Effect of calcination temperature on the light burned MgO matrix and its physical properties

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ABSTRACT
Light-burned MgO cement has a lower calcination temperature than ordinary Portland cement. It has been widely studied as a measure to reduce carbon dioxide because of its property of absorbing carbon dioxide during curing. This study investigated the effects of calcination temperature on the physical properties of light hydrated magnesium carbonate and calcined MgO hydrated in moisture and CO₂ at 25 °C and 60 °C. The crystal size of light-burned MgO increased with increasing calcination temperature, and carbones were formed through carbonation curing. Further, nesquehonite and hydromagnesite were formed in the 25CC and 50CC specimens, respectively, and the carbonate formation reduced with increasing crystal size. The highest compressive strength of 3.5 MPa was obtained for the 25CC specimens in which nesquehonite was formed; however, hydromagnesite exhibited better CO₂ sequestration capacity.

1. Introduction

Although concrete made from ordinary Portland cement (OPC) is the most widely used building material in the world, 900 kg of CO₂ gas is emitted to the atmosphere to produce 1 t of cement (Hasanbeigi, Menke, and Price 2010; Benhelal et al. 2013). Researchers have proposed to use carbon capture and storage (CCS) technology in the cement industry to reduce these emissions. Light-burned MgO cement, which is being recently developed, is an example of such technology.

Light-burned MgO cement, also referred to as carbon negative cement uses light-burned MgO obtained by calcining magnesium carbonate at lower temperatures below 1000 °C. This is the primary raw material and is capable of absorbing carbon dioxide during the curing process (Harrison 2001). Light-burned MgO has a calcination temperature of 700–1000 °C (Chui, Liu, and Tang 1992), approximately 450 °C lower than the 1450 °C (Puertas et al. 2008; Chen, Ma, and Dai 2010; Aouad et al. 2012) used for OPC. As a result, the environmental impact of burning fossil fuels can be reduced (Dung and Unluer 2016). Moreover, the material absorbs the same amount of carbon dioxide generated during the calcination process of magnesium carbonate in the curing process (Harrison 2001).

A recent study reported that the strength of light-burned MgO cement manufactured by adding hydrated magnesium carbonates (xMgCO₃-yMg(OH)₂-zH₂O, HMCs) as a carbonic acid catalyst to light-burned MgO and performing compression molding reaches 22 MPa after 7 days (Unluer and Al-Tabbaa 2013). HMCs added as carbonic acid catalysts reduce the formation of Mg(OH)₂ film on the MgO surface during hydration, thereby allowing space for the exposed surface and carbonate to produce the product, leading to high strength (Thomas, Jennings, and Chen 2009). Additionally, the formation and carbonation of HMCs as the light-burned MgO cement matrix is characterized by the degree of hydration of the light-burned MgO. A study was conducted in which wettable powder, such as HCl, MgCl₂, and (CH₃COO)₂Mg, was added to promote MgOₓ(CH₃COOH)ₜ₋, reaction and maximize the initial hydration rate (Dung and Unluer 2017). A study, which adjusted the temperature and CO₂ concentration of the initial hydration process of the light-burned MgO obtained from Richard Baker Harrison Ltd., identified the rate and degree of carbonation as well as the type of carbonate using X-ray photoelectron spectroscopy (XPS) (Rheinheimer et al. 2017). As the physical properties of light-burned MgO cement are affected by the degree of hydration and carbonation (Dung and Unluer 2016), studies have been conducted on the control of additives and curing environment to activate the light-burned MgO. Several researchers (Valuziene, Kaminskas, and Gasinunas 1976; Pu and Unluer 2019; Yang et al. 2019) have investigated the reaction pathways of the MgO-CO₂-H₂O system. The pathway for the carbonization of brucite is particularly complex because Mg has a strong tendency to form a series of metastable hydrous carbonates (Vågvölgyi et al. 2008a). These metastable hydrous...
carbonates, including hydromagnesite (Mg₅(CO₃)₄(OH)₂·4H₂O), Mg₆(CO₃)₃(OH)₂·3H₂O, artinite (Mg₂CO₃(OH)₂·3H₂O), nesquehonite (MgCO₃·3H₂O), and langfordite (MgCO₃·5H₂O), depend on the partial pressure and temperature of carbon dioxide (Vágvölgyi et al. 2008a). Consequently, the light-burned MgO has distinctive characteristics based on the calcination conditions (Fang 2004), and the carbonates produced differ with the curing conditions. Therefore, to improve the performance of light-burned MgO cement, research on the raw material is needed.

