Research Article

Influence of the Heating Temperature and Fineness on the Hydration and Mechanical Property of Recycled Gypsum Plaster

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Influence of the heating temperature and fineness on the hydration and mechanical property of recycled gypsum plaster was investigated to find the suitable heating temperature and fineness. According to the results, the setting time of recycled gypsum plaster increased with the increase of heating temperature, and the mechanical strength increased first and then decreased at a temperature of 165°C. Therefore, the suitable heating temperature was 165°C, and at this time, the initial setting time and final setting time were 8 min and 12.5 min, respectively, which met the requirements of the Chinese standard of GB/T 9776-2008. The strength of recycled gypsum plaster increased with the increase of specific surface area, and the low water to plaster ratio and high strength were achieved when the specific surface area was 1526 m^2/kg. Therefore, it can be concluded that the suitable heating temperature was 165°C and the suitable specific surface area was 1526 m^2/kg considering the properties and economics of recycled gypsum plaster.

1. Introduction

Increasing amount of waste gypsum and the lack of gypsum resources have become a worldwide problem, which has attracted more and more attention [1, 2]. Research studies to solve the problem of waste gypsum have begun, and new methods for the treatment of waste gypsum in many fields have been proposed, such as preparation of cement [1, 3], soft clay improvement [4, 5], and so on. Among these solutions, the use of waste gypsum as recycled gypsum plaster seemed to be a sustainable solution, and it was also considered a positive step towards circular development in the construction industry [6]. Based on the research of Camarini et al. [7], recycled gypsum plaster can be achieved through simple processes of crushing, sieving, and heating.

In order to promote the widespread application of recycled gypsum plaster in construction activities, many scholars have carried out a series of research studies on recycled gypsum plaster. Erbs et al. [8] believed the performance results of primary, secondary, and tertiary recycled gypsum plaster were similar to that of commercial gypsum plaster. Papailiopoulou

et al. [9] assessed the practice of gypsum recycling from an economical and technical point of view and deemed the incorporation of recycled gypsum could decrease the manufacturing costs. Pedreno-Rojas et al. [10] conducted an environmental analysis of the use of recycled gypsum plaster and believed that the production of recycled gypsum plaster has a significant environmental improvement. Weimann et al. [11] conducted an evaluation of the environmental impacts for the recycling of waste gypsum and showed that the use of recycled gypsum plaster was environmentally friendly. Santana et al. [12] carried out an industrial production of recycled gypsum and proved that the recycled gypsum plaster could be used for the production of block. The above research results confirmed the feasibility of using recycled building gypsum as a fresh cementitious material.

Furthermore, Ren [13] investigated the setting time and strength and found that the setting time of recycled gypsum plaster was prolonged and the strength was decreased. Cao [14] indicated that the water resistance was decreased. Ren and Cao believed that the properties of recycled gypsum plaster were degraded. Li et al. [15] believed that the

unsuitable heating temperature led to the deterioration of recycled gypsum plaster. Zhu et al. [16] believed that the reason for the deterioration of the performance of recycled gypsum plaster was due to the change in its grindability. Thus, it can be concluded that heating temperature and fineness were the determined factors for the performances of recycled gypsum plaster.

Pereira et al. [17] evaluated the properties of recycled gypsum plaster in different heating temperatures and considered that the heating temperature had a great influence on the hydration and mechanical property of recycled gypsum plaster. Calcination at 200°C had good setting times and compressive strength, while the temperature of 150°C presented good hardness. Rossetto et al. [18] analyzed the influence of calcination time on the hydration and mechanical property of recycled gypsum plaster and found that the compressive strength, hardness, and setting times were all good when the calcination time was 5 and 6 hours. In their research, Pereira et al. and Rossetto et al. only considered the influence of limited heating temperature and did not think about the effect of fineness on the performances of recycled gypsum plaster. This seriously hinders the utilization of waste gypsum.

Consequently, influence of the heating temperature and fineness on the hydration and mechanical property of recycled gypsum plaster was investigated, and there was also a study for comparison on properties of commercial gypsum plaster.

2. Materials and Methods

2.1. Materials. The commercial gypsum came from Yingcheng in Xiaogan, China. The chemical composition of commercial gypsum shown in Table 1 and morphology of commercial gypsum shown in Figure 1 were measured by X-ray fluorescence and scanning electron microscopy, respectively. It can be seen that its main chemical compositions were CaO and SO_3, and it was fibrous.

2.2. Preparation of Recycled Gypsum. Figure 2 presents the preparation process of recycled gypsum. First, commercial gypsum was pulverized and milled with a mill for 2 min. Second, the commercial gypsum was calcined in an electric furnace at a temperature of 180°C for 3 h, and then the commercial gypsum plaster was obtained after placing in air for 2 days. Third, the commercial gypsum plaster was mixed with water to obtain the hardened commercial gypsum plaster. Finally, the hardened commercial gypsum plaster was dried at 45°C ± 2°C, which was called recycled gypsum.

Recycled gypsum was very different from commercial gypsum. Commercial gypsum was mined from nature, and it was the raw material for the production of commercial gypsum plaster. Recycled gypsum, also known as waste gypsum, was the raw material for the production of recycled gypsum plaster. It was obtained by crushing, grinding, and calcining the commercial gypsum, followed by hydrating and drying to obtain the recycled gypsum. According to our earlier research [20, 21], commercial gypsum and recycled gypsum had different grindability and pyrolysis

Table 1: Chemical composition of commercial gypsum (%) [19].

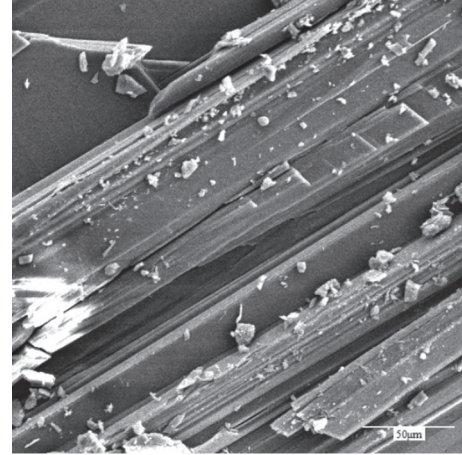| Commercial gypsum	SO_3	CaO	SiO_2	Al_2O_3	Fe_2O_3	K_2O	SrO
Chemical composition	47.57	38.73	1.15	0.42	0.13	0.07	0.04

Figure 1: Morphology of commercial gypsum.

characteristics, which led to their different heating temperatures and fineness for the production of gypsum plaster.

