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# Performance of High-volume Carbide Lime Mortar Under Accelerated $CO_2$ Curing Followed by Postconditioning Treatments

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## ABSTRACT

This study explores the potential of using calcium hydroxide ($Ca(OH)_2$) derived from Carbide Lime Waste (CLW) as a high-volume cement replacement (40%–70% by volume) in mortar. The mortar was subjected to accelerated carbon dioxide ($CO_2$) curing to enhance carbonation capture while maintaining the desired strength, promoting more sustainable construction practices. The optimum high-volume mortar was further analysed to examine its long-term properties under various postconditioning treatments, including water, wet gunny, and air curing, in terms of calcium carbonate ($CaCO_3$) formation and late-age strength. The physical properties, such as water absorption and mechanical properties, including compressive, flexural, and splitting tensile strengths, were evaluated. $CO_2$ capture performance was assessed through carbonation depth testing, and microstructural analysis was performed using Thermogravimetric analysis (TGA) and X-ray diffraction (XRD). Results showed that $CLW_{70}$ exhibited the best mix design, achieving 100% carbonation depth and 70% $CaCO_3$ formation within 7 days of accelerated $CO_2$ curing. Compressive strength increased from 2.62 MPa on day 1 to 17.01 MPa on day 7. XRD analysis indicated that air curing was the most effective postconditioning treatment, resulting in the highest $CaCO_3$ peaks. Accelerated $CO_2$ curing also reduced water absorption, and mechanical strength improved with curing age, demonstrating that the $CaCO_3$ formed during the carbonation process densified the CLW mortar after 7 days of curing.

*Keywords:* Accelerated $CO_2$ curing, $CaCO_3$ precipitation, carbide lime waste, $CO_2$ capturing, postconditioning

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## INTRODUCTION

Concrete remains the dominant construction material worldwide, and ongoing efforts focus on finding environmentally friendly alternatives that maintain strength and durability. The choice of alternative materials often depends on the specific application. For example, supplementary cementitious materials (SCMs) rich in cementitious properties are beneficial because they produce secondary calcium silicate hydrates (CSH) gels, enhancing strength. In addition, SCMs can address environmental concerns such as $CO_2$ emissions. Accelerated carbonation curing (ACC) has been shown to improve initial strength and reduce porosity better than conventional water curing, leading to at least a 20% strength improvement across mixtures (Sharma & Goyal, 2018).

Previous research has extensively explored industrial waste materials, such as fly ash, slag, and recycled concrete aggregates, for mineral $CO_2$ sequestration in the concrete industry. These waste products often contain calcium-bearing phases that facilitate the formation of carbonate compounds, aiding in $CO_2$ sequestration. Early-stage carbonation curing can significantly affect the early and late-stage performance of cement-based composites. ACC treatment, in particular, shows promise for the precast concrete industry, which accounts for about 10% of global concrete consumption every year (Li & Wu, 2022).

There are several noteworthy benefits to using SCMs. First, early strength in SCM concrete can be enhanced by carbonation reactions. Second, carbonate precipitation can improve durability. Third, carbon emissions can be reduced by lowering cement usage and increasing $CO_2$ uptake during carbonation (Zhang et al., 2016).

One material gaining attention is carbide lime waste (CLW), a byproduct of acetylene gas production, which raises concerns about disposal and environmental impact (Adamu et al., 2021). The main component of CLW is calcium hydroxide ($Ca(OH)_2$), which has a high calcium oxide (CaO) content, making it a promising binder material (Lorca et al., 2014). Additionally, CLW has a strong potential for $CO_2$ capture.

Several factors influence the rate of carbonation, including $CO_2$ concentration, which plays a critical role in the carbonation process. A specific concentration of $CO_2$ in waste flue gases is preferred for effective carbonation treatment in concrete. Cement plants typically emit waste flue gas with a $CO_2$ concentration of 14%–33%, while iron and steel plants release gases with 20%–30% $CO_2$ concentration (Li & Wu, 2022). A higher $CO_2$ concentration, such as 20%, has been shown to enhance crystallinity and particle size compared to a lower concentration of 1% (Li & Ling, 2020).

Most earlier studies have used carbonation treatments for building materials at 20–80°C temperatures to achieve cost-effective CO2 sequestration (Li & Wu, 2022). The water-to-cement ratio (w/c) also plays a crucial role in carbonation. A higher w/c can facilitate the separation of cement and limestone particles, promoting carbonation by creating a more aqueous environment. However, excess water in the pores of cementitious materials can hinder $CO_2$ diffusion, limiting penetration depth (Li & Wu, 2022; Zhang et al., 2016). Therefore, preconditioning is necessary to remove excess moisture before $CO_2$ curing. A reduced w/c ratio can improve gas permeability, allowing $CO_2$ to diffuse more effectively into the material. This preconditioning not only affects the initial carbonation process but also has long-term positive implications for the durability and strength of the final product.

