PSC technique while a cement based mortar specimen is subjected to uniaxial compressive stress verify qualitative similarities with the corresponding recordings on rock samples (Triantis et al. 2006b). Quantitative results show that the electrical signals emitted from cement based material are significantly stronger than the corresponding recordings from rock specimens and may reach the order of few nA. Strong electrical PSC signals with repeated spikes appear under a regime of high constant stress, which is directly associated with strain rate variations (Kyriazopoulos et al. 2011). References are available for electrical signal emissions that have been created and recorded using similar techniques on cement mortar under low compressive stress, as well as recordings of electric current due to the piezoelectric effect (Sun et al. 2004, 2000).

This paper discusses systematic measurements of Pressure Stimulated Currents (PSC) conducted on cement based materials (CBM). The PSC measurements are recorded systematically while the specimens are subjected to a temporal variation of the axial compressive stress, either in the form of abrupt steps or at a constant, slow stress rate increase up to a certain level; after a certain stress level is reached the specimen remains loaded under a constant axial stress. A number of experiments are also conducted and the emitted PSC are recorded while the specimen is subjected to a constant mechanical stress in the vicinity of failure for a significantly long time (several days). It is known that during such experiments (i.e. maintaining mechanical stress in the vicinity of failure for a long time) creep phenomena develop and dominate the mechanical behaviour of the specimen, so the correlation between the values of the recorded PSC and the strain rate variations are also examined.

Finally, in this work a possible relationship of the PSC signal temporal values to the corresponding values of the strain rate \((\text{d} \varepsilon / \text{d} t)\) is investigated. The strain rate varies only in the region above the yield stress of the specimen and therefore only data from this region was used to investigate the relationship between the PSC signal and the strain rate. The verification of a linear relationship \(\text{PSC}(t)\) vs \(\text{d} \varepsilon(t)/ \text{d} t\) will support the theoretical estimates of the electrification mechanisms of this relationship according to the moving charged dislocations (MCD) model (Vallianatos and Tzanis 1998; Vallianatos et al. 2004) on cement mortar specimens. In previous work (Triantis et al. 2008) a linear relation between the electrical charge \(Q(t)\) and the corresponding values of the strain was verified for marble specimens. It must be noted that instead of the relationship between the electrical charge and the strain, the corresponding relationship between the values of the PSC\((t)\) and the strain rate \((\text{d} \varepsilon / \text{d} t)\) can be investigated since:

\[
\text{PSC}(t) = dQ(t)/dt.
\]

Additionally, in recent work by Kyriazopoulos et al. (2011) on cement mortar specimens, a linear relation was verified between the maximum values of the PSC \(\text{PSC}_{\text{max}}\) and the corresponding mean values of the strain rate \((\langle \text{d} \varepsilon / \text{d} t \rangle)\), using an experimental procedure where the samples were subjected to an abrupt increase of the axial compressive stress.

2 Experimental setup

The specimen dimensions vary from cubic specimens \((L/D = 1)\) to prismatic \((L/D = 2.5)\) since previous