

Evaluation on Hydration Reactivity of Reactive Magnesium Oxide Prepared by Calcining Magnesite at Lower Temperatures

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ABSTRACT: Three methods were used to evaluate hydration reactivity of calcined magnesite products. Both conventional citric acid coloration reactivity test (index of CT) and MgO hydration conversion method (index of X) cannot properly evaluate the reactivity when the magnesite ore decomposes incompletely at lower calcining temperatures. Therefore, a corrected MgO hydration conversion method containing the index of $X_{corrected}$ is proposed by considering the decomposition ratio of magnesite ore. Results show that decomposition ratio of magnesite ore is quite low at temperatures lower than 650 °C, which influences the reliability of the conventional reactivity test results (index of CT or X). Reactivity of MgO decreased as the calcining temperature and time increased when the index of $X_{corrected}$ was used. Hydration reactivity of calcined magnesite at lower temperatures is much higher than that of magnesite calcined at 1100 °C, no matter which of three evaluation indexes is used (i.e., CT, X, and $X_{corrected}$).

1. INTRODUCTION

Calcined magnesite products are commonly classified into "caustic calcined" magnesium oxide (magnesia, MgO) calcined at low temperatures, and "dead-burned" MgO calcined at much higher temperatures.^{1,2} "Dead-burned" MgO is widely used in the refractory industry, which is the major outlet for magnesite ore and MgO. Additionally, recent uses of MgO have centered on reactive MgO, which is calcined at lower temperatures (<750 °C) and obtains a high surface area giving high hydration rates. Reactive MgO cements have recently been proposed as an alternative for the ordinary Portland cement (OPC).^{3–5} Although potential uses of these reactive MgO will be likely to expand its applications in other cement and chemical industries,^{6–9} except for the application of "dead-burned" MgO in the refractory industry.

The hydration reactivity of calcined magnesite product is a common index in the application of magnesium oxides, and it is a key performance indicator for reactive MgO. Measurement of hydration conversion with magnesium oxide calcined at different conditions has been conducted by several researchers. Rocha et al.¹⁰ and Strydom et al.¹¹ studied the influence of kiln calcining temperature and time on the specific surface area of magnesium oxide. It is commonly known that factors such as temperature, calcining time, and impurities influence the properties of magnesium oxide obtained from heating magnesium carbonate. The quantitative analytical methods for hydration activity of magnesium oxides were the citric acid coloration reactivity test and the MgO hydration conversion method.^{12,13} The indexes of conventional citric acid coloration reactivity test and the MgO hydration conversion method are commonly used as coloration time (index of CT) and MgO hydration conversion ratio (index of X), respectively. Both these traditional measurement methods are for MgO specimens with >98% content of MgO, which are suitable for dead-burned magnesite products calcined at a temperature ≥ 1100 °C, normally with complete decomposition of magnesite ore under such a higher temperature. However, in the case of magnesite calcined at 600-750 °C, content of MgO in the calcined

magnesite product could be much lower than 98% since incomplete decomposition of magnesium carbonate and other impurities (i.e., silica, calcium, and iron etc.) will remain in the calcined magnesite product.

Research on the hydration reactivity of MgO is mainly focused on completely decomposed magnesite with high content of MgO that calcined at relatively higher temperatures in previous literature. So, very few researchers report on the accuracy of traditional indexes for calcined products that are with the content (<98%) of MgO. To prepare higher reactive magnesia in industry, lower calcination temperature and less time may be more suitable, though it may unavoidably decrease some decomposition ratio of magnesite ore. Reactive magnesia used as MgO-based expansive agent^{14,15} or CO₂ sequestration¹⁶⁻¹⁸ in cementitious binders was mentioned in many previous references. In the present case, a new evaluation index for the hydration reactivity of reactive magnesium oxide mentioned in this article could pave the way for the potential utilization of reactive magnesia calcined at lower temperatures in cement and other chemical industries. So, traditional evaluation methods are for MgO specimens with >98% content of MgO, not suitable for evaluation of low content of magnesium oxide in the calcined magnesite products. Thus, both traditional indexes of CT and X cannot properly evaluate reactive MgO prepared at lower temperatures, and a new evaluation index for reactive MgO is needed that takes the decomposition ratio of magnesite ore into consideration.

