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Journal of the European Ceramic Society 25 (2005) 3281–3285

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Internal friction study of the influence of humidity on set plaster

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Received 13 May 2004; accepted 16 July 2004

Abstract

Internal friction, one of the useful techniques for studying material changes at microscopic level, is used to investigate water effect on mechanical behaviour of set plaster. Internal friction was measured as a function of strain amplitude at different humidity conditions. A weak dependence is observed at low-strain amplitude, followed by a steep linear rising above a threshold strain amplitude. Increasing the relative humidity (RH) increases the internal friction and lowers the threshold of the rising part. The results provide an experimental evidence of a relative sliding of gypsum crystals enhanced in the presence of water, and a simple viscoelastoplastic rheological model is proposed.

Keywords: Plaster; Internal friction; Water effect

1. Introduction

Set plaster is a common construction material, mainly used for plasterboards for interior partitions. Moreover, due to its low cost and easy shaping, it is often used as a model to study the mechanical behaviour of porous brittle materials. Plaster is very sensitive to humidity and it is of importance to understand the mechanisms involved in the presence of water. It has a linear elastic behaviour when it is dry[1,2] and becomes non-linear and plastic, with relatively high fracture deformation, in the presence of water.[1] Moreover, water absorption results in a drastic deterioration of mechanical properties.[3,4] Set plaster is also very sensitive to subcritical crack growth[5] and creep at humid environment.[6]

Set plaster is made of entangled needle-shaped gypsum crystals with relatively weak interfaces[7] implication of which, is important for mechanical behaviour. A recent study on fracture behaviour of set plaster[2] showed that the gypsum needles are often debonded and rarely broken and macroscopic crack propagation occurs by linkage with microcracks issued from weak regions. Coquard et al.[3] attributed the water effect to a decrease of the bonds between gypsum crystals rather to the phenomenon of dissolution–precipitation suggested by Murat et al.[8]. Badens et al.[4] correlated the decrease of Young's modulus of plaster with increasing humidity to a thickening of adsorbed water layers between gypsum crystals, which allows their sliding.

In this work, internal friction technique,[9] is used to investigate the effect of humidity on set plaster, in order to identify the microstructural mechanisms involved during mechanical behaviour in the presence of water. This method, applied for the first time to plaster, is one of the most useful techniques for studying the changes in materials at microscopic level (diffusive processes, phase transformation, dislocation motion, grain boundary sliding . . .) and allows to determine associated energy dissipation.

2. Material and procedure

A set plaster with a porosity of 55% was obtained by hydration of a β hemi-hydrate of 96% purity, at a water/plaster weight ratio of 80%. The set paste was hydrated in saturated

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0955-2219/$ – see front matter
doi:10.1016/j.jeurceramsoc.2004.07.035

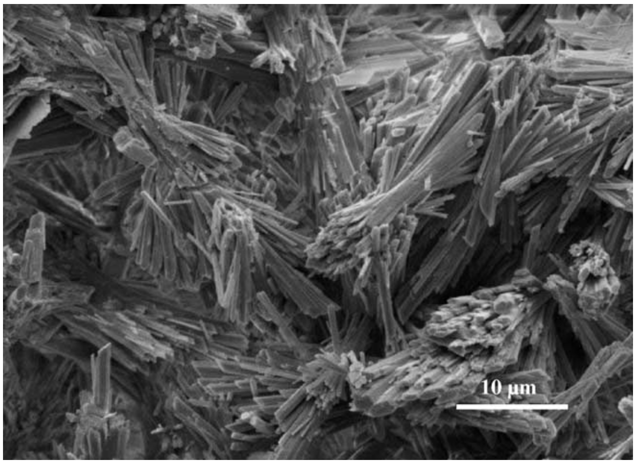

Fig. 1. SEM micrograph showing the microstructure of set plaster.

conditions during 24 h, and dried at 45 °C to evaporate the excess of water trapped in the pores. A network of tangled needles of gypsum characterises the final microstructure, shown in Fig. 1.