However, the carbonation through $CO_2$ curing is an exothermic process that can cause early water loss from the mixture. It can inhibit the further hydration of unreacted cement, particularly when combined with water removal during preconditioning. Water loss during carbonation may hinder future hydration, reducing compressive strength (Sharma & Goyal, 2018). It is especially important in regions where materials are exposed to varied climates and environmental pressures. Postconditioning, such as subsequent water curing, may be needed to replenish lost water, enhance hydration, improve microstructure, and promote further strength development (Liu & Meng, 2021).

Although the carbonation of cement-based materials has been extensively studied, limited research has focused on accelerated $CO_2$ curing, preconditioning, and postconditioning treatments specifically for lime-based materials. Furthermore, many previous studies have primarily investigated factors influencing $CO_2$ curing, such as $CO_2$ concentration, pressure, temperature and humidity (Li & Ling, 2020; Lu et al., 2022; Xu et al., 2022). However, there remains a gap in the research regarding curing regimes that optimise $CO_2$ capturing and mechanical strength properties. Addressing this gap could provide significant insights into curing optimisation, ultimately improving mortar performance.

It is also important to assess the tensile strength of mortar and concrete, as these materials are weak in tension but strong in compression. Applications such as unreinforced concrete roads and runways rely on their ability to bend, distributing concentrated loads over large areas (Gloria et al., 2017). This research aims to determine the mechanical properties of mortar, including compressive, flexural and splitting tensile strengths, to provide baseline data for unreinforced mortar applications. While many studies have investigated high-volume replacement (40% or more) of SCMs or alternative materials for Portland Cement (PC), few have focused on high-volume lime-based materials subjected to accelerated $CO_2$ curing and later strength development under postconditioning treatments. Other alternative materials that have been studied include fly ash, palm oil fuel ash and ground granulated blast furnace slag (Nwankwo et al., 2020).

This research consists of two stages. The optimal high-volume CLW mortar was determined in the first stage based on the highest carbonation rate at a desired strength for non-loadbearing applications. In the second stage, the $CO_2$ capture and mechanical properties of the optimal high-volume CLW mortar were examined under various postconditioning treatments. This study contributes valuable knowledge on the performance of high-volume lime-based materials in mortar under accelerated $CO_2$ curing, particularly in terms of $CO_2$ uptakes and mechanical strength. It also provides insights into later strength performance under postconditioning treatments.

## MATERIALS AND METHODS

### Materials and Sample Preparation

Ordinary Portland Cement (OPC) and Carbide Lime Waste (CLW) were the primary materials used in this study. The fineness of both OPC (99.73%) and CLW (92%) passing a 45µm sieve size was used. CLW was ground using a ball mill to enhance its hydration potential, aligning it with OPC standards. The chemical composition of CLW was predominantly calcium oxide (96% CaO), as shown in Figure 1.

In the first stage, mortar mixes were prepared according to the mix proportions listed in Table 1. A constant water-cement ratio (w/c) of 0.6 and a cement-to-sand ratio (c/s) of 1:3 was maintained across all samples. Mortar samples were cast into 50 × 50 × 50 mm cubes,

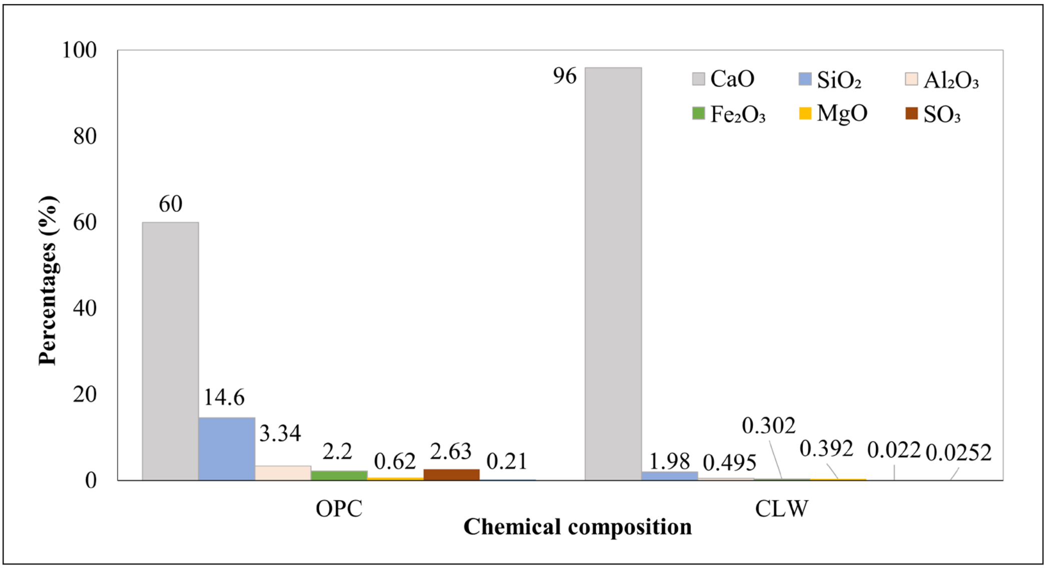



*Figure 1.* Chemical composition of OPC and CLW

Table 1
*Mix design proportion*

| Types of mortar | CLW replacement (kg/m³) | Cement (kg/m³) | CLW (kg/m³) | Sand (kg/m³) | w/c (kg/m³) |
|---|---|---|---|---|---|
| $CLW_{40}$ | 40 | 300 | 200 | 1500 | 300 |
| $CLW_{50}$ | 50 | 250 | 250 | | |
| $CLW_{60}$ | 60 | 200 | 300 | | |
| $CLW_{70}$ | 70 | 150 | 350 | | |

with each mould filled in two layers and subjected to vibration to ensure homogeneous distribution. After that, the mould was levelled, covered with a plastic sheet, and stored at room temperature. After 24 hours, the mortar samples were demoulded and placed in a $CO_2$ curing chamber at 60°C and a $CO_2$ concentration of 20% for 1, 3, and 7 days of accelerated curing.