In this study, decomposition behavior and reactivity of the calcined magnesite at lower temperatures (600–750 °C) and a higher temperature (1100 °C) were comparatively investigated. The schematic of this study is shown in Figure 1. Compared with the conventional citric acid coloration reactivity test (index of CT) and the MgO hydration conversion method (index of

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Figure 1. Schematic of this study.

Table 1. Chemical Compositions of Magnesite Ore Sample (wt	Table 1	. Chemical	Compositions	of Magnesite	Ore Sample	(wt %	6)
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	MgO	SiO ₂	K ₂ O	CaO	Fe_2O_3	Al_2O_3	MnO	Cl	TiO ₂	P_2O_5	SO3	LOI ^a
percentage	40.46	9.67	0.03	1.59	0.28	1.59	0.01	0.02	0.03	0.02	0.05	46.19
^a LOI means loss on ignition at 1200 °C.												

X), a corrected MgO hydration conversion method and its corresponding index of $X_{\text{corrected}}$ are proposed in this study. The approach takes the decomposition ratio of magnesite ore into account, which is more reasonable than the conventional indexes of CT and *X*. Our study provided an effective evaluation support for preparation of reactive MgO by calcining magnesite at lower temperatures.

2. MATERIALS AND METHODS

2.1. Raw Materials and Calcination Process. Magnesite ore was provided by a chemical company in Liaoning Province, China. Chemical compositions of the magnesite ore were characterized by using X-ray fluorescence (XRF) analysis, and the results of elemental percentages are presented in the form of their related oxide proportion (Table 1). The percentage of magnesium which accounts for the main element of magnesite is at 40.46%. MgCO₃ can be decomposed into MgO and CO₂. Therefore, the loss on ignition (LOI) is mainly attributed to the decomposition of MgCO₃ and other components such as CaCO₃.

Magnesite ore sample of 10.0000 ± 0.0005 g was calcined in a muffle furnace under static air at different calcining temperatures of 600, 650, 700, and 750 °C for different calcining times of 90, 120, 150, and 180 min. At the same time, the magnesite ore sample was calcined at a higher temperature of 1100 °C for comparison. Triplicate samples were used to obtain the average result for each case. Mass loss percentage L_0 (%) of each sample was calculated by eq 1.

$$L_0(\%) = \frac{m_0 - m_1}{m_0} \times 100 \tag{1}$$

Here, m_0 and m_1 are the initial and final mass of the magnesite sample before and after calcination, respectively. It is assumed that the mass loss in calcination process was only caused by the emission mass of CO₂ in the decomposition of magnesium carbonate, and all of MgO in magnesite ore might only exist as magnesium carbonate phase. It is also assumed that the mass of other impurities, i.e., CaO and SiO₂, might not change during the calcination process. Thus, MgO phase in the calcined magnesite product could be deduced from emission mass of CO_2 by the mass balance of decomposition reaction of magnesium carbonate, shown in eq 2.

$$MgCO_{3} \rightarrow MgO_{40.30} + CO_{2}$$

$$\frac{40.30(m_{0}-m_{1})}{44.01} \qquad (m_{0}-m_{1})$$
(2)

From the mass balance of the above equation, the mass of the MgO phase in the calcined magnesite product can be expressed as $[40.30(m_0 - m_1)/(44.01)]$.