2.3. Experimental Techniques. Contradistinctive methods were employed to analyze the influence of the heating temperature and fineness on the hydration and mechanical property of recycled gypsum plaster. One was the investigation on the performances of recycled gypsum plaster in different heating temperatures and fineness. Another was the study on the performances of commercial gypsum plaster in different heating temperatures and fineness.

To understand this work, Figure 3 presents a chart depicting the preparation and test program. For the heating temperature, commercial gypsum and recycled gypsum were pulverized and milled with a mill for 2 min. After that, the commercial gypsum and recycled gypsum were calcined in an electric furnace at different temperatures (130°C, 150°C, 160°C, 165°C, 170°C, 175°C, 180°C, and 200°C) for 3 h, and the commercial gypsum plaster and recycled gypsum plaster were achieved after placing in air for 2 days. At last, the water to plaster ratio, setting time, flexural and compressive strengths, and water absorption of commercial gypsum plaster and recycled gypsum plaster were measured.

As for the fineness, commercial gypsum and recycled gypsum were pulverized to small pieces. Then, commercial gypsum was milled for the specific surface areas of 214 kg/ m³, 452 kg/m³, 541 kg/m³, 669 kg/m³, 838 kg/m³, 929 kg/m³, and 989 kg/m³, and recycled gypsum was grinded with a ball mill for the specific surface areas of 412 kg/m³, 630 kg/m³, 800 kg/m³, 1063 kg/m³, 1114 kg/m³, 1349 kg/m³, 1456 kg/ m³, 1518 kg/m³, and 1526 kg/m³ due to its good grindability [20]. Besides, the ground commercial gypsum and recycled gypsum were calcined in an electric furnace at a temperature
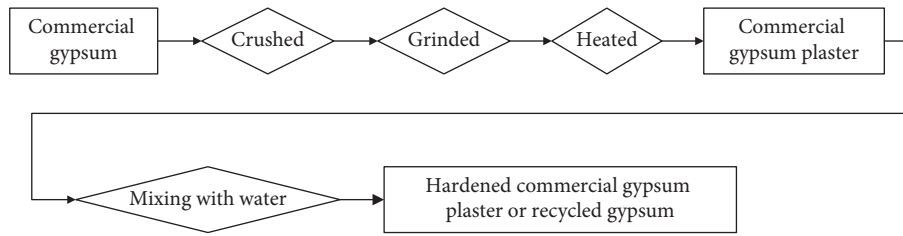
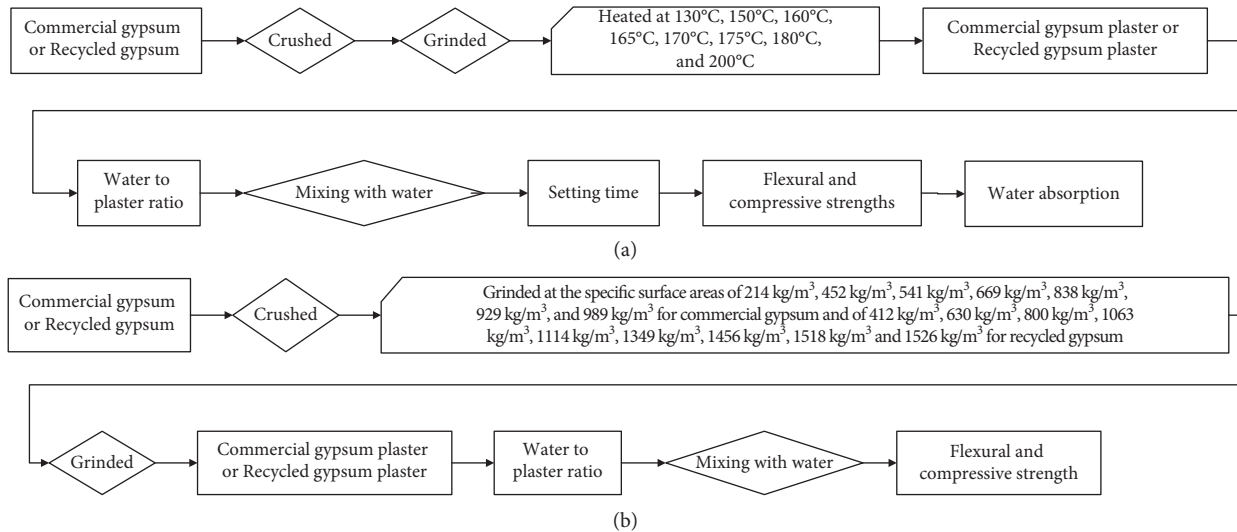FIGURE 2: Preparation process of recycled gypsum.

(a)

(b)

FIGURE 3: Testing procedure. (a) Heating temperature. (b) Fineness.

of 180°C for 3 h, and the commercial gypsum plaster and recycled gypsum plaster were achieved after placing in air for 2 days. At last, the water to plaster ratio and strength of commercial gypsum plaster and recycled gypsum plaster were measured.

2.4. Performance Testing and Material Characterization. The measurement of water to plaster ratio, setting time, flexural and compressive strengths, and water absorption was done according to the Chinese standard of GB/T 9776-2008 [22], and the experiment processes have been described in our previously published articles [23, 24]. The average statistical method was used in this article, and the specific test times for each performance were as follows: the water to plaster ratio, setting time, and water absorption were measured twice, and the average of the two measured values was taken as the result of the sample. The flexural strength was measured three times, and the average of the three measurements was taken as the result of the sample. The compressive strength was measured six times, and the average value of the six measurements was taken as the result of the sample. The flexural and compressive strengths were tested after drying the hardened body. Strength is the most important mechanical property of gypsum plaster, including flexural strength and compressive strength. Strength is closely related to other properties of gypsum plaster. Generally, the strength of gypsum plaster is usually used to assess

and control the quality of gypsum plaster, and measurement of strength has been specified in many international standards.

The morphological investigations of hardened commercial gypsum plaster and recycled gypsum plaster were studied by SEM (TESCAN VEGA III LMH), and the morphological investigations of recycled gypsum plaster powder were studied by SEM (TESCAN MIRA III LMH).

