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► **To cite this version:**

Pascal Reynaud, Malika Saadaoui, Sylvain Meille, Gilbert Fantozzi. Water effect on internal friction of set plaster. *Materials Science and Engineering: A*, 2006, pp.500-503. 10.1016/j.msea.2006.01.152 . hal-00436174

HAL Id: hal-00436174

<https://hal.science/hal-00436174>

Submitted on 17 Jan 2022

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Water effect on internal friction of set plaster

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Set plaster is brittle when it is dry and becomes plastic with a drastic drop of mechanical properties in the presence of water. In this work, mechanical spectroscopy has been used to investigate this water effect. 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 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. A simple viscoelastoplastic rheological model is proposed to describe this effect.

Keywords: Set plaster; Internal friction; Water effect

1. Introduction

Set plaster, a common construction material mainly used for plasterboards for interior partitions, is very sensitive to humidity [1]. Its macroscopic mechanical behaviour is linear elastic when it is dry [2,3] and becomes non-linear and plastic, with relatively high fracture deformation, in the presence of water [2]. Moreover, water absorption results in a drastic deterioration of mechanical properties [1–6]. Set plaster is also very sensitive to subcritical crack growth [7] and to creep at humid environment [8]. Thus it is of importance to understand the mechanisms involved in this material in the presence of water.

The microstructure of set plaster is made of entangled needle-shaped gypsum crystals with relatively weak interfaces (Fig. 1). Coquard et al. [4] 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. [9]. Badens et al. [5] 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, mechanical spectroscopy [10] is used to investigate the effect of humidity on set plaster and to identify

the microstructural mechanisms involved during mechanical behaviour in the presence of water.

2. Material and procedure

A set plaster with a 55% porosity 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 conditions during 24 h and dried at 45 °C to evaporate the excess of water trapped in the pores. Dog-bone specimens were directly moulded, with a central part of 2 mm \times 5 mm \times 2 mm and a total length of about 40 mm. A network of tangled needles of gypsum characterizes the final microstructure shown in Fig. 1.

A forced torsion pendulum [11] was used to measure internal friction for a large variation of the deformation at a low frequency (1 Hz). The shear stress was applied by electromagnetic coils and the strain was measured optically. Special care was paid to sample clamping to minimise experimental artefacts due to sliding or material damage. Confining atmospheres in equilibrium at different partial pressures of water varied the relative humidity in air, determined with a resolution of 5%. Before the experiments, the samples were maintained for 24 h in the testing conditions to ensure their equilibrium.

The internal friction experiments were performed by applying increasing strain amplitudes at ambient temperature under a

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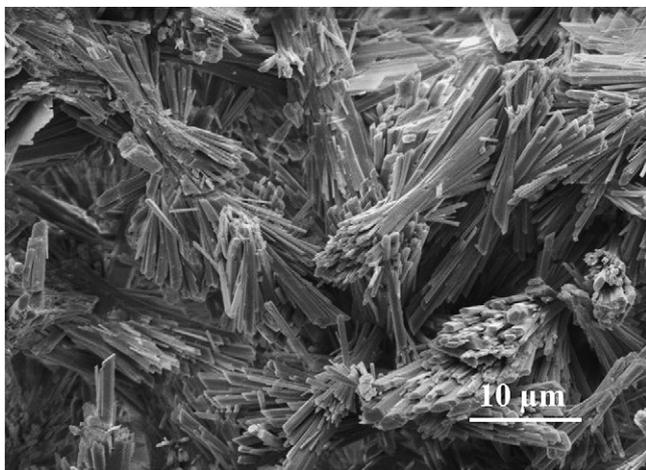


Fig. 1. Scanning electron micrograph showing the microstructure of set plaster.

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 relative humidity, with a temperature of 25 °C,
- water saturated plaster obtained by wetting the central part of the specimen maintained in equilibrium during 24 h, to saturate the porosity of the material with water.

3. Results and discussion

3.1. Strain dependence of internal friction and influence of humidity

The influence of the relative humidity on the damping is shown in Fig. 2, where the results corresponding to dry conditions and to a saturated water plaster, are also reported. On dry set plaster at low vacuum environment, no significant increase of the damping was observed in the range of the applied strain amplitudes. At ambient air (35% relative humidity) and for more humid environment a transition from a weakly damping amplitude dependence to a steep linear dependence was observed. Increasing the relative humidity increases the internal friction and shifts the strain-amplitude-dependent stage towards lower strain amplitude. For the water saturated material, the internal friction at low amplitude is seven times greater than that observed at 35% relative humidity and the rising part is steeper.

