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Application of Photothermal Techniques in Magnesium Oxysulfate Cement

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Abstract

The impact of polyvinyl acetate polymer (PVAc) on the thermal performance of magnesium oxysulfate (MOS) cement was investigated in this study. PVAc was introduced into the cement matrix at varying proportions: 0%, 5%, 10%, 15%, and 20% relative to the weight of MOS. Thermal properties, including thermal conductivity and thermal diffusivity, were evaluated using the Photothermal Deflection Technique (PTD). This method involved fitting experimental photothermal signal curves to appropriate theoretical models. The results demonstrated that incorporating PVAc polymer improved the thermal insulation of MOS cement. Specifically, the addition of 10% PVAc polymer resulted in the most significant improvement in thermal performance compared to other samples. The study highlighted that the size and quantity of air bubbles formed within the cement matrix played a crucial role in improving the thermal properties

Keywords: Photothermal; Magnesium; Oxysulfate; polyvinyl acetate polymer; Material Science

Introduction

Magnesium oxysulfate (MOS) cement was first developed by Olmer and Delyon in 1934 [1]. It is a non-hydraulic cementitious material formed through the reaction of magnesium sulfate, magnesium oxide, and water. MOS cements exhibit various advantageous properties such as lightweight composition, rapid setting, high fire resistance, and resistance to abrasion and chemicals [2-3]. These properties make MOS cement suitable for a range of architectural applications, including binding lightweight panels, insulating materials, fireproofing, decorative uses, and as additives for reinforcement [4-5].

In this study, we analyzed the thermal characteristics of MOS cement. The thermal insulation properties of building materials are crucial for enhancing both thermal comfort and reducing energy loss. Accordingly, we investigated the thermal properties of MOS cement using the photothermal deflection technique [6]. This method involves studying the amplitude and phase variations of the photothermal signal with respect to modulation frequency to determine the thermal conductivity and thermal diffusivity of the cement.

This paper presents, possibly for the first time, the impact of polyvinyl acetate polymer (PVAc) on the thermal conductivity and thermal diffusivity of MOS cement using PTD.

Materials and Methods

Specimens preparation

The materials utilized in this study include magnesium sulfate ($MgSO_4$) sourced from Scharlab in Spain, magnesium oxide (MgOH) from HiMedia in India, and water (H_2O). Magnesium oxide was obtained by calcining magnesite powder at 900°C. A saturated solution of magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$) was prepared by dissolving it in distilled water, with a mass concentration ratio of 1.75. The mass fraction of magnesium sulfate to magnesium oxide was maintained at 1.42.

Magnesium pastes were prepared by simultaneous mixing of MgO powder, $MgSO_4 \cdot 7H_2O$ saturated solution, and varying weight percentages of PVAc polymer (0%, 5%, 10%, 15%, and 20% based on MgO). The resulting MOS composites (samples) were labeled as MOS0 (0% PVAc), MOS5 (5% PVAc), MOS10 (10% PVAc), MOS15 (15% PVAc), and MOS20 (20% PVAc). These mixtures were poured into cylindrical molds and cured in air for 28 days.

Methods

Thermal analysis of the samples was conducted using the photothermal deflection technique (PTD).

The compressive strength of specimens was tested using the Liyold (LR50K) mechanical testing instrument. At 28 days of age, the compressive strength of samples measuring 25 mm in diameter and 50 mm in height was measured at room temperature.

Results

To determine the thermal properties of MOS cement, we followed the methodology detailed by Zgueb et al. [6] in two steps.

The first step, we determine the thermal diffusivity of the cement.

The second step, we increase the amplitude of the signal by absorbing almost all the incident radiation by a black layer deposed on the surface of the samples in order to determine the thermal conductivity.