The total mass of MgO in magnesite ore can be induced from the composition in Table 1, expressed as $(40.46\%)(m_0)$. Then, the decomposition ratio of magnesite (η) can be simplified as eq 3.

$$\eta (\%) = \frac{\text{mass of MgO phase in calcined product}}{\text{total mass of MgO in magnesite ore}} \times 100$$
(3)

2.2. Magnesium Oxide Hydration Reactivity Experiment. 2.2.1. Citric Acid Coloration Reactivity Test. When MgO chemically reacts with citric acid, magnesium citrate and water are formed.¹⁹ Approximately 1.7000 ± 0.0001 g of calcined magnesite product was added to 100 mL of 0.07 mol L⁻¹ citric acid solution containing the phenolphthalein indicator and stirred at a speed of 500 rpm at 40 °C. The solution would start to color due to the reaction between magnesium oxide and citric acid as indicated by phenolphthalein. A shorter discoloration time means a higher reactivity.

2.2.2. Magnesium Oxide Hydration Conversion Method. The magnesium oxide hydration conversion method was used to evaluate the hydration reactivity of MgO by calculating the mass increase of the MgO sample after hydration. It was carried out with 2.0000 \pm 0.0001g calcined magnesite product and 100 mL H₂O at 20 $^\circ\text{C}$ for 24 h. The reaction took place in a glass bottle, immersed in a thermostatic water bath. After 24 h, solids were filtered by vacuum, washed with methanol, and dried at 120 °C for 2 h. The initial mass (w_0) before the hydration test and final mass (w_1) after the hydration test of the calcined magnesite sample were measured. It is assumed that the increased mass in hydration conversion method is attributed to the amount of water reacted with MgO. Thus, the amount of water reacted with MgO could be expressed as $(w_0 - w_1)$. Consequently, the amount of MgO in the calcined magnesite sample reacted with water could be deduced from mass of H₂O by the mass balance of hydration reaction of magnesium oxide, shown in eq 4.

$$\begin{array}{rcl} MgO & + & H_2O & \rightarrow Mg(OH)_2 \\ & & & \\ \frac{40.30(w_0 - w_1)}{18.02} & & & \\ & & & \\ \end{array}$$
(4)

From the mass balance using eq 4 as above, the amount of MgO in the calcined magnesite sample reacted with water can be expressed as $[40.30(w_0 - w_1)/(18.02)]$.

It is assumed that the total mass of MgO phase in the calcined magnesite sample might be the initial mass (w_0) of the calcined magnesite sample. This assumption should be acceptable when magnesite ore decomposes completely. Then, an index of MgO hydration conversion ratio (X) could be calculated as eq 5.

$$X(\%) = \frac{\text{mass of MgO phase hydrated reaction with water}}{\text{initial mass of the calcined magnesite sample}} \times 100$$
(5)

According to the mass balance calculation of eq 4 and the above assumption, MgO hydration conversion ratio (X) could be expressed as eq 6.

$$X(\%) = \frac{40.30(w_0 - w_1)}{18.02w_0} \times 100$$
(6)

Equation 6 can only be applied for the highly pure magnesium oxide sample with the content of MgO > 98%. It was also proposed in the previous literature.¹⁰ Generally the traditional index of X can be applied to evaluate the hydration reactivity of "dead-burned" MgO sample since magnesite ore can decompose completely at temperature of ≥ 1100 °C. However, the traditional index of *X* becomes inaccurate for the evaluation of reactive magnesium oxide sample since reactive MgO sample is calcined at temperatures lower than 750 °C. In this case, the total mass of MgO phase in the calcined magnesite sample could not be assumed as the initial mass (w_0) of the calcined magnesite sample because incomplete decomposition of magnesium carbonate and other impurities, i.e., silica, calcium, and iron, etc., will avoidably remain in calcined magnesite product. Thus, a corrected index should be proposed by considering the incomplete decomposition of magnesite in low calcination temperature.

