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Physical and mechanical properties of gypsum-based composites reinforced with PVA and PP fibers

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HIGHLIGHTS

- The properties of gypsum-based composites with polymeric fibers were studied.
- PVA fibers could remarkably accelerate the hydration process of the fresh mixtures.
- The toughness of the composites with PVA fibers was significantly increased.
- The ITZ between the PVA fiber and gypsum was remarkably compact.

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ABSTRACT

The aim of this study was to investigate the influence of polyvinyl alcohol (PVA) and polypropylene (PP) fibers on such properties of gypsum-based composites as workability, hydration kinetics, flexural strength and toughness. In recent decades, polymeric fibers have been widely applied in construction industry due to their good performance. Hence, several series of gypsum-based composites reinforced with PVA and PP fibers (6–12 mm length, 0–1.2% by volume fraction) were developed in this research and the physical, mechanical properties were tested. The results showed that PVA fibers could remarkably reduce the workability, accelerate the hydration process and increase the flexural strength and toughness of the hardened gypsum-based composites, compared to PP fibers. Through the use of SEM, it was observed that the ITZ between the PVA fiber and dihydrate crystals was remarkably compact and much small gap.

1. Introduction

As an ancient building material, gypsum has been widely used in the field of construction engineering for many years due to its various unique advantages [1–5] including low energy consumption, cost effective, good fire resistance, thermal and sound isolation properties etc. In addition, gypsum can be recycled endlessly in an appropriate preparation process based on the basic theory [6,7]. Therefore, gypsum has been a popular subject among many researchers in recent decades [8]. However, low water resistance [9–11] and brittleness matrix [12–14] are two serious issues that restrict the use of gypsum under some special conditions.

To overcome the degradation of the gypsum performance in a humid environment, the additions, such as aluminate cements [15], slag [15], rice husk [16] and isostatic graphite [17,18], were used to enhance the mechanical performance of gypsum-based composites. Furthermore, surfactants were also employed to improve gypsum water resistance [19,20]. It is believed that these chemicals can combine with calcium ion to produce new complexes, resulting in the reduction of gypsum solubility.

It was widely accepted that the use of fiber was one of the most effective methods to increase the flexural strength, toughness and fracture energy of the gypsum-based composites [12–14] and the fibers were mainly glass fibers [11,14], polypropylene (PP) fibers [13,21], and textile fibers [12]. The literatures [13,22] reported that more than 3% fiber dosage by volume fraction could result in mixing problems in fresh mixtures, which had a negative impact on the properties of gypsum-based composites. The researchers [23] showed that the sisal fibers could reduce the compressive strength of gypsum-based materials.

Polypropylene (PP) fiber with light quality, high strength, low cost and rich in resources [24] is widely used in building materials. Numerous experiments were carried out to study the effect of PP

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fibers on gypsum-based composites [13,21,25] and other kind of composites [26–28]. Deng et al. [13] showed that 12% dosage of 12 mm PP fibers and 9% dosage of 3 mm PP fibers were optimum for the internal bond strength of gypsum-based composites. Gencel et al. [25] reported that vermiculite could remarkably reduce the compressive strength of gypsum-based composites, while PP fibers slightly increased the strength. The researchers [29] also found that when the content of PP fibers was 0.5 and 1% by weight, the compressive strength of gypsum-based composites increased 22.2% and 55.6%, respectively. However, the article [23] drew a contradictory conclusion that PP fibers had a negative effect on the compressive strength of gypsum-based composites. Therefore, it is necessary to systematically study the influence of PP fibers on the physical and mechanical properties of gypsum-based composites.

Polyvinyl alcohol (PVA) fibers have an extensive application in engineered cementitious composite (ECC) design over last decade due to its excellent mechanical properties, great corrosion resistance, high bond strength and non-toxic [30–32]. A large number of literatures reported that PVA fibers were used to enhance the physical and mechanical properties of cement-based composites [33–36]. It was concluded that PVA fiber could increase the adhesive strength between fiber and cement matrix due to its hydrophilic nature [34,35,37]. The factors, such as fiber type, geometric characteristic and volume dosage, had a great impact on the properties of cementitious composites [38]. Bezerra et al. [37] reported that PVA fibers was more effective than PP fibers to increase the flexural strength and toughness of cement-based composites, which was ascribed to high adhesion performance and strong tensile strength of PVA fibers.