At lower calcination temperatures of light-hydrated magnesium carbonates (4 MgCO₃·Mg(OH)₂·4H₂O, LHMC), the crystal size of MgO decreases (Tripathi et al. 2003) and the internal energy increases, resulting in faster kinetics of reaction between the particles and gases. Therefore, in this study, the mineralogical and physical properties of light-burned MgO at different calcination temperatures were investigated. In addition, a matrix was manufactured using the light-burned MgO calcined by temperature. The curing temperature and CO₂ concentrations were controlled to investigate the effects of light-burned MgO characteristics on compressive strength, crystal phases, and thermodynamic properties. This study sought to identify the effects of light-burned MgO characteristics and curing conditions on the formation of carbonate, and to determine the conditions that can result in favorable mechanical properties and CO₂ sequestration ratio.

2. Materials and methods

2.1. Experimental materials

The LHMC (YIYingTeng Import and Export Co., Ltd. China) was used as a raw material. Its chemical compositions are listed in Table 1.

2.2. Experimental method

2.2.1. Preparation of light-burned MgO powder

The light-burned MgO was manufactured using LHMC as the raw material. The calculation temperature was set from 700 °C, at which the decomposition reaction of magnesium carbonate is completed, to 1000°C, at which the reactivity of the calcined MgO sharply decreases and the characteristics of the light-burned MgO are lost (Birchal, Rocha, and Ciminelli 2000). The LHMC was placed in a crucible, transferred to an electric furnace, and heated to 700–1000 °C at intervals of 100 °C at a heating rate of 10 °C/min, and maintained for 2 h at each temperature. Then, the temperature was immediately cooled to room temperature in a vacuum to prevent reaction with CO₂ and H₂O in the air.

| Specimen | Calculation temperature (°C) | Curing temperature (°C) | CO₂ concentration (%) |
|----------|-----------------------------|------------------------|-----------------------|
| 700C25MC | 700                         | 25                     | 0.03                  |
| 800C25MC | 800                         | 25                     | 0.03                  |
| 900C25MC | 900                         | 25                     | 0.03                  |
| 1000C25MC | 1000                       | 25                     | 0.03                  |
| 700C60MC | 700                         | 60                     | 0.03                  |
| 800C60MC | 800                         | 60                     | 0.03                  |
| 900C60MC | 900                         | 60                     | 0.03                  |
| 1000C60MC | 1000                       | 60                     | 0.03                  |
| 700C25CC | 700                         | 25                     | 0.20                  |
| 800C25CC | 800                         | 25                     | 0.20                  |
| 900C25CC | 900                         | 25                     | 0.20                  |
| 1000C25CC | 1000                       | 25                     | 0.20                  |
| 700C60CC | 700                         | 60                     | 0.20                  |
| 800C60CC | 800                         | 60                     | 0.20                  |
| 900C60CC | 900                         | 60                     | 0.20                  |
| 1000C60CC | 1000                       | 60                     | 0.20                  |

MC: moisture curing, CC: carbonation curing

2.2.2. Specimen fabrication and curing

To confirm the mechanical properties of the lightly burnt MgO mortar, we mechanically beamed light-burned MgO calcined at 700 °C, 800 °C, 900 °C, and 1000 °C according to the KS L 5109 at a 1:3 ratio with fine aggregate, and specimens with a size of 50 mm × 50 mm × 50 mm were fabricated. While the specific surface area of OPC powder is less than 1 m²/g (Monteiro and Mehta 2014), that of light-burned MgO is very high at more than 10 m²/g; hence, the waterbinder (W/B) ratio was set to 2 to maintain workability at a level where molding is possible. Furthermore, to confirm the physical and thermodynamic properties of the light-burned MgO hydrate, light-burned MgO pastes were prepared with the same W/B ratio and specimen size as the mortar.

All the molded specimens were cured at temperatures of 25 °C and 60 °C for 28 days in a thermohygrostat with CO₂ concentrations of 0.03% and 20% in moist curing (MC) and carbonation curing (CC), respectively. The humidity inside the thermohygrostat was maintained at 95% for moist curing (Table 2).

