

Porous Materials Composed of Flue Gas Desulfurization Gypsum and Textile Fiber Wastes

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Abstract Flue gas desulfurization (FGD) gypsum and textile fibers constitute two large-scale industrial wastes generated in China. In this work, these wastes were used for making foamed concrete which can increase the energy efficiency of buildings. The effects of the W/S ratio, super plasticizer amount, foaming agent as well as textile fibers contents on the compressive strength and density values of the porous FGD gypsum plaster materials was systematically investigated. The highest compressive strength value of the gypsum blocks was 1.6 MPa after 7 days of curing, and the measured density value was 617 kg/m³. The obtained results suggest an effective way to recycle FGD gypsum and textile fiber wastes in order to produce not only low-cost and effective buildings materials, but also to lessen the environmental impact.

Keywords Porous materials · Industrial wastes · FGD gypsum · Textile fibers

Introduction

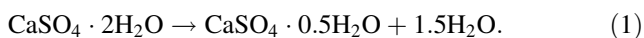
The manufacture of construction materials by using industrial wastes is potential substitutes for making new materials undoubtedly contribute to saving of natural resource and protecting of the environment, such as phosphogypsum disposal with cement plant CO₂ removal [1], fly ash is used for manufacturing unfired brick and cement [2–6], fluidized bed combustion wastes are manufactured for building components [7–9], calcium looping spent sorbent as a limestone replacement in the manufacture of cements [10]. Flue gas desulfurization (FGD) gypsum, a common solid waste from coal power and heating plants, is worthy of consideration because they are generated in huge amounts and are utilized to a still unsatisfactory extent [11]. Wet limestone is often used to absorb SO₂ to reduce emission of pollutants to the atmosphere but the process generates the by-product, FGD gypsum. As flue gas desulfurization is increasingly used in these plants, more FGD gypsum is produced and the annual production of FGD gypsum in China has been projected to be nearly a billion tons after 2010 [12]. Since recycling of the waste is insufficient, it is usually dumped at waste disposal sites [13]. In view of resource management, economics, and environment, it is imperative to recycle FGD gypsum waste. The main FGD gypsum constituent is CaSO₄·2H₂O [14, 15], therefore the construction industry can utilize the materials as cement retarders [15–17] and manufacturing of CaSO₄·0.5H₂O or CaSO₄ based on calcination [18, 19]. Moreover, calcined natural or chemical gypsum after accelerated curing is a basic component in prefabricated lightweight building elements [20]. Apart from these, FGD gypsum is also used for building materials [21], such as fire resistant panels [22], cement and concrete [16, 21]. Calcined gypsum can be produced from FGD gypsum by

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dehydration at 110–150 °C. The β -calcined gypsum forms according to Eq. (1):



During hydration, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ is formed [12]. However, though this compound has a solubility of 0.256 g per 100 g of water at 20 °C, it cannot be used directly on the exterior of buildings because rain water will dissolve it [23, 24], although gypsum blocks are ecologically and energy friendly due to their good properties, small dimensional change, and easy application [25, 26].

Many types of wastes produced by the textile industry have ecological effects because they are not biodegradable and may release toxic fume to the environment [27]. Most of the fibrous wastes are composed of natural and synthetic polymeric materials such as cotton, wool, silk, polyester, nylon, polypropylene, etc. [28]. It is therefore also important to identify means to recycle these materials to reduce the environmental impact and conserve energy.

In this paper, we describe the use of FGD gypsum as basic component for the production of foamed concrete which exhibits attractive energy-saving properties and other advantages such as light weight and good thermal insulation. Light foamed concrete with excellent thermal insulation performances is prepared from FGD gypsum and textile fibers. The foamed concrete is subsequently toughened with textile fibers and the properties and performance of the materials are determined systematically. The reinforcing mechanism is proposed to discuss the properties and performance of the materials.