3. Results and Discussion

3.1. Effect of Heating Temperature on Performances of Recycled Gypsum Plaster. The water to plaster ratio, setting time, flexural and compressive strengths, and water absorption of recycled gypsum plaster were measured (Figure 4). Figure 4(a) shows that the water to plaster ratio decreased sharply to 0.82 around 165°C and then increased to 0.85 at 180°C as the heating temperature increased. In Figure 4(b), it could be observed that there was an increasing trend in the setting time for recycled gypsum plaster. The initial setting time of recycled gypsum plaster was only 2 min around 130°C and rose dramatically to 25 min at 170°C. At last, it increased again to 45 min at 200°C. Correspondingly, the final setting time of recycled gypsum plaster increased significantly to 32 min at 170°C and increased again but more steeply to 56 min around 200°C. It took more than 30 min and could not meet the requirements of the Chinese
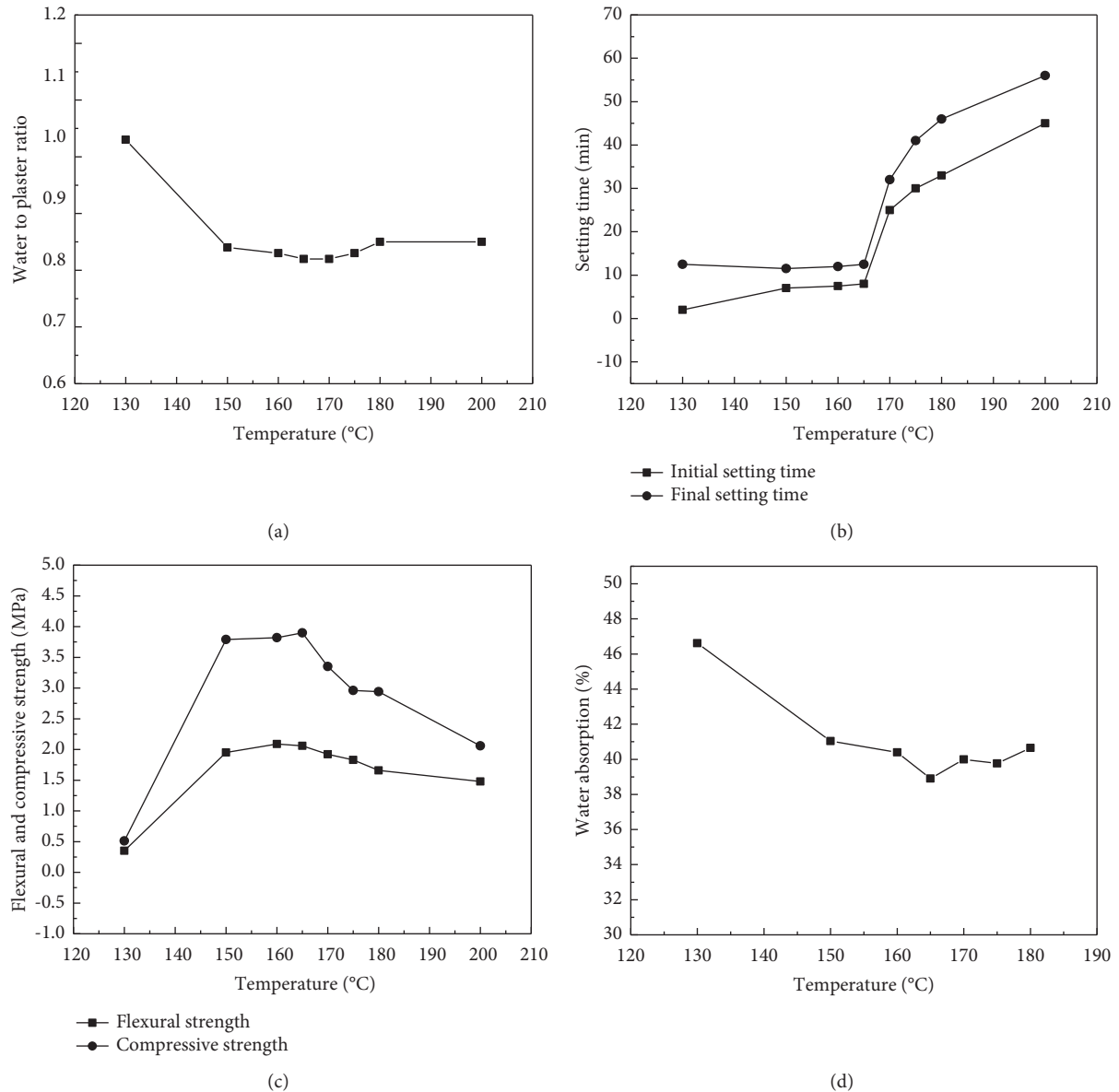
(a)

(b)

(c)

(d)

Figure 4: Effect of heating temperature on properties of recycled gypsum plaster.

standard of GB/T 9776-2008. The development trend of setting time was similar to the ones obtained by Pereira et al. [17] and Bardella et al. [25], but the number of setting time measured was different. Pereira et al. found that the initial setting time and final setting time of recycled gypsum plaster were 8 min 51 s and 14 min 50 s at 100°C, respectively, and increased to 17 min 57 s and 30 min 55 s at 150°C, respectively, when the water to plaster ratio was 0.70. Finally, they increased again to 25 min and 39 min 41 s around 200°C, respectively. As for the studies of Bardella et al., the initial setting time and final setting time of recycled gypsum plaster were 22 min 29 s and 41 min 37 s at 150°C, respectively, and increased to 25 min 50 s and 45 min 17 s at 180°C, respectively. At last, they increased again to 26 min 22 s and 52 min 25 s around 200°C, respectively, showing that the recycled gypsum plaster prepared at 200°C had a delayed reaction and

prolonged setting time. Measurements of flexural and compressive strengths and water absorption in different heating temperature are shown in Figures 4(c) and 4(d), respectively. At a temperature of 130°C, the flexural and compressive strengths of recycled gypsum plaster were only 0.35 MPa and 0.51 MPa, respectively. These numbers rose sharply to 2.06 MPa and 3.90 MPa around 165°C and then suffered a sharp drop. Ultimately, the flexural and compressive strengths of recycled gypsum plaster were reduced to 1.48 MPa and 2.06 MPa, respectively. It can be seen that the development trend of flexural and compressive strengths was opposite to the change of water to plaster ratio. It was consistent with the findings of Pereira et al. [17], and the compressive strength diminished as the water to plaster ratio increased. When the water to plaster ratio was increased from 0.60 to 0.70, the compressive strength of recycled

gypsum plaster was decreased from 7.1 MPa to 6.5 MPa at 150 °C and decreased from 11.8 MPa to 7.5 MPa around 200°C. As for the water absorption, it presented the opposite trend with the flexural and compressive strengths. The water absorption of recycled gypsum plaster was 46.62% around 130°C and then decreased sharply to 38.9% at 165°C. At this point, it increased to 40.65% around 180°C. Therefore, the suitable heating temperature of recycled gypsum plaster was 165°C. To our surprise, Pereira et al. [17] found that calcination at 200°C had good setting time and compressive strength, and Bardella et al. [25] considered that the heating temperatures of 180°C and 200°C increased the strength of recycled gypsum plaster, which were very different from our findings. This was may be due to the difference in the source of gypsum waste.

