



## A mechanism to explain the creep behavior of gypsum plaster



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### ABSTRACT

Gypsum plaster is a widely used building material, as it is inexpensive and mechanically strong. However, the main disadvantage of gypsum is its significant loss of mechanical strength in a humid environment. As a result for instance gypsum wallboards bend when exposed to humidity. Despite intense research on this topic, the origin of the mechanisms that ultimately cause this deformation of bulk gypsum, i.e., the creep of gypsum is not yet thoroughly understood.

In this work, the creep of gypsum is reviewed with fundamentally new experimental design approaches and modern analytical methods. The surface reactions of calcium sulfate dihydrate crystals are related to the macroscopic behavior of polycrystalline gypsum. The acquired data supports a model for moisture-triggered, pressure solution creep as the fundamental mechanism for the deformation of gypsum under mechanic load in a moist atmosphere.

### 1. Introduction

Gypsum plaster is an important building material for indoor applications as an inexpensive and easy to use material with a whole bunch of advantageous attributes. Gypsum boards have good properties in terms of heat insulation, comply with the standards for fire safety and provide a pleasant room climate [1–3]. On top of that, gypsum can be recycled almost endlessly, requiring only moderate processing temperatures [4]. Gypsum products are made via hydration of the precursor calcium sulfate hemihydrate. The resulting gypsum material, a bulk of polycrystalline calcium sulfate dihydrate needles, possesses an open porosity and a good mechanical stability [5].

Unfortunately, there is one huge drawback: The use of gypsum materials is limited because of its adverse trait upon contact with water. The mechanical properties of gypsum, i.e., its hardness, compressive strength, flexural strength and elastic modulus deteriorate in humid environment. Because humidity adds additional water to the polycrystalline calcium sulfate dihydrate, which, under static load, eventually is responsible for the creep of gypsum [6–9]. This ultimately leads to a deformation of the building-material, as for instance in the bending of gypsum boards.

To overcome this creep behavior in a humid environment, several additives have been proposed during the last hundred years as potential

remedy to this issue [10].

For instance, one of the first attempts made, was to make gypsum water-repellent. This had been achieved when water-resistant materials like inorganic salts, soaps, pitch, paraffin or resin were added to the gypsum [11]. In other approaches, plaster components were impregnated with bitumen, wax, oil or plastic emulsions with the same aim of making the whole material “waterproof” [11,12]. It turned out that all of these methods increased the short-term water resistance of gypsum. The long-term creep behavior, however, could not be overcome [11,12].

Another interesting attempt was to add hydraulic binders with slow-setting properties during gypsum synthesis [11]. After the setting of the gypsum, the binder remains as a gel in the pores of the structure. Ultimately, the binders then harden and thus solidify the structure. Additives such as diatomite, pozzolana, slag or aluminate cements were employed in the studies and succeeded in giving a creep-resistant building material [11]. However, sulfate expansion was observed in long-term tests, which eventually caused damage to the components [11].

Nowadays gypsum industry uses surfactants in order to reduce the creep of gypsum. These chemicals are believed to form a complex with the  $\text{Ca}^{2+}$ -ions on the surface of gypsum crystals, which is meant to decrease the solubility or speed of dissolution of gypsum in water

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[13,14]. Anti-creep additives in the form of surfactants not only influence the surface character, but also the shape of gypsum crystals in a polycrystalline structure [10]. Above all, phosphates and phosphonates such as sodium trimetaphosphate (STMP) and aminotris(methylenephosphonic acid) (ATMP) are applied as state of the art nowadays [13,15,16].

Obviously, substantial effort has been made to suppress the creep behavior of gypsum. Yet, none of the current approaches is the ultimate solution to overcome the creep behavior of gypsum completely. The mode of action of these additives is either only partially known [17] or not published.

Hence, it is important to go one step back and, first of all, develop a basic understanding for the mechanism that causes the creep behavior of gypsum. In the past attempts have been made to relate the observed creep behavior of gypsum to adequate models.

It is widely accepted that the bonds between calcium sulfate dihydrate crystals in natural gypsum rock are weakened by the ingress of water at the grain boundaries [18]. The creep behavior of gypsum thus results from the formation of a layer of water between the gypsum grains that allows the crystals to slide past each other. Depending on the exact moisture conditions, these only a few nanometer thick layers of water between the individual gypsum crystals of the porous polycrystalline plaster body vary in size (Fig. 1a).

In the context of this hypothesis, Pritzel et al. [19] described a decrease of the mechanical strength of gypsum with the rise of relative humidity (RH). According to the authors, this is due to swelling of the water layers which cause a change in the friction regime from *solid-solid* to *solid-liquid*, enhancing the chance of single crystals to slide past each other [19].