2.2.3. Characterization

The crystal phase and crystal size of the light-burned MgO were investigated by X-ray diffraction (XRD; X’pert Pro Powder, PANalytical) using Cu Kα radiation, and the particle shape and size were observed by field emissions.
emission scanning electron microscopy (FE-SEM; Carl Zeiss, SUPRA 40VP, Germany). The light-burned MgO paste specimen was cured for 28 days, taken out of the thermohygrostat, and stored in acetone for 3 days to prevent hydration; then, it was dried for 24 h at 90 °C to remove residual moisture. The fully dried paste specimen was collected; then, the mineral structure was analyzed using XRD and the weight loss and endothermic peak were analyzed using thermogravimetry and differential scanning calorimetry techniques (TG-DSC; TA Instruments Ltd. SDT Q600). The light-burned MgO mortar specimens were taken out of the thermohygrostat after 3 days, 7 days, and 28 days of curing, and their compressive strengths were measured.

3. Results and discussion

3.1. Characteristics of light-burned MgO powder

The light-burned MgO powders calcined at various temperatures were analyzed using XRD with a tube current of 30 mA and generator voltage of 40 kV. The crystal size of the light-burned MgO was calculated via the Scherrer equation (\( \tau = \frac{K\lambda}{B\cos\theta} \)) using the full width at half maximum (FWHM) of the XRD pattern (Suryanarayana and Norton 1998). While the highest peak of the XRD patterns is typically used to calculate the crystal size, in the case of MgO, the FWHM of the first peak is too small, leading to a large data error. Therefore, the second peak was used observe the FWHM accurately. We measured it in the range of 61.3–63.3°, which are the start and end point of the peak.

As the calcination temperature increased, the peak intensity and shape of the XRD pattern became much higher and clearer, respectively, as shown in Figure 1. Table 3 presents the crystal size of the calcined MgO according to the calcination temperature. The table shows that the MgO crystal size grows as the calcination temperature increases. The crystal sizes of the MgO calcined at 700 °C and 800 °C were 38.7 nm and 39.9 nm, respectively, indicating a 3% growth in size at 800 °C. Meanwhile, the crystal size of the MgO calcined at 900 °C was 57.1 nm, 43% larger than that at 800 °C, whereas that at 1000 °C was 108.7 nm, 90% larger than that at 900 °C. Material transportation increased as the temperature rose, causing the crystal to grow as the calcination temperature increased. In particular, the rapid crystal growth at approximately 900 °C is considered to be due to sufficient activation energy over 900 °C, which could elevate mass transportation. Consequently, the largest crystal can be produced because of the highest mobility at 1000 °C calcination. However, the trend of crystal growth with increasing calcination temperature not only reduces the specific surface area, but also decreases the driving force for mass transfer (Pimpinelli and Villain 1998).

During calcination, MgCO₃ decomposes into MgO nano-sized crystals and CO₂, and a porous structure is formed as CO₂ escapes from MgCO₃. MgO nano-sized crystals begin to grow at 700 °C, and as a result of calcination, the pore size increases and the specific surface area decreases, though the total pore volume decreases (Birchal, Rocha, and Ciminelli 2000). As the calcination temperature of MgCO₃ increases, the specific surface area and total pore volume of MgO decrease, as presented in Table 3. The specific surface area decreased by 73% at 800 °C compared with that at 700 °C, 56% at 900 °C compared with that at 800 °C, and 76% at 1000 °C compared with that at 900 °C, whereas the pore volumes decreased by 72%, 46%, and 58%, respectively.

Figure 1 shows the SEM images of MgO particles calcined at various temperatures. MgO particles typically have a spherical shape. The crystal gradually grows as the calcination temperature increases to 900 °C and then becomes larger rapidly at 1000 °C. Additionally, a neck was formed between the MgO particles, thereby forming a hard aggregate above 900 °C. The MgO particle sizes were similar to the crystal sizes obtained from the XRD pattern.