Experimental Details

Materials

FGD gypsum was provided by Xinghua Gypsum Plant (Tangshan Hebei, China). In order to obtain calcined gypsum, FGD gypsum was heated in an electric oven at 170 °C for 2 h. Afterwards, it was stored in a desiccator at room temperature to avoid any contamination. The foaming agent (KC-15) was supplied by Beijing Zhongke Building Materials Technology Co., Ltd, a naphthalene sulfonate-formaldehyde condensate (FDN), a kind of water-reducing agent, purchased from Beijing Muhu Concrete Admixture Co., Ltd was also employed.

Sample Preparation

A weighed quantity of FGD gypsum which was filtered in through a 0.075 mm sieve was mixed under dry condition prior the addition of regular tap water. After casting, they were laid aside for 2 h. After demolding, the specimens

were cured for 7 days at a relative humidity of 50 % and room temperature before the evaluation of mechanical properties.

Techniques and Test Methods

X-ray diffraction (XRD) analysis was performed on a Philips PW 1050 powder diffractometer (Cu-K α radiation, filtered by graphite, and excited by 100 mA at 40 kV, the scanning rate was 8°/min, as shown in Fig. 1). The major chemical composition were determined by X-ray fluorescence (XRF) on a Thermo electron corporation ARL ADVANT XP+ system equipped with Rh radiation at 50 kV as shown (Table 1). Thermogravimetric–differential thermal analysis (TG–DTA) of the precursors was performed in air from the ambient temperature to 600 °C at a rate of 10 °C/min controlled by a computer as shown in Fig. 2.

The apparent density value of the materials was determined through the evaluation of the ratio between weight and dimensions of the products. Compression tests were performed on 40 × 40 × 40 mm³ on samples by using UTS machine at a loading rate of 5 mm/min. In this experiment, three samples were measured to improve the statistics.

Results and Discussion

The water–solid (W/S) ratio was adjusted by mixing different volumes of water with FGD gypsum to produce stable gypsum-based blocks. Each FGD gypsum block with a different W/S ratio had a different bulk density and compressive strength values. Figure 3 shows the variation in the compressive strength and density values with

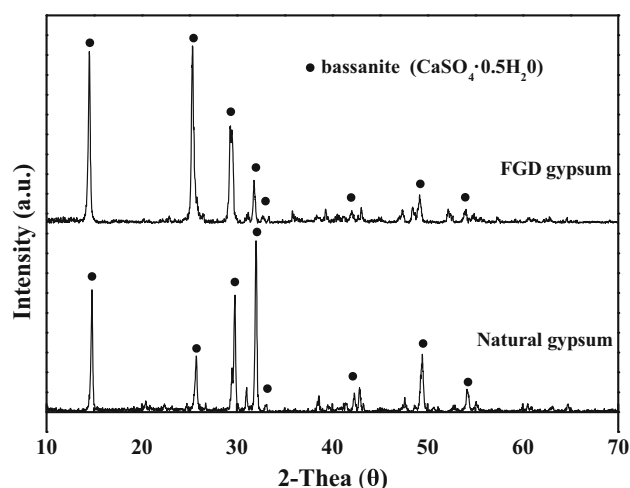


Fig. 1 XRD pattern of natural and FGD gypsum

Table 1 Chemical Composition of the raw materials (wt%)

CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	SO ₃	Na ₂ O	K ₂ O	Loss	Total
41.31	3.24	1.85	0.306	1.86	43.76	0.161	0.246	6.92	91.1