The morphologies of hardened recycled gypsum plaster are shown in Figure 5. It is evident that the morphologies and habits are significantly modified in different heating temperatures. At a temperature of 150°C, many plate-like gypsum crystals appear owing to the speeding up of setting and hardening, which decreases its flexural and compressive strengths. When the temperature is up to 165°C, the crystals are fully grown, and many needle-like crystals appear. The complete development and close overlapping of crystals reinforce the recycled gypsum plaster. To our surprise, the size of the gypsum crystals is obviously coarsened, and the overlapping between the crystals is also greatly weakened around 180°C. The loose crystalline network leads to the decrease of flexural and compressive strengths at 180°C. Analysis of hardened recycled gypsum plaster confirms that the suitable heating temperature is 165°C.

3.2. Effect of Heating Temperature on Properties of Commercial Gypsum Plaster. Figure 6 shows the water to plaster ratio, setting time, flexural and compressive strengths, and water absorption of commercial gypsum plaster. It can be seen that the water to plaster ratio changed with the increase of heating temperature in Figure 6(a). Below 170°C, the water to plaster ratio was very low due to the existence of dihydrate gypsum, which had lower water requirement than hemihydrate gypsum. The presence of dihydrate gypsum reduced the content of effective hemihydrate gypsum, and the cohesive force was insufficient during use. Thus, the heating temperature of commercial gypsum plaster should be higher than 170°C. At 170°C, the dihydrate gypsum disappeared, and the water to plaster ratio was increased from 0.55 to 0.64. It decreased to 0.63 around 180°C and then increased to 0.65 at 200°C. Figure 6(b) shows that there was an increasing trend in the setting time for commercial gypsum plaster, which was consistent with recycled gypsum plaster. The initial and final setting times were very short at 3 min and 5 min, respectively, at a temperature of 130°C. These numbers rose rapidly to 5.5 min and 8.5 min, respectively, when the temperature was up to 165°C. Finally, the initial and final setting times were increased to 11 min and 17 min, respectively, at 200°C. Determination of flexural and compressive strengths and water absorption in different heating temperatures is shown in Figures 6(c) and 6(d), respectively.

The flexural and compressive strengths were very low at 1.00 MPa and 1.85 MPa, respectively, when the temperature was 130°C. These values increased steeply to 2.94 MPa and 5.95 MPa, respectively, at 180°C and then suffered a marked reduction to 2.46 MPa and 4.83 MPa, respectively. The water absorption presented an adverse trend with the flexural and compressive strengths, and it was very low at 29.50% when the heating temperature was 180°C. Therefore, it can be concluded that the suitable heating temperature of commercial gypsum plaster was 180°C, which was higher than recycled gypsum plaster. The setting time and flexural and compressive strengths results were in accordance with Ren [13], and the setting time of commercial gypsum plaster increased as the calcination temperature increased. The flexural and compressive strengths of commercial gypsum plaster increased first and then decreased with the increase of calcination temperature. At a temperature of 180°C, the flexural and compressive strengths of commercial gypsum plaster reached the maximum. Thus, Ren thought that the suitable calcination temperature of commercial gypsum plaster was 180°C, which was consistent with our findings.

The morphologies of hardened commercial gypsum plaster are shown in Figure 7. At a temperature of 165°C, many plate-like crystals appeared, although it had more needle-like crystals knitted together, which also could be responsible for the low flexural and compressive strengths and high water absorption of commercial gypsum plaster. As for the heating temperature of 180°C, the morphology was dramatically changed. It was composed of many needle-like crystals, which was a typical gypsum crystal morphology, so that commercial gypsum plaster had good properties. This proved that the suitable heating temperature for commercial gypsum plaster was 180°C.

From the above studies, it was found that the water to plaster ratio of recycled gypsum plaster was higher than that of commercial gypsum plaster at different heating temperatures. When the heating temperature was 165°C and 180°C, these numbers of recycled gypsum plaster were 0.82 and 0.85, respectively, and those of commercial gypsum plaster were only 0.61 and 0.63, respectively. Also, the setting times of recycled gypsum plaster were longer than those of the commercial gypsum plaster. At a heating time of 180°C, the initial and final setting times of recycled gypsum plaster were 33 min and 46 min, respectively, while the values of commercial gypsum plaster were only 8.5 min and 13.5 min, respectively. However, the flexural and compressive strengths of recycled gypsum plaster were very lower than those of commercial gypsum plaster. At a heating temperature of 165°C, the flexural and compressive strengths of commercial gypsum plaster were 2.62 MPa and 5.12 MPa, respectively, while those of recycled gypsum plaster decreased to 2.06 MPa and 3.90 MPa, respectively. When heating temperature rose to 180°C, these numbers of commercial gypsum plaster increased to 2.94 MPa and 5.95 MPa, which were also much higher than 1.66 MPa and 2.94 MPa of recycled gypsum plaster. Therefore, it could be concluded that at different heating temperatures, the water to plaster ratio and setting times of recycled gypsum plaster were higher than those of commercial gypsum plaster, while
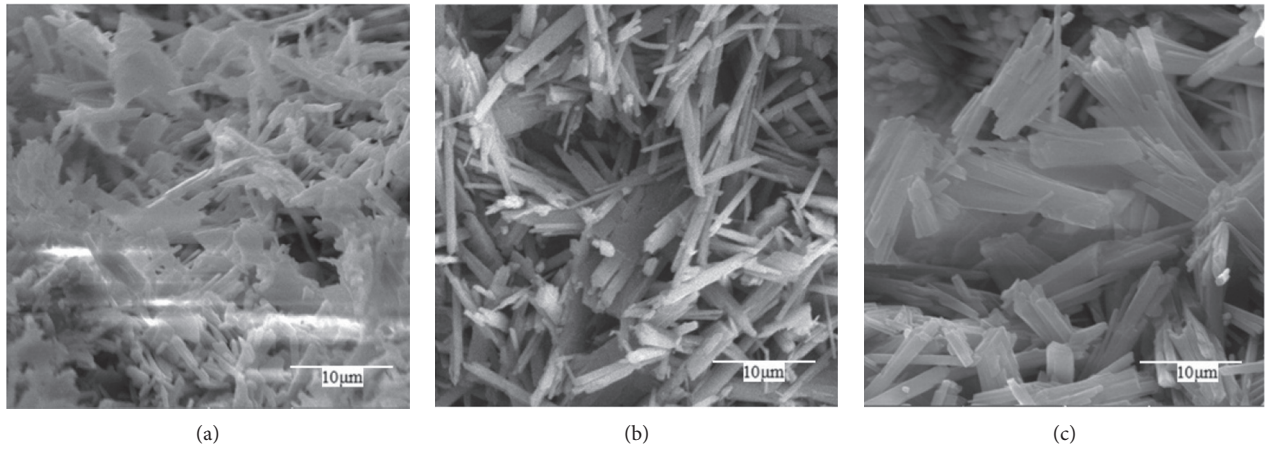
(a)   (b)   (c)

FIGURE 5: Effect of heating temperature on morphology of hardened recycled gypsum plaster. (a) 150°C. (b) 165°C. (c) 180°C [15].