Strain dependence of internal friction 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 low strains (constant internal friction) and a frictional sliding between the gypsum needle crystals at sufficient large strains.

These results provide an argument for relating water effect to sliding mechanism, enhanced by lubrication due to an increase

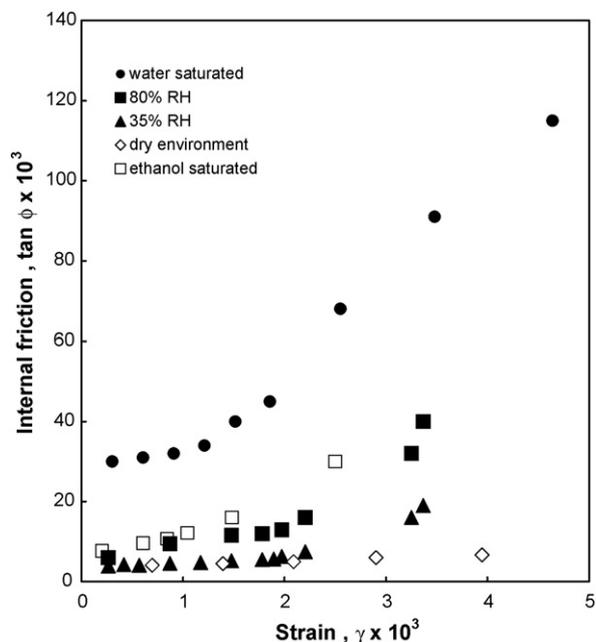


Fig. 2. Internal friction vs. strain amplitude at different conditions of humidity and comparison with ethanol saturated plaster. RH status for relative humidity.

in water thickness between crystals. The high value of internal friction of water saturated plaster at low strain can be attributed to a decrease of intrinsic surface cohesion of gypsum crystals due to water adsorption. By infiltrating between gypsum crystals, water molecules form a layer that act to shield their interaction, resulting in weaker bonding, compared to that of dry material [4].

To confirm the wetting effect, internal friction was measured on set plaster wetted with ethanol, which spreads on the crystal surfaces without any dissolution–recrystallization mechanism, as gypsum is not soluble in it. The internal friction curve (Fig. 2) shows similar strain dependence to that of water saturated plaster, with a lower value of the strain amplitude transition. The shift towards lower level of internal friction for ethanol saturated specimen can be attributed to the influence of the liquid surface energy on the crystal interaction [13]. Due to its larger surface energy, water leads to a larger decrease of the surface energy of plaster resulting in easier sliding.

The high sensitivity of plaster to humidity is due to the weak interactions involved in its cohesion. The presence of water in very small amounts is sufficient to drastically decrease the crystal bonds [14]. A steep increase of internal friction at a low relative humidity was observed in other porous materials and was linked to H-bonding of water on polar sites [15,16]. Similar conclusion can be drawn for set plaster, with a distinction between free water and bound water associated with polar sites. A more detailed study of the interactions between gypsum crystals has been carried out by use of atomic-force microscopy [17]. It appears that the bonding between two gypsum crystals is strongly dependent on the crystallographic faces that come into contact. The macroscopic behaviour characterized in this study is in fact an average of different local behaviours.

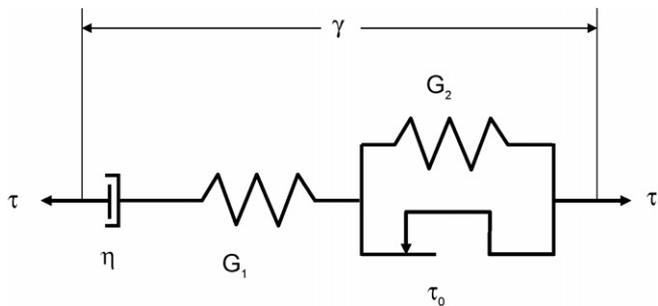


Fig. 3. Viscoelastoplastic model proposed to describe the internal friction of set plaster.

It also has to be noted that dissolution and recrystallization of gypsum in water can be observed and can influence the mechanical behaviour of set plaster (in creep experiments for example). In this study, the solicitation frequency is too high and dissolution does not seem to have a strong influence on the material behaviour.

