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Research on degradation mechanisms of recycled building gypsum

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HIGHLIGHTS

- The recycled gypsum was much easier to grind than the natural gypsum ores.
- The recycled hemihydrate powders had larger specific surface area and void fraction.
- Porosity and larger pore size of the hardened recycled gypsum were increased.
- The crystal morphology of recycled gypsum gradually became short columnar shape.
- The recycled hemihydrate particles had a poor sphericity.

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ABSTRACT

In order to provide a solid theoretical foundation for the efficient reuse of waste gypsum, the research on the degradation mechanisms of recycled gypsum mechanical performance was carried out in this paper. The recycled gypsum was prepared with natural gypsum ores in the laboratory and three rational comparative methods were proposed through constraining the conditions: the preparation process, the particle size distribution and the water/gypsum ratio. The results showed that the recycled dihydrate gypsum was much easier to grind than the natural gypsum ores, resulting in deteriorated particle size distribution, large specific surface area and void fraction, poor sphericity, which remarkably increased the water requirement. The increase in porosity and larger pore size due to excessive water evaporation was the determining factor leading to a significant decrease in the strength of the recycled gypsum. However, the short columnar shape crystals seemly would only have a slight disadvantageous on the flexural strength. Moreover, the crystal morphological characteristics of dihydrate gypsum had a decisive influence on the sphericity of recycled hemihydrate particles.

1. Introduction

With the increasing progress of human society, construction industry accounts for about 30–40% of the total energy consumption in many countries [1]. Moreover, the proportion has a tendency to continue to increase for the coming decades [2]. It was reported that production process was responsible for about 40–60% of the total energy consumption in the whole industrial system [3,4], resulting in a large amount of CO_2 emissions, which had an important impact on our ecological environment. Therefore, in order to protect environment, save resources and reduce energy consumption, the reasonable reassessment of waste materials and useless products is recognized as a more effective method for resource management and the reintroduction of waste materials in the production chain has attracted great attention among researchers from various countries [5].

As one of the earliest building materials, the application history of gypsum can be traced back to 4000 years ago [6]. Nowadays, gypsum building materials have been widely applied in the field of construction projects, which is ascribed to its various outstanding advantages including easy fabrication features, low energy consumption and price, aesthetics, a good fire resistance, thermal properties [7–11]. Additionally, the dihydrate and hemihydrate phases of calcium sulfate can be converted into each other under certain conditions, which provides a basic theory for the recycling of waste gypsum [12,13]. Therefore, many scholars have paid great attention to the study on the international recommended green gypsum building material in recent decades [14].

However, according to Gypsum Recycling International, presently more than 15 million tons of waste gypsum is being sent to landfills yearly in Europe, USA and Asia [15]. It should be noted

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that the accumulation of waste gypsum in garbage dump would break down toxic gases, such as hydrogen sulphide gas and methane gas, causing great pressure on our environment. More importantly, effective reuse of waste gypsum is the only solution that preserves natural gypsum ores resources and prevents future shortages of raw materials. Recycling helps plasterboard manufacturers to source raw materials of high quality at the lowest cost and improves the environmental image of the gypsum and plasterboard industry. Therefore, it is necessary to study the waste gypsum and turn it into an available resource, which is highly significant to protect the environment, save resources and reduce emissions.

With the aim to solve the severe problem, today new gypsum recycling systems have been introduced in many European countries and North America. Norway and Sweden started a project, named "Gypsum to Gypsum" [16], with the overall aim of achieving higher recycling rates of waste gypsum from demolition waste market [17], thereby helping to achieve a resource efficient economy. Meanwhile, numerous studies on the performance of recycled gypsum has been carried out in the last decade and the results shown that waste gypsum had the ability to be reused [18–21]. It was reported that the industrial waste gypsum was re-calcined into regenerated hemihydrate powders and the hydrated recycled gypsum had similar physical, chemical and mechanical properties, compared to the original gypsum [18,19], which meant that the waste gypsum could be reasonably reused. In addition, the DSC/TG and SEM experiments demonstrated that thermodynamic performance and microscopic crystal morphology of the recycled gypsum were close to those of the original gypsum [20,21]. Chandara et al. [22] shown a study on the use of ceramic mold waste plaster instead of natural gypsum to produce cement. It was found that the cement coagulation became faster: the initial and final setting times were shortened by 15.29% and 13.67%, respectively. But the flexural and compressive strength of the cement were consistent, compared to the cement with natural gypsum. Moreover, the studies also shown that recycled gypsum was beneficial to enhance the strength, stability and durability of soft soil foundation [23–28].