(a)   (b)

(c)   (d)
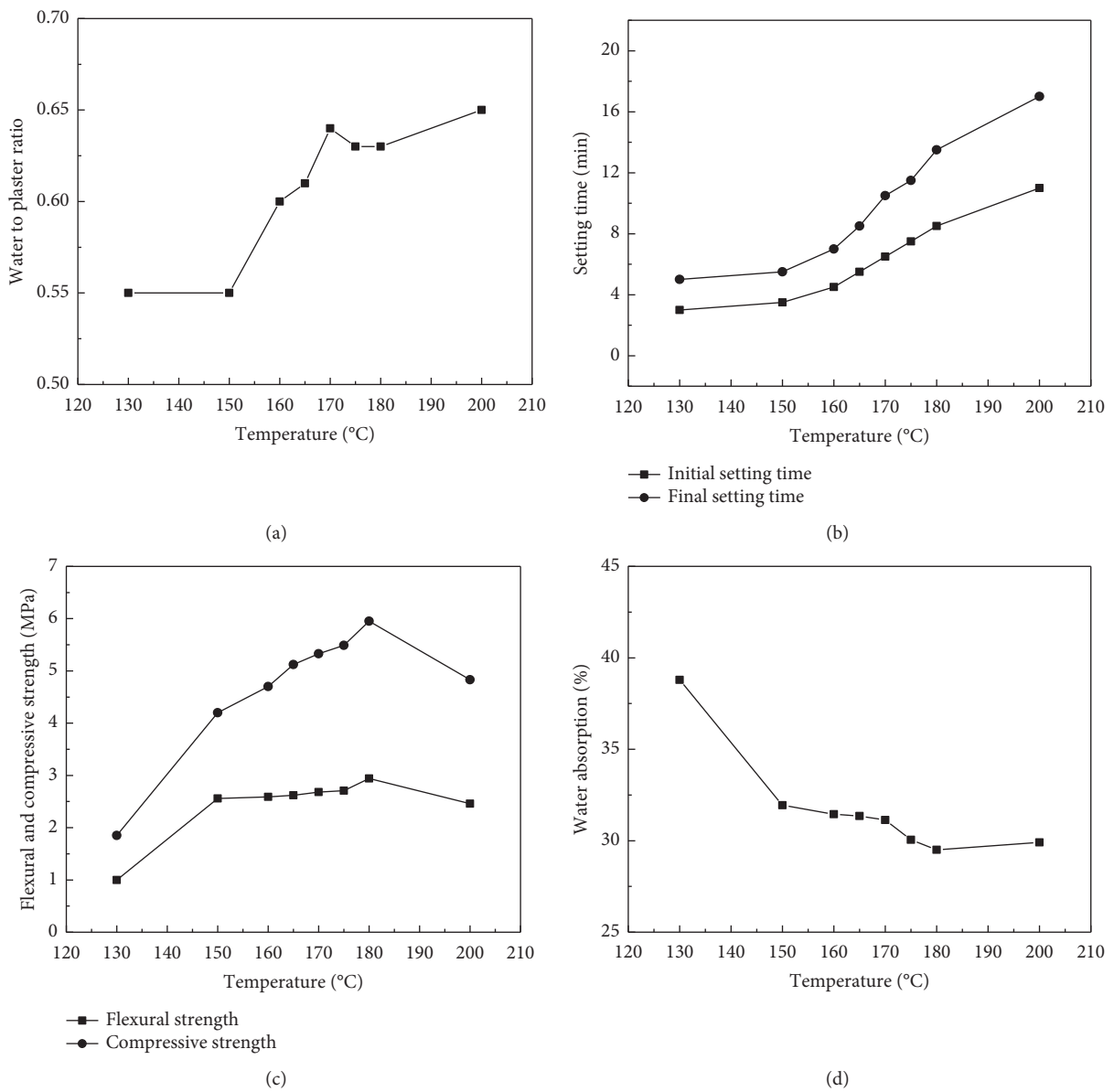
FIGURE 6: Effect of heating temperature on properties of commercial gypsum plaster.
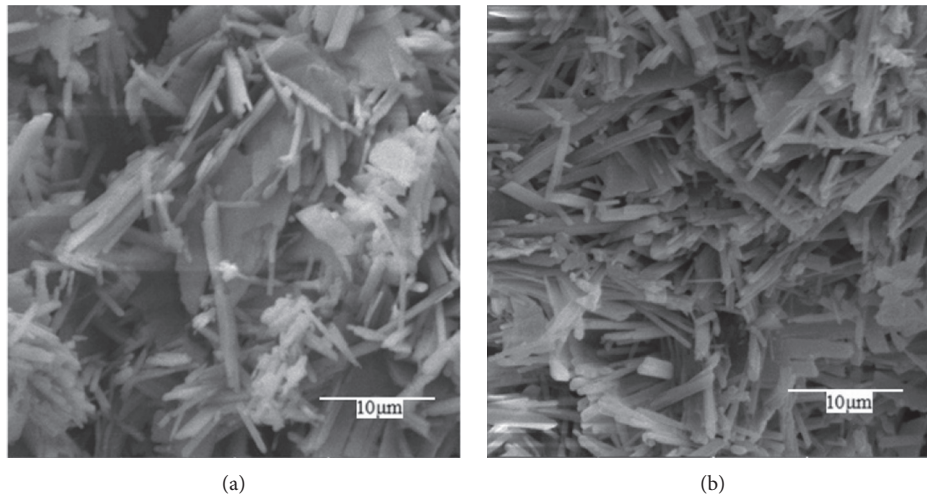
FIGURE 7: Effect of heating temperature on microstructure of hardened commercial gypsum plaster. (a) 165°C. (b) 180°C [15].

the strength of recycled gypsum plaster was lower than that of commercial gypsum plaster. The suitable heating temperature of commercial gypsum plaster was 180°C, while this number decreased to 165°C for recycled gypsum plaster. This was mainly due to the difference in morphology and thermal stability of recycled gypsum and commercial gypsum, which had been reported in our previous papers [21].