2.2.3. Corrected Magnesium Oxide Hydration Conversion Method. In the case of a calcined magnesite sample that decomposed incompletely, the total mass of MgO phase in the calcined magnesite sample cannot be assumed as the initial mass (w_0) of the calcined magnesite sample. A correction factor will be applied. The correction factor can be expressed as eq 7.

$$w_{\rm MgO} = w_0 \times C_{\rm MgO} \tag{7}$$

Here, w_{MgO} is the total mass of MgO phase in the calcined magnesite sample; C_{MgO} is mass percentage of MgO phase in the calcined magnesite sample. Upon substituting w_{MgO} in eq 7 into eq 5, corrected magnesium oxide hydration conversion ratio ($X_{corrected}$) can be expressed as eq 8.

$$X_{\text{corrected}} = \frac{1}{C_{\text{MgO}}} \times X \tag{8}$$

Mass percentage of MgO phase in the calcined magnesite sample (C_{MgO}) depends on calcination temperature and calcination time, and can be expressed as eq 9.

$$C_{\rm MgO}(\%) = \frac{\rm mass of MgO phase in the calcined magnesite product}{\rm total mass of calcined magnesite sample} \times 100$$
(9)

Here, mass of MgO phase in the calcined magnesite product can be expressed as $[40.30(m_0 - m_1)/(44.01)]$, deduced by the mass balance of eq 4; total mass of calcined magnesite sample is m_1 .

2.3. Materials Characterization. The elements of these samples were analyzed by a wavelength dispersive X-ray fluorescence spectrometer (Axios advanced). Loss on ignition (LOI) was calculated as the mass loss ratio calcined at 1200 °C. Thermogravimetric and differential thermal analysis (TG/ DTA) was conducted under a nitrogen atmosphere, with a heating rate of 10 °C/min. The particle size distributions of the magnesite ore and the calcined magnesite products were determined. X-ray diffraction (XRD) patterns for mineral phase of raw magnesite and calcined magnesite products were determined by using Cu K α ($\lambda = 1.54$ Å) at 40 mA, 40 kV,

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and a scanning speed of $0.2785^{\circ}/s$ with a 2θ range from 5° to 75° . The morphologies of the typical calcined magnesite products and their hydration products were examined by Sirion 200 scanning electron microscope (SEM) after coating with Au. The calcined magnesite products and its hydration products, which were dispersed in alcohol, were investigated by transmission electron microscope (TEM) on a FEI-Tecnai G 200 operating at 200 KV. The thinned disks for supporting specimens were finally coated with carbon in order to avoid charging in the TEM operation.

3. RESULTS AND DISCUSSION

3.1. Characterization of Magnesite Ore and Calcined Magnesite Samples. *3.1.1. Thermal Analysis of Magnesite.* The TG/DTA curves of magnesite ore are shown in Figure 2.



Figure 2. TG/DTA curves of the magnesite ore sample.

As shown, the decomposition and weight loss start at about 425 °C, and then an obvious stage of weight loss of 45.90% occurs between 425 and 650 °C, which corresponds to an endothermic peak in the DTA curve at 624 °C. This is due to the intensive decomposition reaction of MgCO₃. When temperature rised from 650 to 750 °C, there was another relative small weight loss stage of 3.90%, corresponding to the endothermic peak at 697 °C in DTA curve. This may be attributable to the decomposition of dolomite (CaMg(CO₃)₂). As the temperature rose up to 750 °C, the mass loss stayed stable at 49.80%. Accordingly, the calcination temperatures for the magnesite ore were selected at 600, 650, 700, 750 °C, respectively.

3.1.2. Mass Loss Percentage and Decomposition Ratio of Raw Magnesite. Figure 3a shows the mass loss percentage L_0 of the calcined magnesite samples calcined under various conditions. While at 650 °C for 90 min, the mass loss percentage is about 42.67%, and increases slightly with calcining time. At 700 and 750 °C, dolomite in magnesite ore starts to decompose after 90 min, with a mass loss percentage slightly increased from 43.67% to 44.03%. When calcined at 1100 °C for 120–180 min, the calcite and dolomite in the calcined magnesite products decompose completely, with the mass loss percentage about 46.17%. From a comparison with LOI of 46.19% shown in Table 1, it is evident that the decomposition of magnesite is nearly complete at about 700 °C for 150 min. From the TG curve of magnesite sample shown in Figure 2, the peak at 697 °C is attributed to the decomposition



Figure 3. (a) Mass loss percentage L_0 (%) and (b) decomposition ratio η (%) of magnesite ore calcined at different conditions.

of dolomite $(CaMg(CO_3)_2)$. Therefore, only MgCO₃ decomposes at temperatures lower than 700 °C. At lower calcination temperature <700 °C, the other impurities such as silica and calcium exist stably during the calcination process. So the mass of the impurities does not change during calcination.