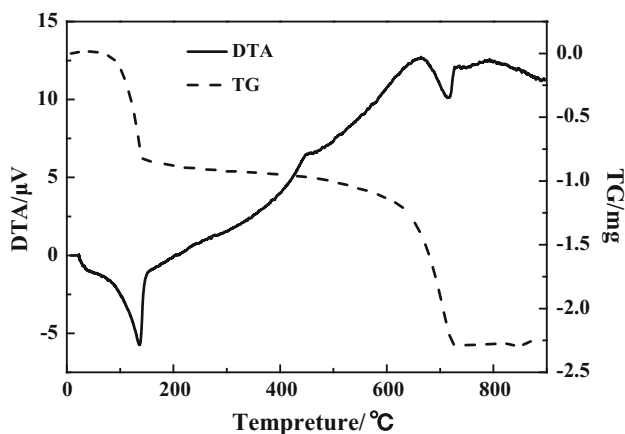


Fig. 2 DTA-TG of FGD gypsum

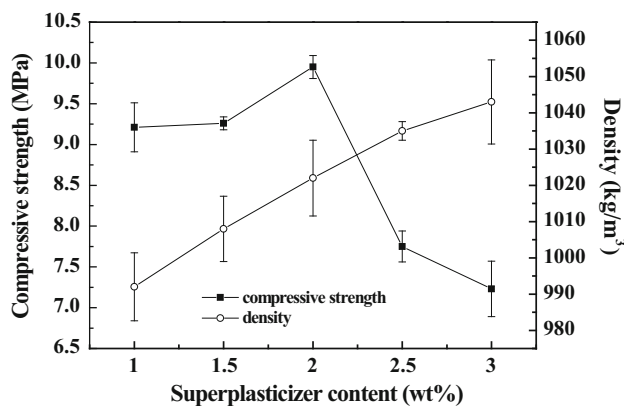


Fig. 4 Physical properties of FGD gypsum blocks with different amounts of superplasticizer

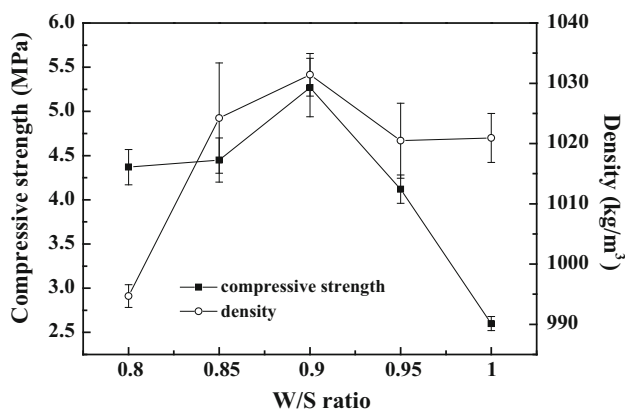


Fig. 3 Physical properties of FGD gypsum blocks with different W/S ratios

different W/S ratios after a curing period of 7 days. FGD blocks displayed compressive strength values ranging from 2.6 to 5.3 MPa as well as densities values ranging from 995 to 1031 kg/m³. As the W/S ratio was increased from 0.8 to 1, compressive strength and density values of FGD gypsum blocks initially increase (reaching the maximum values of 5.3 MPa and 1031 kg/m³), respectively, and then decreased. The compressive strength values ascended slightly when the W/S ratio is low (0.8–0.85) and reached a maximum of about 5.3 MPa when the W/S ratio was 0.9. Further increase led to a rapid decrease in the compressive strength values. The compressive strength values exhibited a similar tendency with initial increase from 995 to 1024 kg/m³ for W/S ratios less than 0.85 and slow increase afterwards from 1024 to 1031 kg/m³. The maximum density value of 1031 kg/m³ was observed when the

W/S ratio was 0.9 and then decreased at larger W/S ratios. According to Eq. 1, the water content is only 19 % weight of the calcined gypsum. However, owing to water absorption by the gypsum and lubrication in the mixing process, the water requirement should be larger than 19 %. When the W/S ratio is lower than 0.9, although there is sufficient water in the hydration process, it is insufficient for lubrication in the mixing process. Therefore, some air and stress are not released in the solidification process and consequently, the compressive strength and density values of FGD gypsum block is relatively low. When the W/S ratio exceeds 0.9, there is enough water for both hydration and lubrication. More water evaporates during the solidification process creating pores in FGD gypsum block. However, if the W/S ratio is increased further, the compressive strength and density values of FGD gypsum blocks decrease. Based on our experimental results, 0.9 is the optimal W/S ratio.