The internal friction or damping, usually denoted, Q^{-1}, is a measurement of energy dissipation in the material.[9] For a vibrating system, it is proportional to the ratio of the dissipated energy in one cycle, ΔW, to the maximum elastic energy stored in the sample W_{el}. For viscoelastic materials, Q^{-1} is given by:

$$Q^{-1} = \frac{\Delta W}{2\pi W_{el}} = \tan\phi \quad (1)$$

were ϕ is the loss angle between the applied load and resulting deformation.

In this study, two different techniques were used: a forced torsion pendulum[10] allowing a large variation of the deformation at a low frequency (1 Hz), and a bending resonant device[11] working at medium frequency about 1 kHz. Two types of samples, directly moulded, were used for internal friction measurements: rectangular bars (40 mm × 5 mm × 1 mm) for bending resonant tests and dog-bone specimens, with a central part of 2 mm × 5 mm × 2 mm and a total length about 40 mm, for torsion pendulum tests. Confining atmospheres in equilibrium at different partial pressures of water varied the relative humidity (RH) in air, determined with a resolution of 5%. Before the experiments, the samples were maintained 24 h, in the testing conditions to ensure their equilibrium.

In the torsion pendulum method, electromagnetic coils applied the shear stress and the strain was measured optically. Special care was paid to sample clamping to minimise experimental artefacts due to sliding or material damage. This has been achieved using a screwed system allowing the adjustment of the clamping force.[1] The internal friction experiments were performed by applying increasing strain amplitudes at ambient temperature under a constant frequency of 1 Hz at various humidity conditions:

- Dry plaster under low pressure (10^{-2} bar) that allowed to eliminate the water without any dehydration of the gypsum,
- Plaster at 35 and 80% of RH,
- Water saturated plaster obtained by wetting the central part of the specimen maintained in equilibrium during 24 h, to allow the hydration of gypsum.

In the bending resonant bar technique, a rectangular sample was horizontally supported, one side covered with silver paint to make it conducting. Then, a flexural vibration was driven electrostatically at the resonant frequency. The internal friction and Young's modulus were measured at a low deformation of 10^{-6} as a function of the RH.

3. Results and discussion

3.1. Strain dependence of internal friction

The internal friction of set plaster, measured on the torsion pendulum at ambient air (35% RH), is plotted versus the strain amplitude in Fig. 2. It can be seen that a transition from a weakly damping amplitude dependence to a steep linear dependence occurs at a critical strain amplitude, about 2×10^{-3}. Moreover, the dependence was observed to be reversible, indicating that the energy dissipation mechanism involved, has no important memory effect. This result can be interpreted by analogy with rocks, presenting a similar strain damping dependence,[12] the linear part of which is attributed to frictional grain sliding. In the case of set plaster, the internal friction curve suggests an anelastic sliding mechanism at

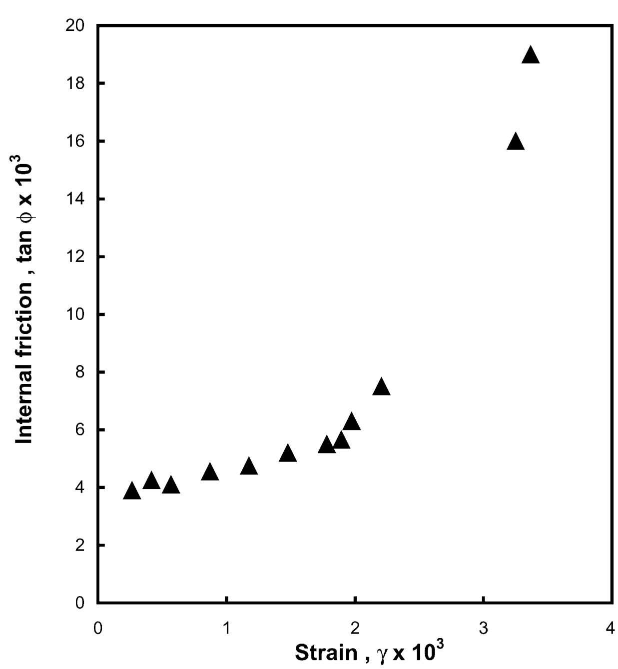

Fig. 2. Internal friction of set plaster, measured on the torsion pendulum at ambient air, vs. strain amplitude.