As shown in Figure 3b, the decomposition ratio of magnesite ore is about 75% at 600 °C for 90 min, and it reaches to 85% when the calcined time is prolonged to 180 min. While at 650 °C, the decomposition ratio of magnesite ore is about 96% when calcined time increases up to 180 min. Thus, the calcined magnesite decomposes incompletely at 600–750 °C. When calcined at 1100 °C for 120–180 min, the calcite and dolomite in the samples decompose completely, with a decomposition ratio of higher than 99.50%.

3.1.3. XRD Patterns of Calcined Magnesite Products. Figure 4a shows the XRD patterns of the magnesite ore and the calcined magnesite products calcined at 600, 650, 700, 750 and 1100 °C for 150 min. The XRD pattern of magnesite ore demonstrates that the MgCO₃ is the dominant mineral phase with a small amount of dolomite and quartz. From Figure 2, it can be seen that magnesite ore starts to decompose into the magnesium oxide at 600 °C; the major phase becomes magnesium oxide, with some residual magnesium carbonate. As the temperature rose from 650 to 700 °C, the diffraction peaks of MgCO₃ disappeared, while a small amount of dolomite existed in the calcined product. When magnesite ore was calcined at 750 °C and above, the calcined magnesite product contained mainly magnesium oxide and some residual



Figure 4. XRD patterns for (a) magnesite ore, calcined magnesite samples prepared at 600, 650, 700, 750 $^{\circ}$ C, and 1100 $^{\circ}$ C for 150 min, and (b) the hydration products of the corresponding calcined magnesite samples.

inert substances such as quartz and talc. The intensities of MgO diffraction peaks were enhanced at a higher temperature of 1100 $^{\circ}$ C, and it indicated that decomposition ratio of magnesite ore increased at 1100 $^{\circ}$ C.

The XRD results suggest that MgCO₃ can decompose almost completely, and the dolomite can decompose completely above 700 °C for 150 min, which is consistent with the TG/DTA results. Accordingly, it is difficult to obtain calcined magnesite product with highly pure magnesium oxide sample (the content of MgO > 98%) when calcination temperature is below 750 °C. Therefore, the conventional hydration reactivity methods cannot be applied to evaluate the reactivity of the incompletely decomposed calcined magnesite products.

Figure 4b shows the XRD patterns of hydration products of calcined magnesite products at 600, 650, 700, 750, and 1100 °C for 150 min. Compared with the XRD patterns of the calcined magnesite products in Figure 4a, brucite appears as a significant hydration product in all the XRD patterns shown in Figure 4b. The major phase in XRD patterns for hydration products of calcined magnesite products at lower temperatures of 600, 650, 700, and 750 °C is brucite. However, the major phase in XRD patterns for hydration gratterns for hydration products of "dead-burned" MgO calcined at 1100 °C is still magnesia (MgO). It demonstrates the lower hydration conversion of "dead-burned" magnesia calcined at 1100 °C, compared to that of reactive MgO calcined at 600–750 °C.

3.1.4. Particle Size Measurement. Ranjitham and Khangaonkar reported that the hydration rate of calcined magnesite was chemically controlled by the reactions occurring on the magnesium oxide particle surface.²⁰ Particle size measurements of magnesite ore and calcined magnesite products are also shown in Figure 5 for comparison. It demonstrates that the



Figure 5. Particle size distribution of magnesite ore and calcined magnesite samples for 150 min.

difference of particle size distribution between magnesite ore and calcined magnesite products is not significant. Therefore, hydration reactivity of MgO is significantly relation to the decomposition ratio of magnesite ore and attributable to the total amount of magnesium oxide and the hydration reactivity of magnesium oxide per unit mass, as discussed in following section.