3.3. Effect of Fineness on Properties of Recycled Gypsum Plaster.

The water to plaster ratio and flexural and compressive strengths of recycled gypsum plaster were measured (Figure 8). Figure 8(a) shows that the water to plaster ratio decreased sharply with the increase of the specific surface area. It was 1.07 when the specific surface area was 412 m^2/kg and decreased steeply to 0.81 with the specific surface area of 1349 m^2/kg. At this point, it decreased steadily to 0.78 when the specific surface area was 1526 m^2/kg. In Figure 8(b), there was an increasing trend in the flexural and compressive strengths. When the specific surface area was 412 m^2/kg, the flexural and compressive strengths were 0.32 and 0.44 MPa, respectively, and then increased substantially to 1.79 and 3.31 MPa, respectively, with the specific surface area of 1456 m^2/kg. At this point, these numbers increased slowly to 1.94 and 3.60 MPa, respectively, when the specific surface area was 1526 m^2/kg. This was consistent with the findings of Bardella et al. [25], who found that the flexural strength increased with decreasing particle size and increasing specific area. Thus, it can be observed that the water to plaster ratio decreased and flexural and compressive strengths increased with the increase of the fineness. Karni et al. [26] thought that the flexural and compressive strengths decreased with the increase of water to plaster ratio in the hardened state. The influence of fineness on water to plaster ratio and flexural and compressive strengths of recycled gypsum plaster agreed well with the findings of Karni et al. [26].

The water to plaster ratio of recycled gypsum plaster was affected by both the specific surface area and morphology. On the one hand, the water requirement increased with the increase of specific surface area. On another hand, the water requirement was affected by its morphology. To find the reasons for the decrease of water to plaster ratio, the morphology of recycled gypsum plaster in different specific surface areas was measured as shown in Figure 9. The aspect ratio of recycled gypsum plaster became short as the specific surface area increased. When the specific surface area was 1063 m^2/kg, its aspect ratio was 7-8: 1. When it increased to 1349 m^2/kg, its aspect ratio dropped to 3-4: 1. When the specific surface area was 1526 m^2/kg, its aspect ratio was close to 1:1. According to Li et al. [15], the water to plaster ratio of plasters increased with the increase of aspect ratio, and crystals with an aspect ratio of 1:1 could reduce the water requirement. Therefore, the short aspect ratio decreased the water to plaster ratio of recycled gypsum plaster, and the morphology had a greater impact than the specific surface area due to its small particles. Figure 10 shows that there were many internal defects when the grinding time was short and the specific surface area was small. It was easy to produce internal stress during hydration and there were still more defects after hydration, thereby reducing its strength. When the recycled gypsum plaster was ground to a large fineness, the internal defects would be exposed to the outside, and there would be no internal stress during hydration. Thus, the mechanical strength of recycled gypsum plaster increased.

Figure 11 shows the crystal morphology of hardened recycled gypsum plaster under a suitable specific surface area and a small specific surface area. Clearly, when the specific surface area was small at 1253 m^2/kg, the crystals were arranged in clusters. It weakened the overlapping between the crystals, thus reducing the mechanical strength, while at a suitable specific surface area of 1526 m^2/kg, although the crystals were relatively coarse, the crystals were still crisscrossed together and the structure was extremely dense, thereby increasing the strength of recycled gypsum plaster.

3.4. Effect of Fineness on Properties of Commercial Gypsum Plaster.

The water to plaster ratio and flexural and compressive strengths of commercial gypsum plaster were
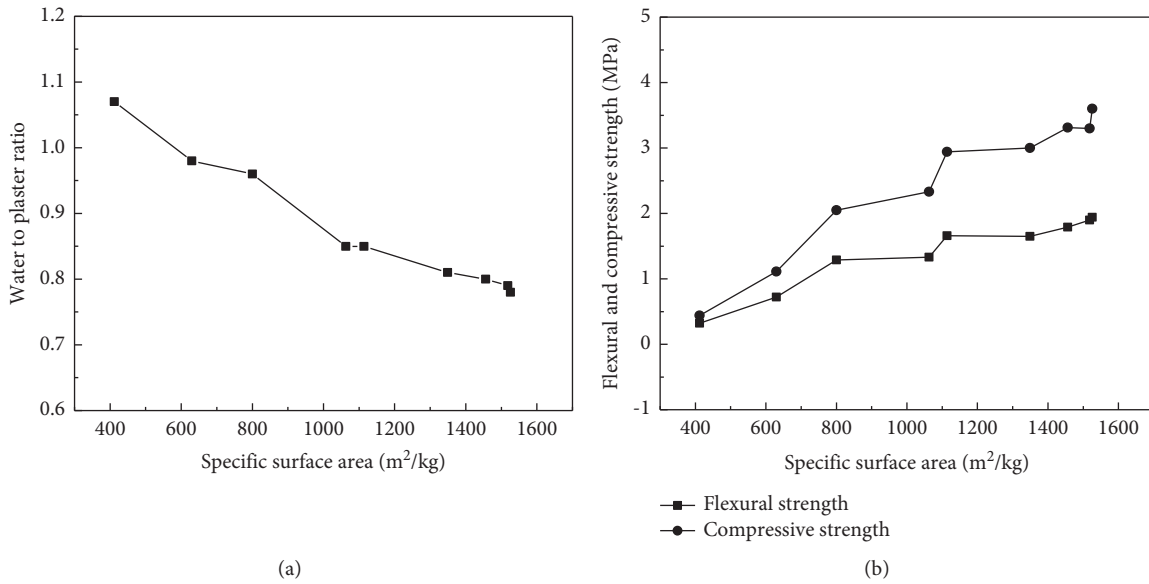
(a)

(b)