3.2. Physical properties of light-burned MgO mortar hydrate according to the curing conditions

This study measured the strength of light-burned MgO mortar hydrates cured for 3 days, 7 days, and 28 days under various temperature and CO₂ conditions. Nearly all samples cured in moisture at 25 °C (25MC) were not

![Figure 1. XRD patterns of light burned MgO powders calcined at various temperatures.](image-url)

**Table 3.** Physical properties of light burned MgO powder according to the calcination condition.

| Calcination temperature (°C) | Crystal size (nm) | Specific surface area (m²/g) | Total pore volume (cm³/g) |
|-----------------------------|------------------|-----------------------------|--------------------------|
| 700                         | 38.74            | 45.9                        | 0.36                     |
| 800                         | 39.86            | 33.54                       | 0.26                     |
| 900                         | 57.10            | 19.02                       | 0.12                     |
| 1000                        | 108.62           | 14.55                       | 0.07                     |
strong enough for their compressive strength to be measured. Light-burned MgO finally becomes brucite through hydration reaction, which is known to be thermodynamically unstable and very weak in terms of the compressive strength (Unluer and Al-Tabbaa 2013; Chaka, Felmy, and Qafoku 2016). Hydration begins at the surface of the MgO particles. During this process, the pores are blocked and the overall structure becomes dense owing to continuous internal hydration, leading to strength enhancement. However, brucite is an assembly of MgO and H₂O, and its volume decreases by 15% when it transforms from MgO and H₂O into Mg(OH)₂ (Cao, Miao, and Yan 2018). Therefore, long-term strength cannot be expected because of the internal crack evolution caused by contraction over the long term. Moreover, as the curing temperature increases, the hydration reaction of MgO accelerates and the amount of brucite and the crystal size significantly increase (Gao, Lu, and Geng 2008). Therefore, the specimen moist cured at 60 °C (60MC) yielded more brucite and strength than that the 25MC specimen. Excluding the 700C25MC specimens (hydrates of light-burned MgO mortars calcined at 700 °C and moist cured at 25 °C), all 25MC specimens exhibited a compressive strength of 0 MPa. The compressive strength of the 60MC specimens tended to increase with the curing time, though samples cured for 28 days still exhibited strengths below 1 MPa. Moreover, the reactivity of light-burned MgO calcined at higher temperature is reduced because of the large crystal size with a small surface area; consequently, the strength of the 700C60MC specimen cured for 28 days was 0.7 MPa, whereas that of the 1000C60MC specimen was 0.26 MPa.

In contrast, the strength of the 25CC specimen (cured in CO₂ at 25 °C) was substantially higher than that of the 25MC specimen, as shown in Figure 3(b). The 700 °C specimens exhibited the highest initial compressive strength owing to their high reactivity, and the strength at 28 days was 3.5 MPa. The initial compressive strength gradually decreases as the calcination temperature of the light-burned MgO increases. However, excluding the 1000 °C specimen, the specimens cured for 28 days exhibited strength of at least 3.5 MPa. This tendency in specimens other than the 1000 °C specimen likely occurred due to the sufficient curing time, which ensured full hydration regardless of the particle size and specific surface area, unlike the initial reaction. The strength of the specimen calcined at 1000 °C is attributed to the considerable decrease in reactivity compared with the other samples owing to the formation of hard aggregates between the MgO particles, as shown in Figure 2(d).

In the case of 60CC, the reactivity of the lightly burnt MgO increases owing to the high initial curing temperature, leading to an initial compressive strength of 2.4 MPa, which is higher than those of other samples. However, this decreased with the curing time to 2.3 MPa after 28 days. This means that loss of water may have collapsed the interlayer structure of carbonate at high temperatures, and explains the corresponding decrease of strength over time (Langmuir 1965; Canterford,
3.3. Crystal phases of light-burned MgO paste matrix

To identify the crystal phases of the light-burned MgO paste matrix, samples aged for 28 days were taken, dried, and then analyzed using XRD at a tube current of 30 mA and generator voltage of 40 kV. X-ray diffraction analysis was also performed in 0.0033° steps at a scanning angle range of 5–80°. Significantly different hydrates are formed based on the curing conditions, as shown in Figure 4. In Figure 4(a), the light-burned MgO hydrate moist cured at 25 °C (25MC) exhibited a main crystal phase regardless of the calcination temperature, and Mg(OH)₂ (brucite) was observed. In Figure 4(c), the specimen moist cured at 60 °C exhibited the same crystal phase as the 25MC specimen. However, as the curing temperature increased, the peak intensity became higher and the XRD pattern became clearer than the 25MC specimen.