3.2. Hydration Reactivity Test. 3.2.1. Citric Acid Coloration Reactivity Test. Figure 6a shows the coloration time of the calcined magnesite samples in the citric acid coloration reactivity test. For the calcined magnesite product calcined at 1100 °C, the coloration time is prolonged with the calcining time. At the higher temperature the magnesium oxide becomes relatively inert with a low adsorptive capacity and dissolves in critic acid with considerable difficulty. The CT of the samples prepared at 1100 °C is much longer than those prepared at lower temperatures of 600, 650, 700, and 750 °C. For "dead-burned" MgO prepared at 1100 °C, the hydration reactivity of the calcined magnesite product is much lower than those of products prepared at lower temperatures, although the decomposition ratio of the "dead-burned" MgO is much higher than those of the reactive MgO prepared at lower temperatures.



Figure 6. (a) Coloration time in citric acid hydration reactivity test (CT) and (b) magnesium oxide hydration conversion ratio (X) of different calcined magnesite samples.

It indicates that hydration reactivity of MgO is more appropriate than decomposition ratio when comparing reactivity of "dead-burned" MgO with reactive MgO. As the results of mass loss percentage mentioned in Figure 3a show, obviously, the same mass of calcined magnesite samples obtains different amounts of reactive MgO. As shown in Figure 3b, the total amount of magnesium oxide in calcined magnesite products prepared at 700 °C is a little lower than that calcined at 750 °C. However, CT of calcined magnesite product prepared at 700 °C is significantly shorter than that of calcined product at 750 °C. The calcined magnesite product prepared at 700 °C for 150 min was the shortest one, evidenced by its shortest coloration time. The results of coloration time obtained from the same mass of calcined magnesite samples with different contents of reactive MgO could not achieve a comprehensive understanding of the hydration activity of reactive MgO.

3.2.2. Magnesium Oxide Hydration Conversion (X). MgO hydration conversion (X) in Figure 6b indicates the calcined magnesite samples prepared at 700 °C for 150 min show the highest conversion ratio; the same conclusion can be drown from the citric acid coloration reactivity test.

The decomposition ratio of magnesite ore calcined at 750 °C is higher than that calcined at 700 °C, which implies the calcined magnesite products at 750 °C have higher contents of reactive MgO. In the two conventional methods of coloration time and magnesium oxide hydration conversion, hydration

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the total amount of MgO and the reactivity of unit mass MgO. Therefore, they cannot evaluate the hydration reactivity of MgO properly when the magnesite ore decomposes incompletely. Using these two methods, static calcination at 700 °C for 90 min could be optimal, which is an obvious misunderstanding in the case of incomplete decomposition.

3.2.3. Corrected Magnesium Oxide Hydration Conversion (X_{corrected}). Calcined magnesite samples with low decomposition ratios could partly contain the products of MgO and a comparatively small amount of magnesium carbonate. $X_{\text{corrected}}$ was proposed by considering the decomposition ratio of the calcined magnesite ore. Figure 7 shows that the most reactive



Figure 7. Corrected magnesium oxide hydration conversion ratio $(X_{\text{corrected}})$ of calcined magnesite samples.

MgO was prepared at 600 °C for 90 min with a corrected MgO hydration conversion of 92.64%. The calcination conditions with temperatures below 600 °C and calcining time less than 90 min were not presented here because of the low decomposition ratios of magnesite ore. The hydration reactivity of calcined magnesite products declined significantly as the calcination temperature increased. The calcining time has an effect similar to that of the calcining temperature.

No matter which method was used, the hydration reactivity of the samples prepared at 1100 °C was much lower than that of the other samples prepared at lower temperatures. On the basis of the corrected magnesium oxide hydration conversion (index of $X_{\text{corrected}}$), MgO with the highest hydration reactivity was prepared at 600 °C for 90 min, but the decomposition ratio of magnesite ore at such calcination condition was low.