FIGURE 8: Effect of fineness on properties of recycled gypsum plaster.
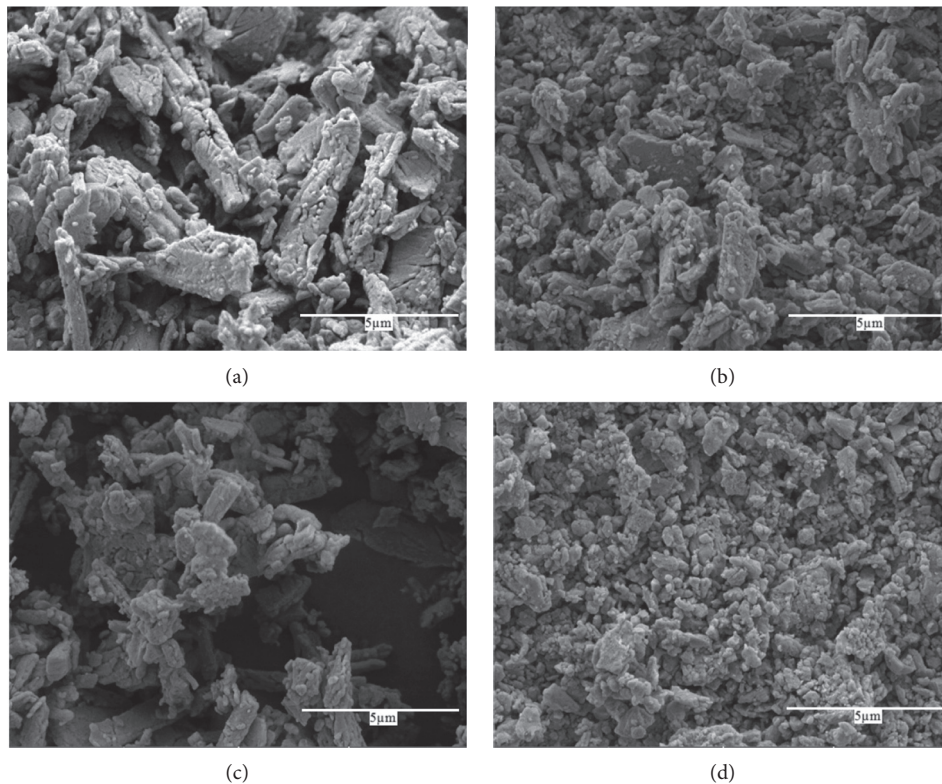

(a)

(b)

(c)

(d)

FIGURE 9: Effect of fineness on microstructure of recycled gypsum plaster. (a) 1063 m²/kg. (b) 1349 m²/kg. (c) 1456 m²/kg. (d) 1526 m²/kg.

determined (Figure 12). Figure 12(a) shows that the water to plaster ratio increased from 0.62 to 0.68 with the increase of the fineness. When the specific surface area was 214 m²/kg, the water to plaster ratio was 0.62, and it increased only slightly to 0.63 with the specific surface area of 669 m²/kg. At this point, it began to increase substantially to 0.68 when the specific surface area was 989 m²/kg. In general, the water to

plaster ratio increased with the decrease of the particle diameter and increase of specific surface area. This was in agreement with the study of Pinheiro et al. [27]. In Figure 12(b), there was a trend of increasing first and then decreasing in the flexural and compressive strengths. When the specific surface area was 214 m²/kg, the flexural and compressive strengths were 2.76 and 5.53 MPa, respectively,
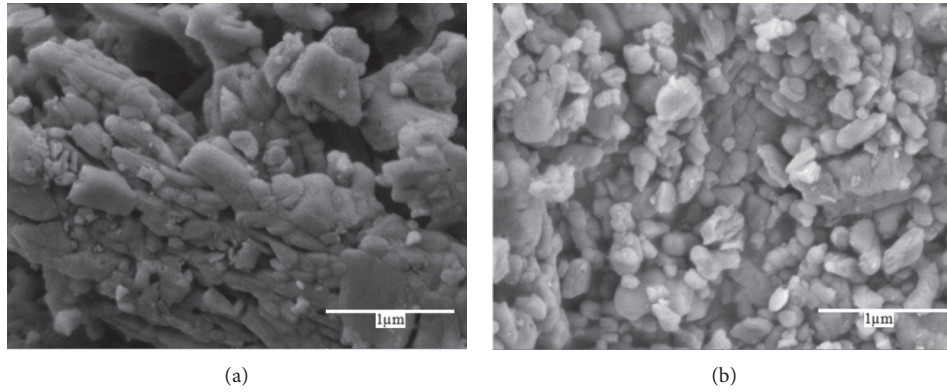
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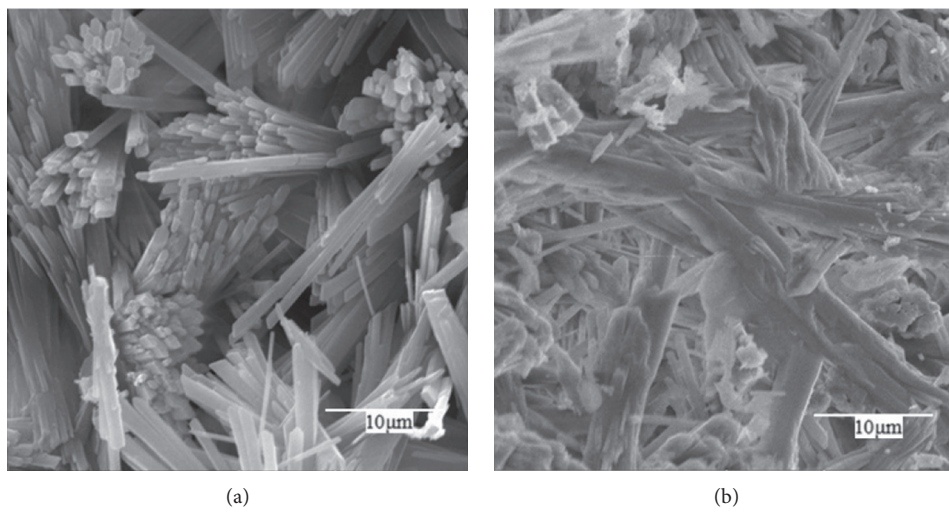FIGURE 10: Effect of fineness on defects of recycled gypsum plaster. (a) 1063 m^2/kg. (b) 1526 m^2/kg.