The optimal mix based on $CO_2$ capture and strength was selected in the second stage for further analysis. The optimal mix was subjected to extended accelerated $CO_2$ curing for 3 and 7 days, followed by postconditioning treatments (air, wet gunny, and water curing) for up to 28 days. The design codes and curing conditions are summarised in Table 2.

Table 2
*Sample code and its corresponding curing condition*

| Code | Description | Subsequent postconditioning (method) | Test age (days) |
|---|---|---|---|
| $CLW_{40}$<br>$CLW_{50}$<br>$CLW_{60}$<br>$CLW_{70}$ | CLW mortar without preconditioning (*numeric refers to the cement replacement proportion*) | - | 1, 3, 7 |
| $CLWpc_{70}$ | CLW mortar with preconditioning treatment | - | |
| $CLWpc_{70WG}$ | 70% of CLW mortar with preconditioning treatment + postconditioning | Wet gunny | 1, 3, 7, 28 |
| $CLWpc_{70WC}$ | 70% of CLW mortar with preconditioning treatment + postconditioning | Water curing | 1, 3, 7, 28 |
| $CLWpc_{70AC}$ | 70% of CLW mortar with preconditioning treatment + postconditioning | Air curing | 1, 3, 7, 28 |

## Physical and Mechanical Properties

A series of tests were conducted to assess the performance of both control and CLW mortars, including compressive strength, flexural strength, splitting tensile strength, and water absorption. Three samples were used per test condition, and each property's average value was recorded. Compressive strength was evaluated at both stages, while flexural and splitting tensile tests were carried out after postconditioning.

### *Compressive Test*

Compressive strength tests were performed on 50 x 50 x 50 mm cubes using a Universal Testing Machine (3000 kN capacity) with a load rate of 2000 N/s (ASTM C109/C109M-02, 2012).

### *Flexural Test*

The three-point loading test was used to evaluate the flexural strength of mortar prisms (40 × 40 × 160 mm) subjected to postconditioning treatments. The test followed ASTM

C348-21 (2021) standards with a load rate of 40 N/s to ensure failure occurred between 30 s and 90 s without any sudden impact.

### *Splitting Tensile Test*

Splitting tensile strength was measured on cylindrical samples (50 mm diameter by 100 mm height) using the same Universal Testing Machine as the compressive test, with a loading rate of 1mm/min (ASTM C109/C109M-02, 2012; Nwankwo et al., 2020). The compressive force was applied on the ends of the cylindrical mortar samples splitting along the central plane.

### *Water Absorption Test*

Optimum mortar samples were dried in an oven at 105°C to a consistent weight before water absorption tests. After cooling, the initial mass ($m_1$ in g) was recorded, and samples were submerged in water for 24 hours. After that, the final mass ($m_2$ in g) was measured to calculate water absorption using Equation 1 (Luo et al., 2022).

$$WA\,(\%) = \frac{m_2 - m_1}{m_1} \times 100\% \qquad [1]$$

### *$CO_2$ Capturing Properties and Visual Evaluation of Carbonation Depth*

The carbonation depth of control and CLW mortars was evaluated using phenolphthalein spray after flexural testing. This was done in both stages to first determine the optimal mix and then examine the carbonation performance at a later age after various postconditioning treatments. The phenolphthalein spray turned the alkaline region purple, and the more acidic region was colourless (Roy et al., 1999). The carbonation depth was taken as the average of ten measurements across the cross-section of the sample (Liu et al., 2019).

### *$CO_2$ Sequestration by Thermogravimetric Analysis Test (TGA) Test*

Thermogravimetric analysis (TGA) assessed $CaCO_3$ precipitation in the mortars during the first stage. To prepare the samples, the CLW pastes with the highest $CO_2$ capturing based on carbonation depth were immersed in acetone for 24 hours to stop hydration (Zhang et al., 2016). The pastes were then dried at 105°C for a day and then crushed to a powder with a particle size of less than 45 µm. About 5 to 10 mg of this powder was then heated at 10°C/min to reach 1000°C in the presence of flowing $N_2$ gas (Ma, 2014). The amount of $Ca(OH)_2$ and $CaCO_3$ was determined by measuring the mass loss using Equations 2 and 3.

$$Ca(OH)_2\,(\%) = \left(\frac{M_{350} - M_{500}}{M_{350}}\right) * 100 \qquad [2]$$

$$CaCO_3\,(\%) = \left(\frac{M_{500} - M_{800}}{M_{500}}\right) * 100 \qquad [3]$$

### *X-ray Diffraction (XRD) Test*

X-ray diffraction (XRD) was used to identify mineral compositions, focusing on raw and carbonated samples. The samples were in powder form and crushed into particle sizes of less than 75 μm. The diffraction angle range used to scan the sample was from 10° to 90° within a 2θ range and at a speed of 1°/min (Wu et al., 2021).