The variation in the 7-day compressive strength and density values with different plasticizer contents is illustrated in Fig. 4. The compressive strength values of FGD gypsum varied from 7.2 to 9.9 MPa and the density values varied from 992 to 1043 kg/m³. As the super plasticizer content was increased, the compressive strength values increased initially and then decreased. The maximum value of 9.9 MPa was achieved at a super plasticizer content of 2 wt%. The density values of FGD gypsum blocks increased steadily with super plasticizer contents from 992 to 1043 kg/m³. The purpose of the super plasticizer is to reduce water consumption during hydration and lubrication in the mixing process. When the extra water evaporates,

less air is left in FGD gypsum block and so the compressive strength and density values of FGD gypsum blocks increase when the super plasticizer concentration is 2 wt%. As more super plasticizer is introduced to FGD gypsum block, the extra plasticizer prevents the gypsum crystal to evolve consequently reducing the strength value of the gypsum crystal. Hence, the compressive strength value begins to decrease. The large amount of super plasticizer leaves less air and the density value of FGD gypsum block increases. Based on these results, the optimal concentration of 2 wt% is adopted in subsequent experiments.

The variation in the compressive strength and density values of the samples (super plasticizer concentration of 2 wt% and W/S ratio of 0.9) with foaming agent contents is plotted in Fig. 5. The strength values varied from 0.5 to 7.5 MPa and the density values varied from 321 to 989 kg/m³. As the foaming agent content is increased, the compressive strength and density values decrease due to more air bubbles in GD gypsum blocks. The results suggest that air bubbles replace FGD gypsum content resulting in lower compressive strength and density values. When the foaming agent content is 0.3 wt%, most of the air bubbles exist in FGD gypsum block but if it is increased above 0.3 wt%, there are too many air bubbles which are then released and the unit volume is not changed significantly. This explains why the compressive strength and density values of FGD gypsum blocks decrease when the foaming agent content is less than 0.3 wt% but stabilizes at over 0.3 wt%. In the following experiments, the optimal foaming agent content is selected to be 0.2 wt%.

The variation in the 7-day compressive strength and density values with different textile fiber contents is displayed in Fig. 6 for the W/S ratio of 0.9, super plasticizer content of 2 wt%, and foaming agent content of 0.2 wt%. The compressive strength values ranged from 0.9 to 1.6 MPa and density values from 422 to 620 kg/m³. As the

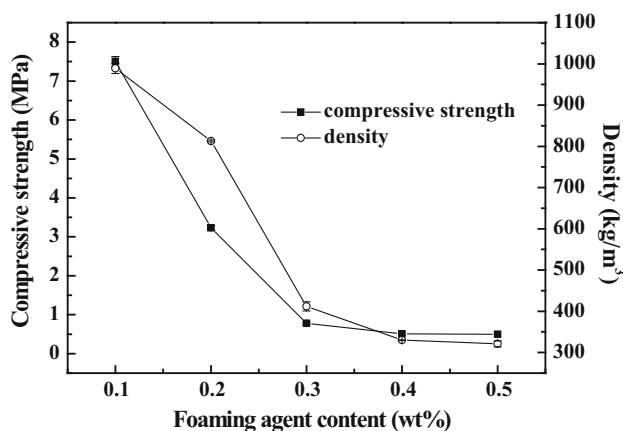


Fig. 5 Physical properties of FGD gypsum blocks with different foaming agent amounts