Unlike moist curing, magnesium carbonate and hydroxide were formed in carbonation curing. The 700C25CC and 800C25CC specimens hydrated from light-burned MgO calcined at low temperatures formed columnar nesquehonite (magnesium carbonate, MgCO₃ · 3H₂O), as shown in Figure 4(b) (Kloprogge et al. 2003; Ferrini, De Vito, and Mignardi 2009), and a small amount of brucite was observed. The 900C25CC and 100025CC specimens, however, which have higher calcination temperatures, formed columnar brucite and a small amount of nesquehonite. The hydration degree of MgO is quite low under ambient conditions due to its low rate and degree of dissolution (Jin and Al-Tabbaa 2013; Unluer and Al-Tabbaa 2014a; Dung and Unluer 2018), as well as the precipitation of hydration and carbonation products on the surface of unhydrated MgO particles, thereby inhibiting further hydration. The precipitation of carbonate phases on unhydrated Mg(OH)₂(aq, s) can also prevent the progress of carbonation reaction. As the crystal size of the light-burned MgO increased, the reactivity decreased and carbonate formation reduced, leading to more brucite production. Conversely, in the case of the 60CC specimen, hydromagnesite (4Mg (CO₃)₂·Mg(OH)₂ · 4H₂O) was formed, unlike the 25CC specimen (Morozov, Malkov, and Malygin 2003). This is due to the transformation of the initially produced carbonate mineral to thermodynamically stable hydromagnesite at temperatures above 50 °C (Unluer and Al-Tabbaa 2013).
3.4. Thermogravimetric analysis (TGA) of light-burned MgO paste matrix

Figure 5 shows the TGA and DSC analysis results of the cured MgO matrix cured under various conditions. Based on this result, each weight reduction section and endothermic peak were identified and used for analysis. To investigate the weight loss of the light-burned MgO hydrate, we performed TG analysis in the temperature range of 25–900 °C at a heating rate of 10 °C/min. There are three main decomposition stages in the weight loss of light-burned MgO hydrates (Vágvölgyi et al. 2008b; Hollingbery and Hull 2010; Ballirano et al. 2010; Dung and Unluer 2016) (Table 4). The decomposition reactions at each temperature range are summarized in Table 4.

Table 5 (a) presents the weight reduction of light-burned MgO hydrates with curing conditions and calcination temperatures. Dihydroxylation of brucite is known to occur between 300 °C and 400 °C. All moist cured MgO hydrates exhibited only one step decomposition at 300–400 °C regardless of the curing temperature. While the 700C25CC specimens decreased by 31.2%, the other specimens showed similar weight loss of approximately 26%. As the theoretical weight loss due to the dihydroxylation of pure brucite is approximately 31% (Assima et al. 2013), the 700C25CC specimen can be considered to be pure brucite. However, in the other specimens, the crystal size was so large that full hydration did not occur under these curing conditions.

In carbonation curing, weight loss occurred in sections above 400 °C for most of the specimens, confirming the formation of carbonate. In the 25CC specimen, however, the dehydration section of nesquehonite and the dehydroxylation section of brucite overlap at approximately 300–400 °C, as presented in Table 4. Therefore, this study compared the weight reduction of the decarbonation section of the > 420 °C section to confirm the amount of nesquehonite. The 700C25CC specimen exhibited the highest weight loss of 24.38%, with similar values at 800 °C and 900 °C and the lowest value at 1000 °C (12.9%). The weight reduction rate of pure nesquehonite crystals by decarbonation confirmed in previous studies is approximately 33.4%, indicating that the 700C25CC specimen forms nesquehonite with approximately 73% purity and brucite with 27% purity. However, as the calcination temperature of MgO increased, the nesquehonite content gradually decreased, and in the 1000C25CC specimen, the nesquehonite content decreased to less than 40%.
Figure 5. TG-DSC characteristics of light burned MgO for various curing conditions.

Table 4. Thermal decompositions of hydrate and carbonate phases within hydromagnesite.

| Phase                  | Decomposition temperature | Decomposition steps                                                                 |
|------------------------|---------------------------|--------------------------------------------------------------------------------------|
| Brucite (Mg(OH)_2)     | 300–400 °C (Dehydroxylation) | Mg(OH)_2 → MgO + H_2O                                                                |
| Hydromagnesite (4MgCO_3·Mg(OH)_2·4H_2O) (Unlüer and Al-Tabbaa 2014b) | <250 °C (Dehydration) | 4MgCO_3·Mg(OH)_2·4H_2O → 4MgCO_3·Mg(OH)_2·4H_2O                                    |
|                        | 250–350 °C (Dehydroxylation) | 4MgCO_3·Mg(OH)_2 → 4MgCO_3 + MgO + H_2O                                              |
|                        | >350 °C (Decarbonation)     | MgCO_3 → MgO + CO_2                                                                  |
| Nesquehonite (MgCO_3·3H_2O) (Vágvolgyi et al. 2008a) | <300°C (Dehydration) | MgCO_3·3H_2O → MgCO_3·H_2O + 2H_2O                                                  |
|                        | 300–420°C (Dehydration)    | MgCO_3·H_2O → MgCO_3 + H_2O                                                          |
|                        | >420°C (Decarbonation)      | MgCO_3 → MgO + CO_2                                                                  |
3.5. CO₂ sequestration