## RESULTS AND DISCUSSION

### Optimisation of CLW Mortars Based on $CO_2$ Capture and Strength

Figure 2 shows the compressive strength of high-volume CLW mortars (40%–70%) at different curing ages. Two key trends emerge: first, a decrease in strength as CLW content increases, and second, a significant increase in strength with longer accelerated $CO_2$ curing durations. By day 7, $CLW_{60}$ and $CLW_{70}$ reached compressive strengths around 17 MPa. As a comparison, Luo et al. (2022) replaced 60% of cement with carbide slag (CS) at lower $CO_2$ concentrations. At 5% $CO_2$ concentration at 25°C, the study reported compressive and flexural strengths of 2.0–5.7 MPa and 9.9–19.3 MPa after 7 and 28 days of accelerated $CO_2$ curing. In contrast, after 7 days of accelerated $CO_2$ curing, $CLW_{60}$ demonstrated a compressive strength of 17.19 MPa—an 83% improvement. This strength enhancement highlights the significant influence of accelerated curing parameters, particularly the higher $CO_2$ concentration and temperature, on the early-age mechanical properties. Similarly, $CLW_{70}$ mortar achieved full carbonation (100%) with a compressive strength of 17.01 MPa after 7 days.

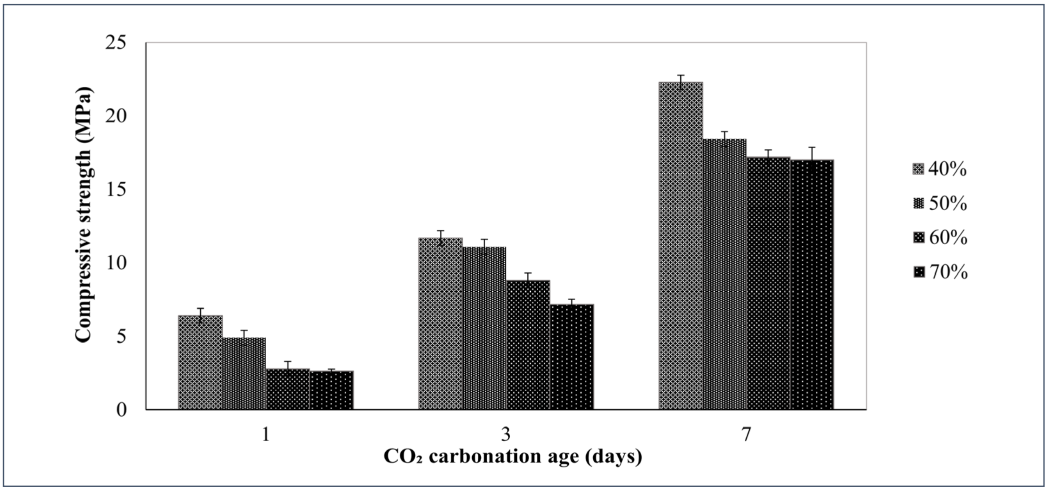



*Figure 2.* The compressive strength performance of CLW mortars at all ages

Figure 3 shows the carbonation depth for similar high-volume CLW mortars. The results indicated that all samples' carbonation depth increased with longer accelerated $CO_2$ curing durations. Additionally, there was a notable increase in carbonation depth as the proportion of CLW increased. Since CLW primarily consists of $Ca(OH)_2$, the higher its content, the more $CaCO_3$ would be formed under accelerated $CO_2$ curing conditions as the curing time increased. It suggests that the high CLW content, the high concentration of $CO_2$, and the elevated curing temperature significantly enhanced the carbonation rate. In traditional cement, calcium derives mainly from hydrated products like $Ca(OH)_2$ and CSH, while in CLW mortars, $Ca(OH)_2$ directly reacts with $CO_2$ gas during accelerated curing. As a result, carbonation reduces the amount of $Ca(OH)_2$ in both the cement and CLW, leading to the precipitation of $CaCO_3$. Moreover, higher curing temperatures and water content can further enhance carbonation (Li & Wu, 2022).