(a)

(b)

FIGURE 11: Effect of fineness on morphology of hardened recycled gypsum plaster. (a) 1253 m^2/kg. (b) 1526 m^2/kg.
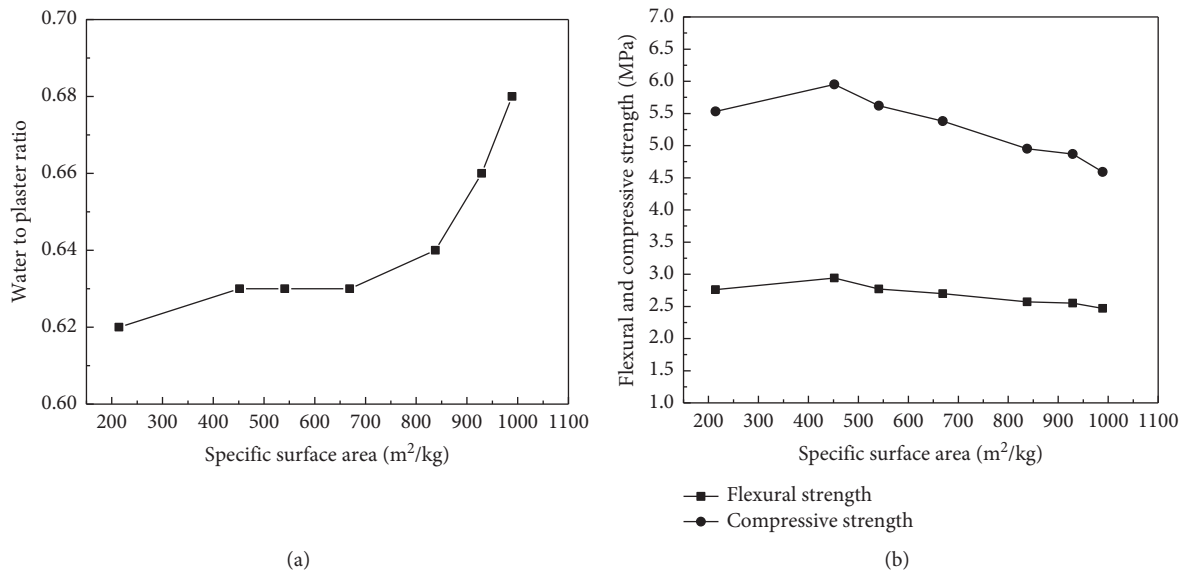

(a)

(b)

FIGURE 12: Effect of fineness on properties of commercial gypsum plaster.

and then increased substantially to 2.94 and 5.95 MPa, respectively with the specific surface area of 452 m^2/kg. At this point, this numbers began to decrease to 2.47 and 4.59 MPa, respectively, when the specific surface area was 989 m^2/kg. Thus, the suitable specific surface area was 452 m^2/kg for commercial gypsum plaster.

From the above studies, it was found that the water to plaster ratio of recycled gypsum plaster was higher than that of commercial gypsum plaster. When the specific surface area was about 630–669 m^2/kg and 800–838 m^2/kg, these numbers of recycled gypsum plaster were 0.98 and 0.96, respectively, and those of commercial gypsum plaster were only 0.63 and 0.64, respectively. However, the flexural and compressive strengths of recycled gypsum plaster were lower than those of commercial gypsum plaster. When the specific surface area was about 630–669 m^2/kg, the flexural and compressive strengths of commercial gypsum plaster were 2.70 MPa and 5.38 MPa, respectively, while those of recycled gypsum plaster decreased to 0.72 MPa and 1.11 MPa, respectively. When the specific surface area rose to 800–838 m^2/kg, these numbers of commercial gypsum plaster decreased to 2.57 MPa and 4.95 MPa, which were also much higher than 1.29 MPa and 2.05 MPa of recycled gypsum plaster. Therefore, it could be concluded that the water to plaster ratio was higher than that of commercial gypsum plaster, while the strength of recycled gypsum plaster was lower than that of commercial gypsum plaster. The suitable specific surface area of commercial gypsum plaster was 452 m^2/kg, while this number increased to 1526 m^2/kg for recycled gypsum plaster. This was mainly caused by the differences in grindability between recycled gypsum and commercial gypsum, which had been reported in our previous papers [20].

Therefore, by investigating the influence of heating temperature and fineness on the hydration and mechanical property of recycled gypsum plaster, it was concluded that the appropriate heating temperature was 165°C, and the suitable specific surface area was 1526 m^2/kg. At this time, it could reach the Chinese standard of GB 9776-2008 <gypsum plaster>. However, the results could not be compared with the international standards due to the different testing apparatus, procedures, and their expression of results.

According to the European Standard BS EN 13279 [28, 29], the sprinkling method, dispersal method, and flow table method were used to determine the water to plaster ratio, and the knife method and Vicat cone method were used to determine the setting time. The apparatus, testing procedures, and their expression of results were different from the Chinese standard of GB/T 9776-2008. According to the water to plaster ratio determined previously, the gypsum plaster and water were weighed, and then the specimens of flexural and compressive strengths test were prepared. Thus, the results of water to plaster ratio, setting time, and flexural and compressive strengths could not be compared with this study.

According to the ASTM C472-20 [30], the modified Vicat apparatus method was used to determine the water to plaster ratio. The inner diameter of the bottom and the top of the conical ring should be 60 mm and 70 mm, respectively, and the height should be 40 mm. Molds for compressive strength test should be cube molds with a side length of 50.8 mm. Thus, the used apparatus of water to plaster ratio and compressive strength test were very different from the Chinese standard of GB/T 9776-2008.

According to Indian Standard [31, 32], molds for compressive strength test should be cubes of size 25 × 25 × 25 mm, and molds for flexural strength should be rectangular specimens of size 100 × 25 × 25 mm. The compressive and flexural strength were measured after keeping at room temperature for 24 h and then drying in an electric furnace for two days. Thus, the used molds and testing times of flexural and compressive strengths test were also different from the Chinese standard of GB/T 9776-2008.

According to the Brazilian Standards of ABNT NBR 12127-2019 [33], ABNT NBR 12128-2019 [34], and ABNT NBR 12129-2019 [35], the modified Vicat apparatus was used to measure the water to plaster ratio, and molds for compressive strength test should be cubes of size 50 × 50 × 50 mm. Thus, the used apparatus of water to plaster ratio and compressive strength test were very different from the Chinese standard of GB/T 9776-2008 as well. Thus, the results could not be compared with the international standards.

4. Conclusions

Influence of the heating temperature and fineness on the hydration and mechanical property of recycled gypsum plaster was investigated, and there was also a study for comparison on properties of commercial gypsum plaster. Therefore, the following conclusions can be obtained based on the experimental study:

(1) Different from commercial gypsum plaster, the suitable heating temperature of recycled gypsum plaster was decreased to 165°C. At this time, the water to plaster ratio was decreased to 0.82, and the initial and final setting times were 8 min and 12.5 min, respectively. The flexural and compressive strengths were 2.06 MPa and 3.90 MPa, respectively.

(2) The water to plaster ratio decreased and flexural and compressive strengths increased as the specific surface area increased. Thus, the suitable specific surface area of recycled gypsum plaster was changed to 1526 m^2/kg considering the properties and economics of recycled gypsum plaster.

(3) At the suitable heat temperature and specific surface area, it could reach the standard of GB 9776-2008 <gypsum plaster> (China national standard for plaster of Paris).

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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