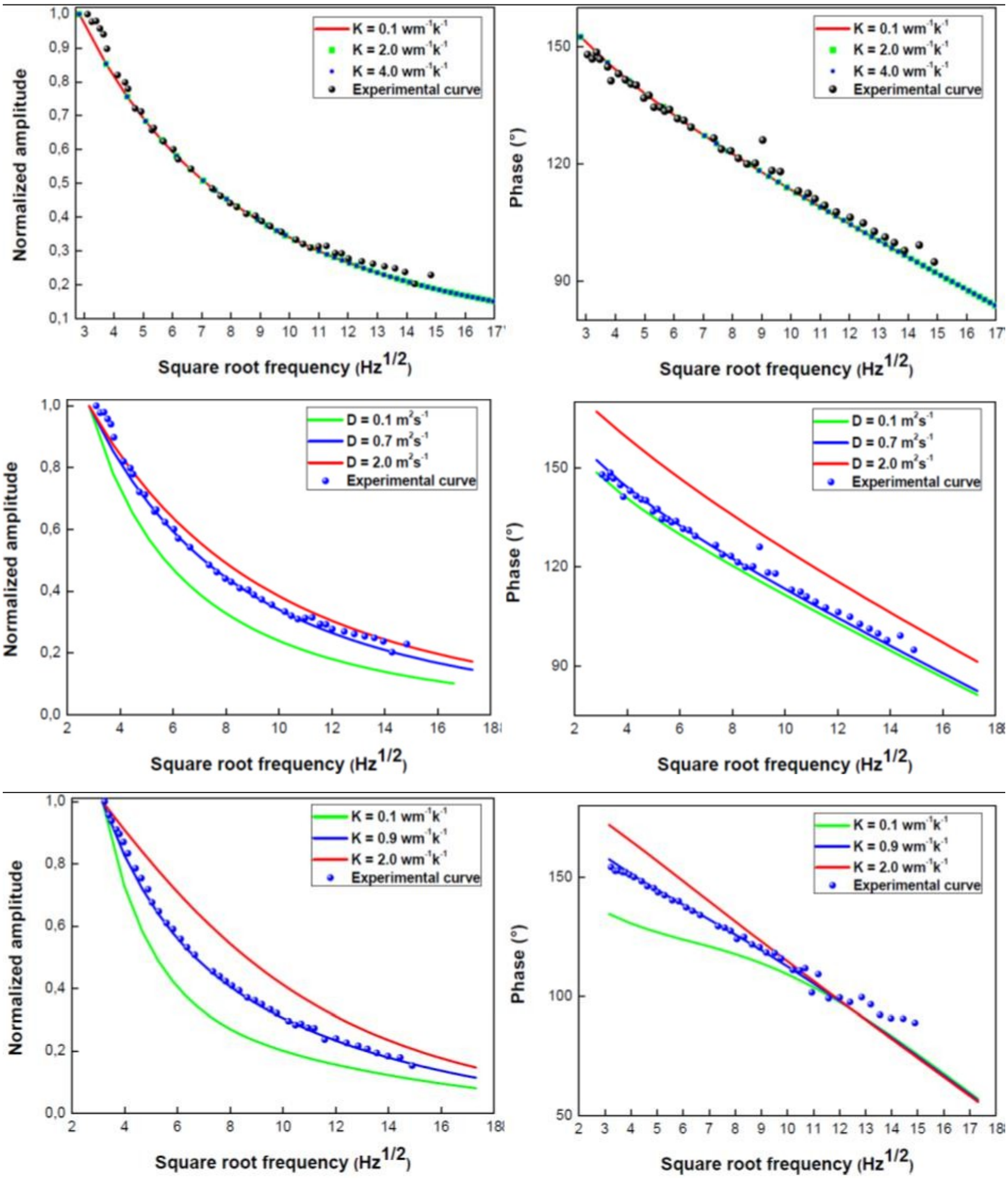

Figure 1: Normalized amplitude (1) and phase (2) of experimental (dots) Photothermal signal versus square root modulation frequency of the MOS without PVAc (MOS0) fitted with theoretical curves (line) (a) Sample without black layer with three thermal conductivity values (b) Sample without black layer with three thermal diffusivity values (c) Sample with black layer with three thermal conductivity values.

Figure 4 illustrates that the photothermal signal of MOS0 (without PVAc: MOS0) is sensitive to thermal diffusivity (b) and thermal conductivity ((c): when the black layer was added) Which makes it possible to deduce its value. The best coincidence between experimental and theoretical curves was achieved with a thermal diffusivity value of 0.7 m^2/s and a thermal conductivity value of 0.9 W/m·K.