However, almost no literature on the application of PVA fibers in gypsum-based materials is reported, which is disadvantageous to promote the application of gypsum-based materials in construction industry. Therefore, it is obvious that extra attention should be paid to determining the effect of PVA fibers on the physical and mechanical properties of gypsum-based composites.

In this paper, the hydrophilic PVA fibers and hydrophobic PP fibers were selected to systematically study the influence of polymeric fiber type, length and dosage on the workability, hydration process, strength and toughness of gypsum-based composites by comparison method, which was advantageous to promote a more efficient use of gypsum as plastering, wallboard, ceiling and so on in the construction industry. Furthermore, the fiber-gypsum interface transition zone (ITZ) and characteristics of dihydrate crystal morphology were also investigated through SEM.

2. Experimental study

2.1. Raw materials

The natural calcium sulfate hemihydrate powders confirming to the requirements of GB/T 9776-2008 [39] was used in this study, produced by Yingcheng Shengchang Gypsum Products Co., Ltd. The fundamental physical properties and chemical composition of the hemihydrate powders are given in Tables 1 and 2, respectively. The particle size distribution of the powders is given in Fig. 1. The physical and mechanical properties of polyvinyl alcohol (PVA) and polypropylene (PP) fibers are presented in Table 3.

Table 2
The chemical composition of the hemihydrate powders used in this experiment.

SO_3	CaO	Al_2O_3	SiO_2	Fe_2O_3	K_2O	SrO
48.23	37.62	0.49	1.83	0.26	0.13	0.07

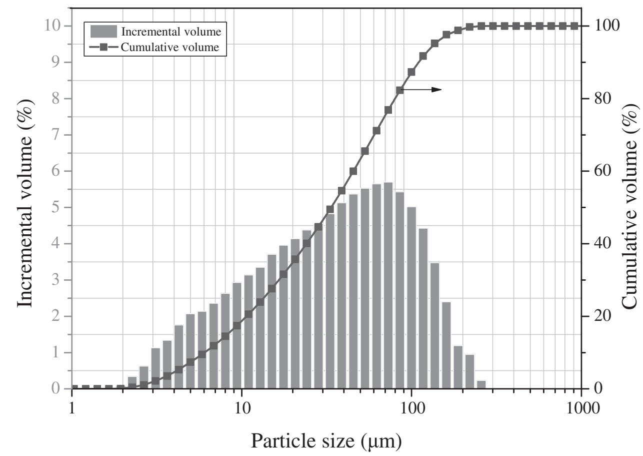

Fig. 1. Particle size distribution of the natural hemihydrate powders.

2.2. Mixture proportions

Two different series of gypsum-based composites reinforced with polymeric fibers were performed. In order to distinguish them, the series with PVA fibers were named GVA-m-n and another series with PP fibers were named GPP-m-n. The m represented the fiber length, varying from 6 to 12 mm, and the n represented fiber dosage, varying from 0 to 1.2% by volume fraction. The mixture proportions of the specimens are shown in Tables 4 and 5. The water/gypsum ratio was maintained 0.6 in order to limit the variables under the study.

2.3. Mixing procedure

The mixing procedure was performed according to Ref. [40]. Firstly, each time 1000 g hemihydrate powders and 600 g water were premixed for 20 s using a mixer. Then, PVA or PP fibers were added to the mixture and mixing were continued for 30 s. Finally, tested the physical properties of fresh slurry. Additionally, prismatic specimens with $4 \times 4 \times 16\ cm^3$ were casted to determine the mechanical properties of the hardened mixtures. In order to exclude the impact of different humidity inside the specimens, after stored in an indoor environment for one day, the specimens used for the determination of dry strength were dried in an oven at $40 \pm 4\ °C$ to constant weight. The dried specimens were immersed in water for 24 h, then performed the water-saturated strength test.

Table 1
The fundamental physical properties of the hemihydrate powders used in this experiment.

Material	Specific surface area (m^2/kg)	Water requirement for normal consistency (%)	Setting times (min)		Flexural strength (MPa)		Compressive strength (MPa)	
			Initial	Final	2 h	Dry	2 h	Dry
Gypsum	687.5	61.0	12	18	3.27	5.18	8.63	13.25