3.3. Morphologies of the Calcined Magnesite Hydration Product. A previous study of Eubank indicated that calcination of magnesite included two distinct steps: (1) loss of gases at temperatures of 300-500 °C and (2) recrystallization or sintering at temperatures above 900 °C.²¹ Therefore, at the lower temperatures (600-750 °C) the loss of gases leaves a very porous structure with a large internal surface area and a great reactivity (adsorptive power); at the high temperature of 1100 °C, recrystallization or sintering leads to a dense particle structure with a smaller surface area and a low reactivity. The SEM images of the calcined magnesite products at 600, 700, and 1100 °C for 150 min, and their 24 h hydration products, are shown in Figure 8. The samples of magnesite calcined at 600, 700, and 1100 °C also have a polycrystalline structure, shown in Figure 8a-c, respectively. The grain size decreases



Figure 8. SEM images of calcined magnesite samples (a) at 600, (b) 700, and (c) 1100 °C for 150 min, and (d-f) their hydration products.



Figure 9. TEM images of calcined magnesite samples (a) at 600, (b) 700, and (c) 1,100 °C for 150 min, and (d-f) their hydration products.

when the calcination temperature rises from 600 $^{\circ}$ C, and the grains reach the finest size at 700 $^{\circ}$ C. The crystals of magnesia grow at the temperature of 1100 $^{\circ}$ C. Hydration products of reactive MgO at a low temperature have plate-shaped morphology as shown in Figure 8d,e. However, morphologies of hydration products of "dead-burned" MgO are lots of

granular-shape crystals combined with few plate-shape crystals, as shown in Figure 8f. It indicates that "dead-burned" MgO at 1100 $^{\circ}$ C is not completely hydrated to Mg(OH)₂, and magnesium oxide of granular-shape is identified to be coexistent.

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TEM images of the calcined magnesite products at 600, 700, and 1100 °C for 150 min are presented in Figure 9a-c, respectively. As shown in Figure 9c, the calcined product at 1100 °C shows more complete crystal shape than that of the calcined products at lower temperature of 600 and 700 °C. TEM images of the hydrated products from magnesia calcined at 600, 700, and 1100 °C for 150 min are presented in Figure 9d-f, respectively. As shown in Figure 9d,e, plate-shaped crystals of many hydrated products agglomerate, and the plateshape is the typical morphology of brucite. However, a separate small granular-shape crystal is dominant in the hydrated product of magnesia calcined at 1100 °C, which is the typical morphology of magnesia. It indicates that the hydration product of "dead-burned" MgO at 1100 °C is not completely hydrated to brucite. In general, the morphologies shown in TEM images are consistent with the results of SEM images in Figure 8.

4. CONCLUSIONS

Three methods were used to evaluate the hydration reactivity of MgO by calcining magnesite ore at different temperatures. The results indicate that the conventional citric acid coloration reactivity test and the magnesium oxide hydration conversion method are only suitable for evaluation of higher content of magnesium oxide in the calcined magnesite products, while the corrected magnesium oxide hydration conversion method is more proper for evaluation of reactive MgO calcined at lower temperatures.

In the two conventional methods, hydration reactivity of MgO is simultaneously attributed to the total amount of magnesium oxide and the hydration reactivity of magnesium oxide per unit mass. Therefore, they may not evaluate the hydration reactivity of MgO properly when the magnesite ore decomposes incompletely. Evaluated from these methods, current static calcination at 700 $^{\circ}$ C for 90 min was found to be optimal, which is an obvious mistake.

In the corrected magnesium oxide hydration conversion $(X_{\text{corrected}})$, the decomposition ratio of magnesite ore is taken into consideration. MgO with the highest hydration reactivity was prepared at 600 °C for 90 min according to the $X_{\text{corrected}}$, but the decomposition ratio of magnesite ore at such calcination condition is low. Therefore, a new calcination alternative for the static calcination process needs to be developed to obtain a higher decomposition ratio.

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Notes

The authors declare no competing financial interest.

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