The amount of CO₂ absorbed was determined by quantifying the CO₂ sequestration ratio (R_{CO₂}). R_{CO₂} was calculated as R_{CO₂} = P_{CO₂}/P_{MgO}, where P_{CO₂} denotes the percentage of sequestered CO₂ (obtained by subtracting the mass loss associated with the loss of H₂O from the total mass loss between 25–900 °C), and P_{MgO} denotes the percentage of final mass at 900 °C (i.e., residual MgO). These figures involved a small loss in mass because of the decomposition of the seeds during thermal analysis.

Table 5 indicates that a weight reduction in the decarbonation range was observed only in the carbonation curing sample; further, its CO₂ sequestration ratio is presented in Table 5. The CO₂ sequestration ratio of both 25CC and 60CC specimens tended to decrease with increasing crystal size (Table 3); however, the amount of CO₂ sequestration differed depending on the produced mineral.

The 25CC specimen, in which nesquehonite was formed, recorded the maximum CO₂ sequestration ratio of 0.66 at 700 °C and reached 0.28 at 1000 °C, exhibiting a significant decrease with increasing crystal size. In contrast, the 60CC specimen, in which hydromagnesite was formed, showed a maximum of 0.92 at 700 °C and recorded 0.83 at 1000 °C, because the effect of the increasing crystal size was minimal. Based on these results, it is inferred that hydromagnesite is affected lesser by the crystal size than nesquehonite. This is because hydromagnesite is the most thermodynamically stable material in the magnesium carbonate group, and can be easily formed at high temperatures.

### 3.6. Differential Scanning Calorimetry (DSC) analysis of light-burned MgO hydrate according to curing conditions

Table 6 shows the DSC analysis results according to the curing conditions. In moist curing, an endothermic peak was observed at 380–391 °C. This resulted in a phase change from Mg(OH)₂ to MgO at 380 °C, and is consistent with the XRD result. In the case of the 700C60MC specimen (636 J/g), the heat of absorption was substantially lower than that of the other moist-cured specimens (1100–1300 J/g) despite the presence of Mg(OH)₂. Figure 6 shows that the 700C25MC and 700C60MC specimens have different mineral morphologies. Generally, Mg(OH)₂ nanoparticles are characterized by a hexagonal platelet-like morphology with a thickness of 50–110 nm and lateral dimensions of several micrometers. All moist cured specimens, except for the 700C60MC specimen, maintained a hexagonal platelet morphology, whereas the 700C60MC specimen formed a sheet morphology. The morphology of Mg(OH)₂ is determined by the amount of Mg^{2+} ions and the reaction temperature during the formation process (Balducci, Diaz, and Gregory 2017), and in fine MgO power with a crystal size of 40 nm or less, the MgOH⁺ ions serve as Mg(OH)₂ nuclei that induce particle and sheet growth during high-temperature conditions.
curing, thereby forming the sheet morphology of Mg (OH)$_2$. The difference in the DSC values is as a result of the formation of bell-shaped peaks in the crystal shapes of certain samples; however, crystals with a rough morphology sometimes formed a rather irregular graph, as shown in Figure 6(a), which is expected to correspond to the 700C60MC results.