3.2. Modeling

The strain dependence of internal friction allows to conclude that energy dissipation is produced by viscoelastic (non-strain-dependent) and plastic (linear strain-dependent) sliding mechanisms. The experimental results shown in Fig. 2 are described by a simple viscoelastoplastic rheological model (Fig. 3), composed with a Maxwell element (stiffness G_1 , viscosity η), in series with a slipper (threshold shear stress, τ_0) in parallel with a spring (stiffness G_2). Under torsional strain amplitude γ , the loss angle of the model is given by:

$$\tan \phi = \frac{G_1}{2\pi f \eta}, \quad \text{for } \gamma \leq \frac{\tau_0}{G_1} \quad (1-a)$$

$$\tan \phi = \frac{G_1}{2\pi f \eta} + \frac{4G_1}{\pi(G_1 + G_2)} \left(\frac{G_1}{\tau_0} \gamma - 1 \right), \quad \text{for } \gamma \geq \frac{\tau_0}{G_1} \quad (1-b)$$

where f is the frequency.

The Maxwell element corresponds to the behaviour at low amplitude (constant internal friction), the energy dissipation of which is dictated by the viscosity η . The association of the springs and the sleeper, the threshold of which is correlated to the strain dependence transition, reflects the increase of internal friction at a fixed relative humidity. Using the measured value of the shear modulus G_1 at low strain amplitude [14], the viscosity, η and the threshold shear stress, τ_0 , were adjusted to the internal friction curves at different humidity conditions (Table 1).

Table 1
Effect of relative humidity (RH) on micromechanical parameters

| RH (%) | η (Pa s) | τ_0 (MPa) |
|--------|-----------------------|----------------|
| 35 | 11.0×10^{10} | 6.0 |
| 80 | 5.2×10^{10} | 5.7 |
| 100 | 1.6×10^{10} | 4.0 |

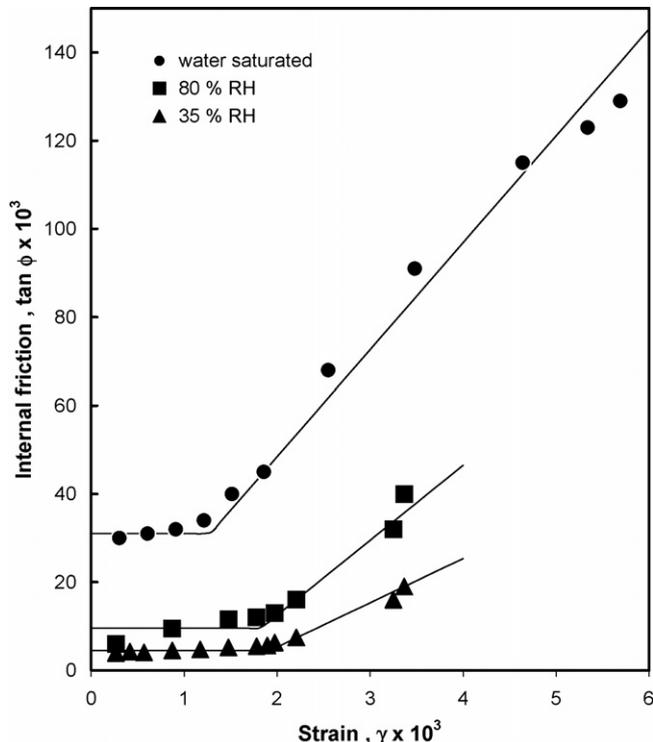


Fig. 4. Comparison of the experimental internal friction curves obtained at different humidity conditions (symbols) with theoretical curves (lines) corresponding to the model. RH stands for relative humidity.

A good agreement is found (Fig. 4) between the experimental and the theoretical curves corresponding to the model. The decrease of τ_0 and η with increasing humidity (Table 1) reflects the wetting process, allowing easier sliding at the gypsum crystal interfaces.

4. Conclusion

Water has an important effect on the mechanical behaviour of set plaster. When the amount of water absorbed increases, the material becomes more plastic and the mechanical properties drop. Mechanical spectroscopy has been used to investigate this effect, and has been successfully applied to set plaster at different humidity rates. The experimental results are seen as evidence of a sliding mechanism between gypsum crystals, enhanced by water absorption. Internal friction shows a transition from weak strain dependence to a rising linear dependence, corresponding to frictional sliding above a threshold value of the strain amplitude. The results are described in the basis of a viscoelastoplastic model, in agreement with easier relative sliding of crystals when water is adsorbed.

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