Although the current research on recycled gypsum has made some progress, they are limited to once-recycled gypsum and the inherent causes of changes in performance of recycled gypsum is still vague. Therefore, it is obvious that extra attention should be paid to determining the deterioration mechanisms of recycled gypsum mechanical performance, which was advantageous to efficient endless reuse of waste gypsum. This paper proposed three rational comparative methods through constraining the conditions: the preparation process, the particle size distribution and the water/-gypsum ratio, with the aim to gradually determine the factors influencing the performance of recycled gypsum. Additionally, the pore structure characteristics and the microscopic morphology were also studied through mercury intrusion and SEM methods, respectively.

2. Experimental study

2.1. Raw materials

In order to effectively study the effect of regeneration frequencies on the physical and mechanical properties of building gypsum, the same preparation process and high purity need to be guaranteed to limit the variables under the study. Therefore, the natural gypsum ores produced by Yingcheng Shengchang Gypsum Products Co., Ltd, were selected to prepare four kinds of hemihydrate powders. Table 1 shown that the purity of the gypsum ores was about 90%, which could availably avoid the impact of impurities on the experiment. It could be observed from Fig. 1 that the crystal morphology of the gypsum ores was short column shape, which was advantageous to reduce the water demand for normal consistency.

2.2. Preparation process

According to Fig. 2, the detailed process of dehydration of dihydrate into hemihydrate was as follows: Firstly, the dry gypsum blocks were crushed into coarse particles using a jaw crusher, then, each time approximate 20 L of the coarse particles were grinding for 5 min through a ball mill. After that, the 2 cm thick calcium sulfate dihydrate powders in an iron plate were calcined in an oven at 160 ± 4 °C for 3 h and then placed the dehydrated powders in an indoor environment, aging for two days. Finally, the calcium sulfate hemihydrate powders were produced out in laboratory. The detailed process of hydration of hemihydrate into dihydrate was as follows: Firstly, each time mixed 1000 g hemihydrate powders with 600 g water fully (0.6 water/gypsum ratio), then the homogenous slurry was casted to $4 \times 4 \times 16\ cm^3$ prismatic specimens. After one day, the demolded gypsum blocks were dried in an oven at 40 ± 4 °C to constant weight.

Finally, the original, once-recycled, twice-recycled and thrice-recycled hemihydrate powders were determined by the recycle number times of natural gypsum ores. It should be noted that the preparation process of each cycle need to maintain the same, with the aim to limit the impact of other variables in the study.

After the four hemihydrate powders were prepared according to the preparation process (Fig. 2), in order to systematically study the degradation mechanisms of recycled building gypsum mechanical properties, three rational comparative methods were proposed through constraining the conditions: (1) The amount of water requirement was directly determined by normal consistency and the first comparative method was marked as "under the same preparation process". (2) On the basis of the first method, the four hemihydrate powders were divided into five particle size ranges (<15, 15–45, 45–80, 80–145, >145 μm) by sieving method respectively, then mixed fully each interval powders by mass ratio 20: 30: 20: 20: 10. The amount of water requirement was determined by normal consistency and the second comparative method was marked as "under the same particle size interval". (3) On the basis of the second method, the water/gypsum ratio were maintained 0.6, 0.7, 0.8, respectively, in order to limit the variables of the hardened gypsum porosity. The third comparative method was marked as "under the same water/gypsum ratio".

2.3. Test procedures

The particle size distribution (PSD) of the four hemihydrate powders was measured through the Hydro 2000MU (A) type laser particle size analyzer with anhydrous ethanol dispersing agent and 1.520 refractive index. Firstly, added the dry hemihydrate powders until the optical concentration of the solution reached 10–20%, then started the test. The experimental result was the arithmetic mean of three samples. The specific surface area (SSA) of the four hemihydrate powders was determined by the ASAP 2020 instrument (BET method). Firstly, weighed about 1 g dry hemihydrate powders, then degassed the powders with the aim to remove the internal moisture and organic matter, finally used the instrument for testing.

The specific density (SD) ρ_s of the four hemihydrate powders was determined according to the GB/T 208–2014 [29]. The test instrument was the Lee bottle and the dispersing agent was anhydrous kerosene. It should be noted that the ambient temperature maintained at 20 ± 1 °C. Firstly, weighed 40 g of dry hemihydrate powders and recorded as m_0 (accurate to 0.001 g) the reading of