In the case of the 25CC specimen, endothermic peaks were observed at various temperatures. For the 700C25CC specimen, endothermic peaks occurred at 123, 230, and 445 °C, consistent with those of nesquehonite (Vágvölgyi et al. 2008a). However, as the calcination temperature of light-burned MgO increased, the peaks at 230 and 445 °C decreased gradually. Additionally, the heat of adsorption increased from 143.2 J/g to 275.9 J/g, and subsequently to 281.2 J/g and 492 J/g in the temperature range of 380–400 °C, at which the main endothermic peak of Mg(OH)$_2$ occurs. MgO at 800–1000 °C with a large crystal size is unfavorable for carbonate formation; therefore, it was identified to be partially carbonated under the moist-curing condition of 25 °C. Moreover, for the third peak, which corresponds to the decarbonization process of nesquehonite, the head of adsorption reduces gradually from 400.3 J/g to 223.5 J/g, 223.8 J/g, and 87.7 J/g. This is because the energy required for the CO$_2$ decomposition reduces, suggesting that the carbonate formation reduces and the thermal stability decreases with increasing crystal size. In the 800–1000C25CC specimens, a peak was observed in the range of 120–170 °C, unlike the theoretical endothermic peak of Mg(OH)$_2$. This results in moisture adsorption onto the attapulgite structure of Mg(OH)$_2$ during moist curing and evaporation at 120–230 °C (Meiling, Zhou, and Yihong 2012). Accordingly, this peak is attributed to the release of free water and adsorbed water that did not evaporate at 90 °C during the drying process.

In the case of 60MC specimen, two endothermic peaks were observed respectively at 251–257 °C and 446–450 °C, consistent with those of hydromagnesite. The first endothermic peak occurred due to dehydration decomposition, and the second peak due to decarbonization (Bhattacharjya and Selvamani 2012). During decarbonization, the increasing crystal size caused a decrease in heat of adsorption from 613.8 J/g to 572 J/g, and then to 556 J/g and 546.3 J/g. This is because increasing the calcination temperature of hard magnesia results in low reactivity, causing low nucleation of hydromagnesite.

Therefore, it was confirmed that the CO$_2$ sequestration ratio derived through TGA, and the heat of absorption of decarbonation derived through DSC analysis were very consistent. Thus, it is inferred that they are determined by the crystal size of MgO listed in Table 3.

### 4. Conclusions

The following conclusions are drawn from the findings of this study.

1. Particle size and surface area of light-burned MgO depend on the calcination temperature, and particles grew and the surface area decreased with increasing temperature. As the calcination temperature increased to 1000 °C, particles grew and

### Table 6. DSC analysis results of light burned MgO paste matrix at various curing conditions and calcination temperatures.

| Temperature (°C) | DSC analysis | 25MC Peak1 | 60MC Peak1 | 25CC Peak1 | 60CC Peak1 |
|------------------|--------------|------------|------------|------------|------------|
| 700              | temp (°C)    | 364.9      | 390.8      | 123.4      | 230.8      | 445.3      | 256.7      | 450        |
|                  | J/g          | 1249       | 636.4      | 232.4      | 143.2      | 400.3      | 288        | 613.8      |
| 800              | temp (°C)    | 371.8      | 382.3      | 129.1      | 397.2      | 448.3      | 215.5      | 446.4      |
|                  | J/g          | 1184       | 1130       | 461.0      | 274.9      | 223.5      | 283.7      | 572.2      |
| 900              | temp (°C)    | 370.2      | 383.4      | 130.1      | 388.6      | 448.4      | 252.2      | 445.5      |
|                  | J/g          | 1170       | 1122       | 634.2      | 281.2      | 223.8      | 234.1      | 556        |
| 1000             | temp (°C)    | 372.8      | 381.4      | 164.7      | 406.3      | 446.4      | 252.7      | 446.5      |
|                  | J/g          | 1187       | 1144       | 553.2      | 492.6      | 87.7       | 206.2      | 546.3      |

![Figure 6. FE-SEM images of light burned MgO mortar.](image-url)
the neck also grew, thereby decreasing the pore volume, creating hard aggregates, and significantly decreasing reactivity.

(2) The light-burned MgO cured in moisture at 25 °C and 60 °C formed brucite. These matrixes showed a compressive strength of less than 1 MPa in all specimens because brucite is thermodynamically unstable and much weaker than carbonate minerals. The heat of absorption and the total weight reduction rate of the range corresponding to dehydroxylation were higher at high curing temperature of 60 °C than at 25 °C, thereby increasing the formation of brucite.

(3) The light-burned MgO hardened in CO2 formed brucite and magnesium low-temperature carbonate, i.e., nesquehonite at 25 °C and hydromagnesite at 60 °C. The compressive strength of nesquehonite was the highest, but its CO2 sequestration capacity was lower than that of hydromagnesite. Furthermore, the increasing crystal size of MgO caused a reduction in carbonate formation and CO2 sequestration capacity of both nesquehonite and hydromagnesite. It was additionally confirmed that the CO2 sequestration capacity of nesquehonite is affected more by the crystal size, compared with that of hydromagnesite.

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