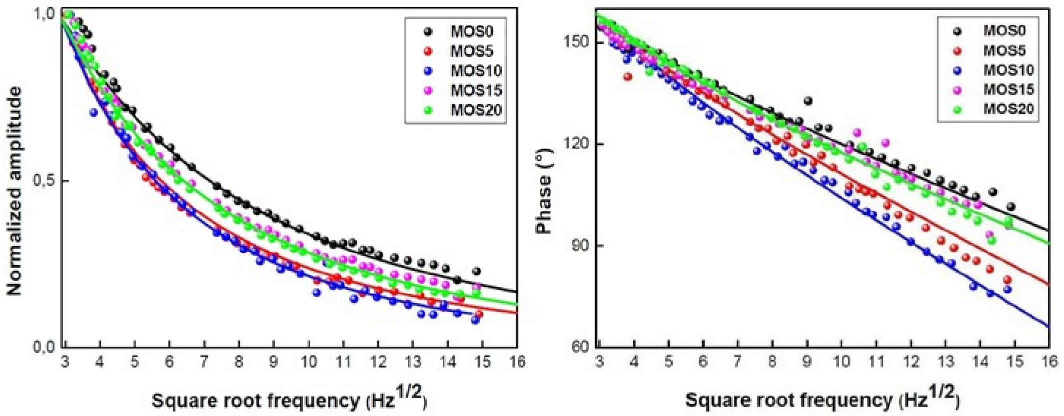

Figure 2: Normalized amplitude (a) and phase (b) of experimental Photothermal signal versus square root modulation frequency of the MOS with PVAc fitted with theoretical curves (line)

We applied a similar approach to determine and present the thermal properties of the composite material (MOS+PVAc) in Table 1.

specimens	Thermal conductivity (W/mK)	Thermal diffusivity × 10^{-7} (m^2/s)
MOS0	0.90 ± 0.04	0.70 ± 0.10
MOS5	0.53 ± 0.02	0.10 ± 0.05
MOS10	0.30 ± 0.03	0.09 ± 0.005
MOS15	0.52 ± 0.01	0.50 ± 0.03
MOS20	0.51 ± 0.01	0.50 ± 0.02
PVAc [7]	0.10 ± 0.02	0.01 ± 0.005

Discussion

The addition of PVAc polymers tends to decrease the thermal conductivity and thermal diffusivity of MOS (Table 1). This reduction in the cement's thermal properties is attributed to the insulating effect of polyvinyl acetate particles. The thermal properties of PVAc were determined using our PTD technique [7], revealing lower thermal conductivity ($k = 0.1$ W/m·K) and thermal diffusivity ($D = 0.01$ m^2/s) compared to the cement matrix. Therefore, the thermal conductivity and thermal diffusivity values of sample MOS0 are significantly higher compared to the various MOS+PVAc samples.

It is well known that the thermal conductivity of amorphous is considerably lower than that of crystals. It decreases in the presence of disorders. When the mean free path is limited by the collision of phonons with a surface, interfaces, impurities and crystal defects, the thermal conductivity decreases. We can therefore explain the reduction in the thermal properties of MOS by the appearance of a large quantity of fine air bubbles in the cementitious matrix. Moreover, it is also known that the quantity and the size of the pores influence the diffusion of the phonons and therefore the mean free path and consequently the thermal conductivity [7]. We see that the optimal sample is the MOS with 10% PVAc, this corresponds to reducing the thermal diffusivity by 66% and the thermal conductivity by 87%.

Conclusion

This research investigated the impact of varying percentages of PVAc on the thermal of MOS cement. The key findings are summarized as follows:

- The thermal properties of MOS cement decreased with the addition of PVAc. Specifically, thermal conductivities and thermal diffusivity values decreased from 0.90 to 0.30 W/m·K and from 0.70 to 0.09 m^2/s, respectively.
- Adding 10% PVAc notably improved the thermal performance of MOS compared to other samples. This enhancement is attributed to the formation of small air bubbles within the cement matrix, as observed experimentally.

Acknowledgment

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