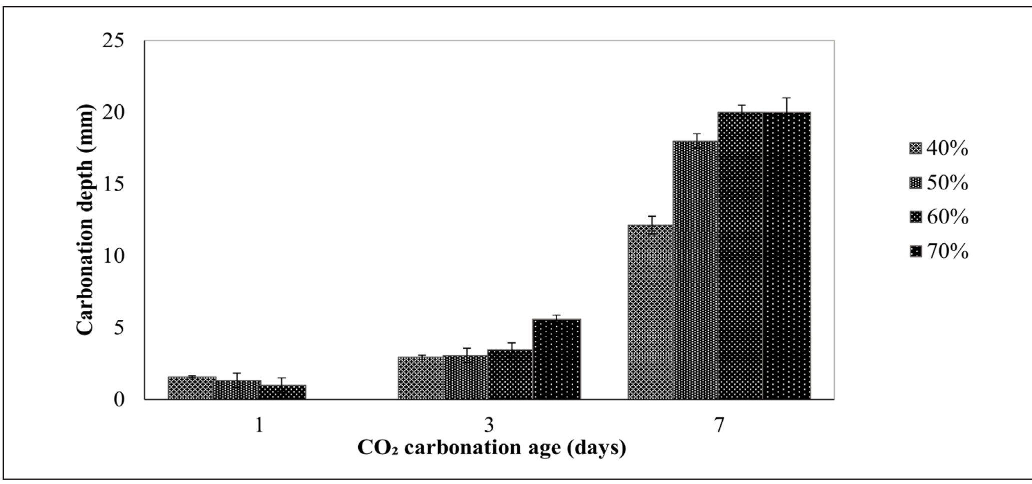



*Figure 3*. The carbonation depth performance of CLW mortars at all ages

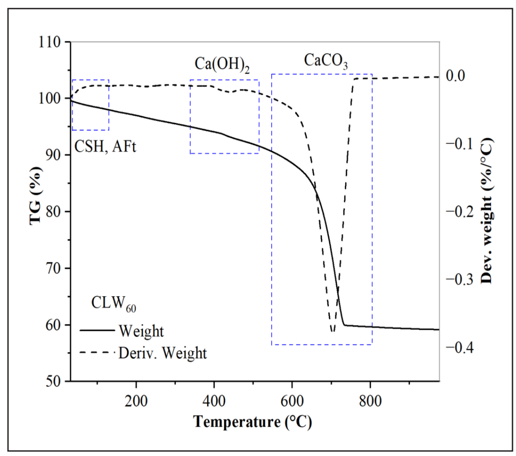
## Physical, Mechanical and $CO_2$ Capture Performance of Optimum CLW Mortars

The optimum mix was selected based on its $CO_2$ capture performance. Figure 4 shows that $CLW_{60}$ and $CLW_{70}$ exhibited similar carbonation depths, leading to further investigation. The DTG curves from TGA revealed three distinct peaks of mass loss between 30–400°C. The main reason is due to the dehydration of CSH gels, monosulfate ($AF_m$), and ettringite ($AF_t$) (Zhang et al., 2023). According to Luo et al. (2022), the major mass loss at 100°C is due to the dehydration of CSH gels formed by the hydration of silicate phases. The loss of $Ca(OH)_2$ due to dehydroxylation occurs between 350–450°C, while the decomposition of $CaCO_3$ takes place at temperatures above 600°C (Cizer et al., 2012).

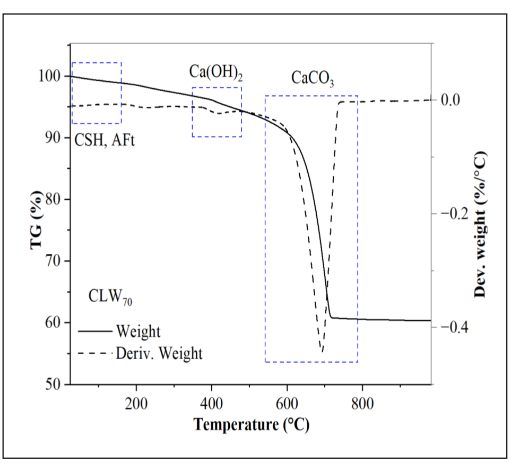
After 7 days of accelerated $CO_2$ curing, as shown in Figures 4(a) and 4(b), $CLW_{60}$ exhibited 1.11% of $Ca(OH)_2$ and 65.41% of $CaCO_3$ precipitation, while $CLW_{70}$ showed slightly higher $CO_2$ capture with less than 1% of $Ca(OH)_2$ and 70% of $CaCO_3$ as shown in Figure 4(c). These findings suggest that $CLW_{70}$ achieved greater $CaCO_3$ formation. Since this study aimed to identify the optimum mix based on $CO_2$ capture and desired strength, $CLW_{70}$ was selected for further evaluation under various postconditioning treatments to investigate its later-age strength.

To verify the effectiveness of accelerated $CO_2$ curing, Figure 4(c) compares mortar subjected to conventional curing (non-$CO_2$ curing). The uncarbonated $CLW_{70}$ mortars showed only 41.40% Ca $(OH)_2$ and 17.86% $CaCO_3$. The 98.41% reduction in $Ca(OH)_2$ after accelerated $CO_2$ curing confirms the significant role of this process in promoting $CaCO_3$ precipitation. These findings demonstrate that CLW is highly effective in capturing $CO_2$ and efficiently converts portlandite into calcite through accelerated $CO_2$ curing.