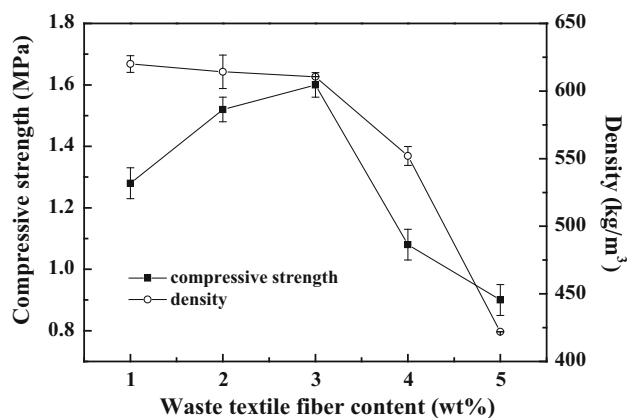


Fig. 6 Physical properties of FGD gypsum blocks with different textile fiber amounts

textile fiber content was increased, compressive strength value first increased and then decreased when the textile fiber concentration was higher than 3 wt%. The compressive strength value reached a maximum of 1.6 MPa when the textile fiber content was up to 3 wt%. Unlike the compressive strength values, the density values of FGD gypsum block showed a decreasing trend with textile fiber concentrations. The textile fibers improved the compressive strength value of FGD gypsum block when the fiber content was 3 wt%. If additional textile fibers are incorporated to replace FGD gypsum, the overall compressive strength value decreases. As the textile fibers are lighter than gypsum per unit volume, the density values of FGD gypsum blocks decrease. According to our data, a textile fiber content of 3 wt% leads to the best performance in terms of compressive strength and density values.

The variation in the 7-day compressive strength and density values with different gypsum between FGD gypsum and natural gypsum is displayed in Fig. 7 for the W/S ratio of 0.9, super plasticizer content of 2 wt%, foaming

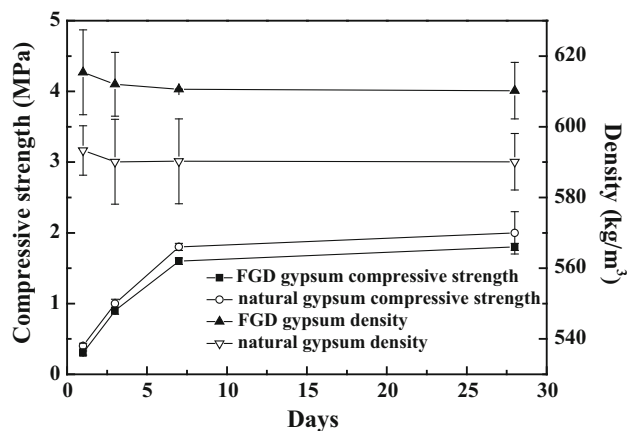


Fig. 7 Physical properties of FGD gypsum blocks with different textile fiber amounts

agent content of 0.2 wt%, and waste textile fiber content of 3 wt%. FGD gypsum compressive strength values varied from 0.3 to 1.8 MPa and the density values from 610.2 to 615.4 kg/m³. The natural gypsum compressive strength values varied from 0.4 to 2 MPa and natural gypsum density values from 590.1 to 693.3 kg/m³. The natural gypsum compressive strength value was bigger than FGD gypsum compressive strength value, and the natural gypsum density value was smaller than FGD gypsum density value. It is because the particle size of FGD gypsum is more uniform and their distribution is very narrow and worse than that of natural gypsum.

Conclusion

Foamed gypsum blocks were prepared from FGD gypsum and textile fiber wastes. The effects of the W/S ratio, super plasticizer content, foaming agent amount, and waste textile fiber content on the mechanical properties were investigated and discussed. The optimal W/S ratio, super plasticizer content, foaming agent amount, and waste textile fiber content were 0.9, 2, 0.2, and 3 w%, respectively. The maximum compressive strength value was equal to 1.6 MPa after 7 days of curing while the density value was 617 kg/m³. The obtained results suggest a possibility of making effective process to recycle industrial wastes and by-products which can undoubtedly to lessen the environmental impact due to utilize disposal.

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