Another model for this creep or sag of gypsum is proposed as shown in Fig. 1b and c [16,20,21]. It involves local dissolution and recrystallization of gypsum in the surface water layers at the contact points between interlocking crystals.

A rising humidity leads to an increase of layer thickness of interlocking water between the gypsum crystals. When an external mechanical load causes stress at the interfaces of two crystals, the local

solubility of gypsum increases. Calcium sulfate dihydrate dissolves at sites of high mechanical stress and precipitates in places with little stress (Fig. 1c). This allows aggregated crystals to separate and slide against one another, resulting in a relief of local stress and the macroscopic deformation of the sample. This mechanism is referred to as pressure solution creep [6] and is also believed to be the main cause for creep of other minerals. Besides some hypothesis, there is no experimental evidence to verify a distinct creep mechanism for gypsum [22,23].

Thus, in this work, the creep of gypsum is reviewed with fundamentally new experimental design approaches and modern analytical methods. The reactions at the surfaces of calcium sulfate dihydrate crystals are related to the macroscopic behavior of polycrystalline gypsum. To achieve this, the creep behavior of gypsum is analyzed in dependence of different pore fluids. Up to now, the influence of solubility on the creep rate has only been investigated with respect to the solubility of gypsum in water (or salt containing water). In our work, we ran experiments in concentrated acids in order to increase the solubility by up to an order of magnitude and thus to prove that there is still a linear dependence between the solubility and the creep rate.

To prove, that the creep of gypsum is a surface reaction, creep experiments with different crystal sizes and thereby different crystal surfaces, are accomplished.

As described, besides some hypotheses, there is no direct evidence for a creep mechanism for gypsum based on dissolution and precipitation [22,23]. In order to find direct evidence for a creep model for polycrystalline gypsum, a new creep test is established to increase the creep rate and sag to a maximum. The samples are furthermore adapted to fit as whole sample in a customized SEM sample holder. This setup enabled a highly precise, repetitive placement of samples and thus ultimately yielded access to studies on exactly the same region of interest in samples before and after application of mechanical stress. With this, an attempt is made to give direct evidence to a model of dissolution and precipitation in order to understand the mechanisms that cause the creep behavior of gypsum.

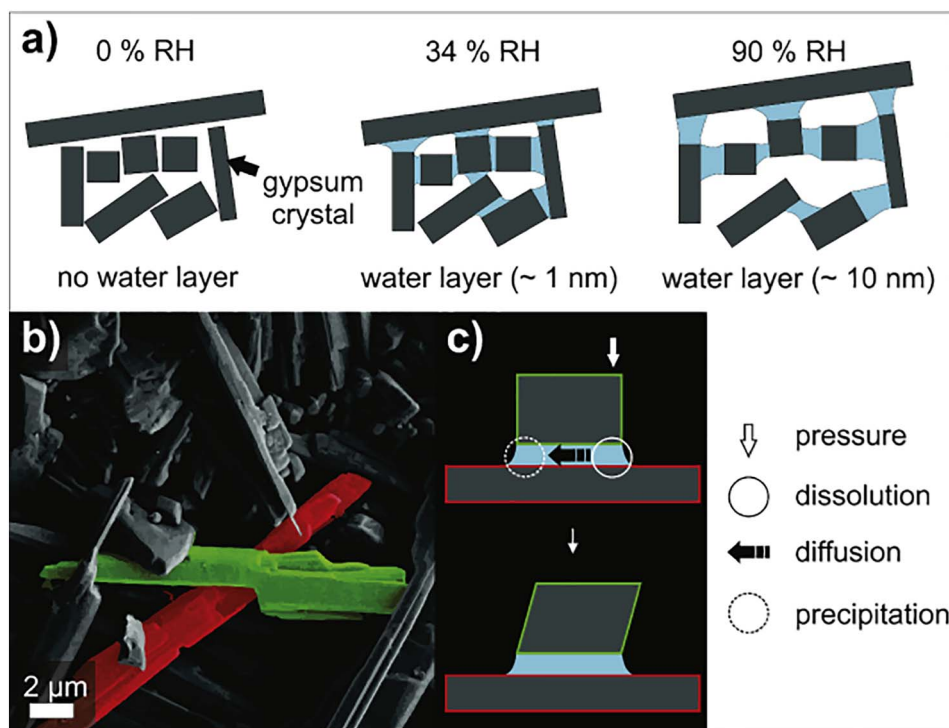


Fig. 1. a) Schematic cross-section of polycrystalline gypsum at different degrees of relative humidity (RH), causing a water layer of varying thickness [6,20], b) SEM image of a polycrystalline gypsum structure with exemplary colored gypsum needles. c) Sketch of the pressure solution creep mechanism referring to the gypsum structure b) [20].

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