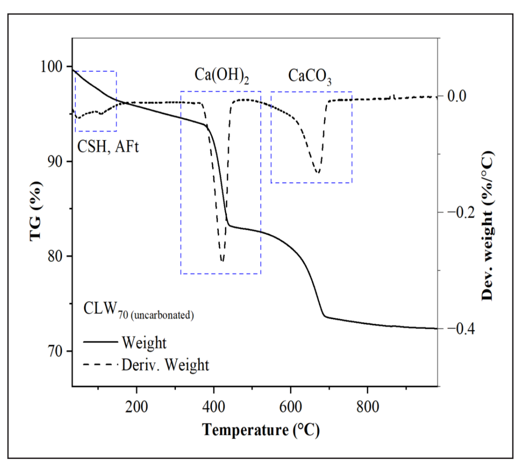
Figure 5 illustrates the mechanical properties of $CLW_{70}$ mortars subjected to various accelerated $CO_2$ curing durations and postconditioning treatments. Wet gunny ($CLW_{PC70WG}$) and air curing ($CLW_{PC70AC}$) improved compressive strength by 16.9%–21.5% and 21.5%– 33.4%, respectively, after 1 and 3 days of accelerated $CO_2$ curing, compared to the control sample ($CLW_{PC70}$), as shown in Figure 5(a). In contrast, water curing had minimal impact on the later-age strength of $CLW_{PC70}$ across all curing durations, likely due to the higher




(a)

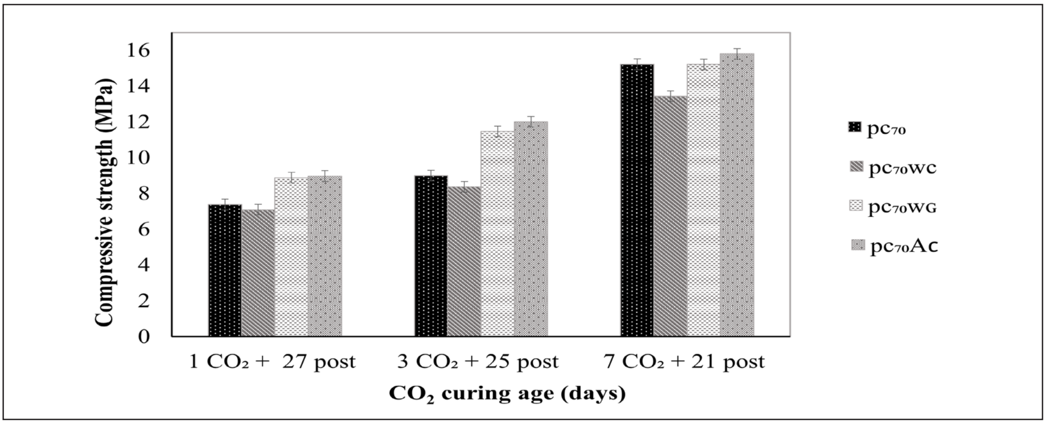



(b)

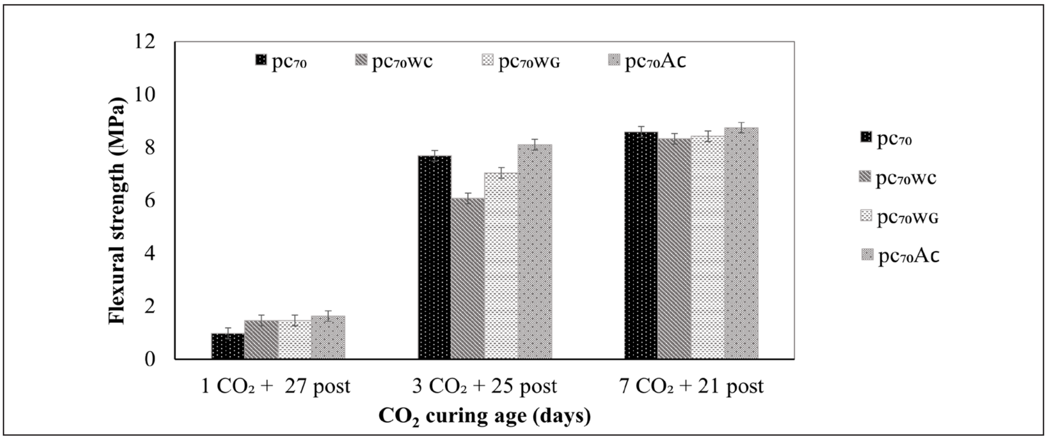



(c)

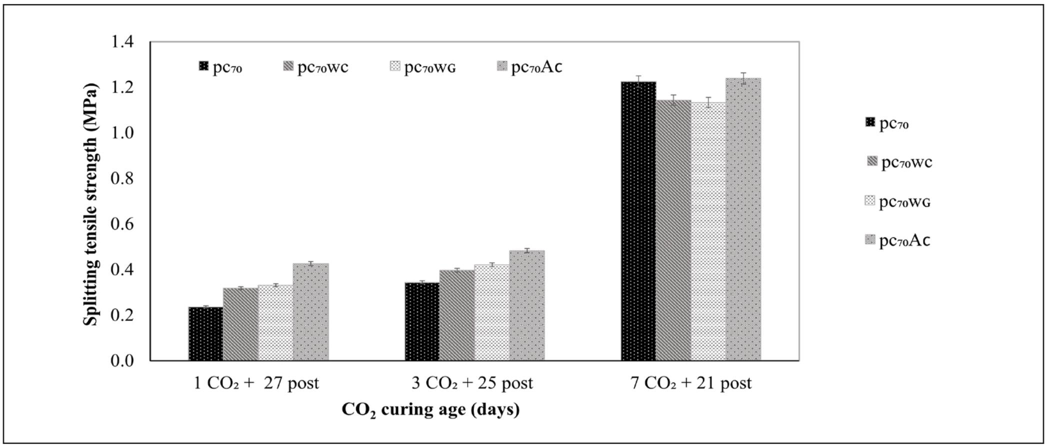
*Figure 4.* TGA of mortar paste samples: (a) $CLW_{60}$; (b) $CLW_{70}$; and (c) $CLW_{70}$ (uncarbonated)




(a)




(b)




(c)

*Figure 5.* Mechanical strength of optimum CLW mortars with different $CO_2$ curing and post-curing age: (a) Compressive; (b) Flexural; and (c) Splitting tensile

water absorption of CLW, which hinders hydration during postconditioning, as shown in Figure 6.

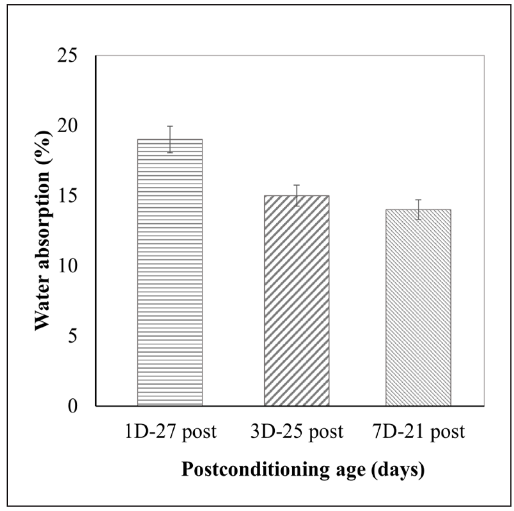



*Figure 6.* Water absorption of $CLW_{70}$

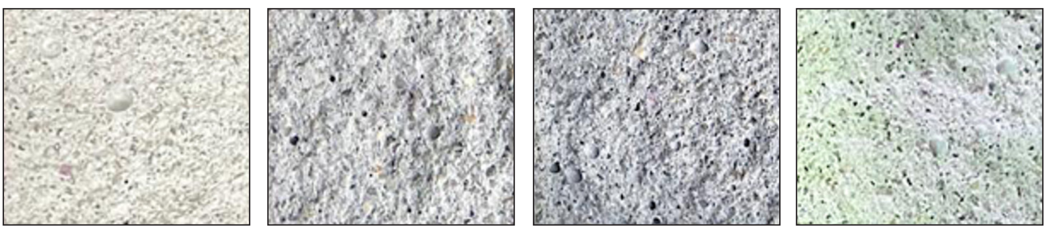
Since CLW primarily consists of $Ca(OH)_2$, it plays a crucial role in reacting with $CO_2$ during postconditioning. In semi-wet and dry conditions, such as wet gunny and air curing, any remaining unhydrated $Ca(OH)_2$ reacts with $CO_2$, contributing to the strength development. However, by day 7 of accelerated $CO_2$ curing, both methods reached a plateau, with no significant strength improvement compared to the control after 28 days of hydration. It is likely due to the complete transformation of $Ca(OH)_2$ into $CaCO_3$, which densifies the mortar and retains its strength. Similar strength trends were observed for flexural and splitting tensile strength tests, as shown in Figures 5(b) and 5(c). Air curing was sufficient to complete the hydration process, as all hydration products had been converted to $CaCO_3$.

Figure 6 shows the water absorption rates for $CLW_{70}$ mortars after 28 days. $CLW_{70}$ mortars had higher water absorption rates than those subjected to postconditioning. The rate decreased from 19% to 14% after $CO_2$ curing. Previous studies have shown that increasing the CS content to 80% in mortars increases water absorption (Luo et al., 2022). CLW, with its large surface area and porous structure, tends to absorb more water, leading to increased water consumption for standard consistency, reduced compressive strength, and higher water absorption of the mortar.

However, the water absorption rate decreased when high-volume CLW mortars (up to 70%) were subjected to accelerated $CO_2$ curing followed by postconditioning. This reduction is attributed to the carbonation process, which forms $CaCO_3$ and fills the pores of the mortar, reducing water uptake. The longer the $CO_2$ curing duration, the greater the strength improvement and reduction in water absorption. It is due to the structural densification of CLW mortars through $CaCO_3$ formation, which limits water absorption. The mechanical strength of the CLW mortars subjected to 7 days of $CO_2$ curing was higher than that of those cured for 1 and 3 days only.

The primary objective of this test was to evaluate the effect of accelerated $CO_2$ curing and postconditioning on water absorption. The results showed that both factors contributed to significant changes in water absorption capacity. The accelerated $CO_2$ curing duration played a critical role in transforming $Ca(OH)_2$ into $CaCO_3$ while postconditioning completed the hydration process. Therefore, longer curing durations resulted in lower water absorption, as $CaCO_3$ precipitated and filled the mortar's pores.

Figure 7 highlights the carbonation depth of $CLW_{70}$ mortars after 7 days of accelerated $CO_2$ curing. Mortars subjected to postconditioning treatments (water curing, $CLW_{PC70WC}$; wet gunny curing, $CLW_{PC70WG}$; and air curing, $CLW_{PC70AC}$) were compared to control samples without postconditioning. In all cases, the cross-section of $CLW_{70}$ mortars was fully carbonated, indicating that CLW is highly effective at capturing $CO_2$. This evaluation confirms that all $Ca(OH)_2$ had been converted into $CaCO_3$, as the phenolphthalein indicator test showed the colourless region of the mortar surface. When the transformation is complete, $CaCO_3$ crystals fill the pores and densify the matrix by $CaCO_3$ precipitation that provides the protection layer of CLW mortar. The XRD test was further examined to confirm the significant calcite transformation at all the peaks.



(a) (b) (c) (d)

*Figure 7.* Accelerated $CO_2$ curing ($CLW_{70}$) under various postconditioning treatments: (a) $CLW_{70}$; (b) $CLW_{PC70WC}$; (c) $CLW_{PCW70WG}$; and $CLW_{PC70AC}$

XRD analysis of the postconditioning $CLW_{PC70}$ mortars revealed the phase changes during further curing, as shown in Figure 8. Calcite ($CaCO_3$) was the dominant mineral, with its highest peak intensity at 29.36°, confirming the high amount of portlandite captured using TGA [Figure 3(a)] that had been converted to calcite. The highest intensity of calcite was observed in air-cured mortars, followed by wet gunny and water-cured mortars.

Water curing limited further carbonation by keeping the mortars moist, resisting $CO_2$ penetration into the material. It explains why water-cured samples had the lowest calcite peak intensity. XRD analysis confirmed the findings from TGA in Figures 4(a) and 4(b) that no further hydration products were produced during postconditioning. The densification of $CaCO_3$ in the mortar's outer layer inhibited water penetration, confirming that the strength gained by CLW mortars was primarily due to $CaCO_3$ precipitation. Besides, the water curing provides moisture that facilitates the hydration of cement, thereby facilitating the development of strength. However, $CO_2$ becomes limited, which is the main reactant in the formation of $CaCO_3$, since the water occupies the pore spaces, preventing $CO_2$ from reacting with any unreacted $Ca(OH)_2$ in the mortars. In addition, $CO_2$ has a low capability to dissolve in water. Hence, the carbonation reaction remains low. This carbonation process efficiently converts $Ca(OH)_2$ into $CaCO_3$; hence, CLW mortar usually does not need water curing as a postconditioning treatment. It is sufficient to use air curing as a postconditioning treatment due to this self-sustaining strength and calcite enhancement. The mortar maintains adequate moisture for further carbonation under ambient environments; hence, the material reaches an appropriate strength range without further water treatment.

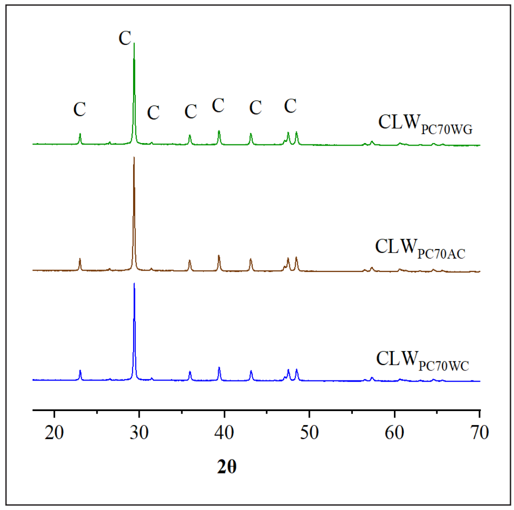



*Figure 8.* The characteristics of carbonation products are optimum $CLW_{70}$ mortar underwater, wet gunny and air curing condition

## CONCLUSION

This study demonstrates the effectiveness of incorporating high-volume CLW as a cement replacement under accelerated $CO_2$ curing. The key findings include:

1. High-volume CLW mortars exhibited enhanced $CaCO_3$ precipitation with an increased accelerated $CO_2$ curing duration, which increased the $CO_2$ capturing capability and compressive strength.
2. $CLW_{70}$ achieved full carbonation 100% and 70% $CaCO_3$ precipitation within 7 days, with compressive strength increasing from 2.62 MPa on day 1 to 17.01 MPa by day 7.
3. Postconditioning treatments, particularly air curing, further enhanced the later-age strength of the optimum $CLW_{70}$ mortars, followed by wet gunny and water curing methods. XRD analysis confirmed that air-cured mortars exhibited the highest calcite content, contributing to superior mechanical performance.
4. Water absorption rates decreased with increased $CO_2$ curing age, reflecting the densification of CLW mortars due to $CaCO_3$ precipitation, which reduced water intake.

The findings underscore CLW's potential for $CO_2$ sequestration and mechanical performance enhancement in mortar applications. Future studies should investigate the durability of CLW mortars under various weathering and chemical exposure conditions to further validate their use in construction.

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