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# The Role of Magnesium Oxide in Enhancing Carbon Capture Ability in Cementitious Mortars

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### ABSTRACT

Cement industries are widely used in construction and contributing around 5% to 7% of the total global carbon dioxide emission in the world. Recent research has focused on developing new types of cementitious mortars with enhanced properties. One such material that has been studied for its potential benefits is magnesium oxide (MgO). MgO can participate in the cement hydration reactions, enhance carbon capture ability, and improve the durability of cementitious mortars. This research paper discusses the impacts of integrating MgO as a cement alternative on cementitious mortars compressive strength, water absorption by capillary action, and carbonation. Two various reactive MgO samples that are readily accessible on the market were assessed as partial cement replacements (at 10%, 15%, and 20%, by weight) in the manufacture of mortars. The findings indicate that when it comes to compressive strength, it is better to have less MgO, exactly 10% or less. When water is absorbed through capillary action, it is best to use MgO values of 10% or less. In terms of carbonation protection, it is best to think about MgO concentrations of 15% or higher. In addition, the article stresses the fact that specimens with a greater content of MgO had a higher carbon dioxide absorption and a faster rate of carbonation. Overall, the use of MgO in cementitious mortars has the potential to improve their properties and reduce their environmental impact.

## 1. Introduction

Cement and concrete industries are widely used in construction that contributing around 5% to 7% of the total global carbon dioxide emission in the world [1]. They are composed of a mixture of cement, sand, and water, and can be reinforced with fibers or other additives to improve their performance. Recent research has focused on developing new types of cementitious mortars with enhanced properties, such as fiber-reinforced cementitious mortars (FRCM) and mortars containing supplementary cementitious materials (SCM) like limestone powder or fly ash [2]. Recent research

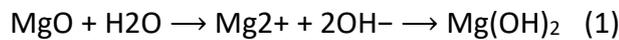
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has focused on developing new types of cementitious mortars with enhanced properties, such as those containing magnesium oxide (MgO).

MgO can participate in the cement hydration reactions, enhance carbon capture ability, and improve the durability of cementitious mortars. Zhang *et al.*, [3] said formation of formation of Mg(OH)<sub>2</sub> occurs when hydration reaction of MgO as shown in Eq. (1).



Since the volume of the hydration products is greater than that of the reagents, the hydration of MgO results in an expansion. This expansion, if it is properly controlled, can be used to compensate for the shrinkage that is typically observed in cementitious composites [4], and it may also be used to compensate for the deformation of cementitious composites that is caused by creep. Several studies have investigated the influence of MgO on the performance of cementitious mortars. Coppola *et al.*, 2020 [5] studied magnesium sulphate-rich solution in cementitious mortars including effects on activated slag-based (AAS) mortars in different environments. It found that mortar with high contain of AAS shows significant in strength and resistance in durability conditions. Mondal *et al.*, 2019 [6] investigated the mix of supplementary cementitious materials behavior GGBS in cement mortar. It claimed that mortar that exposure in magnesium sulphate and sulphuric acid solution provides higher strength and significant in carbonation depth compare to the control sample. José *et al.*, 2020 [7] presented a literature review concerning the characteristics of MgO and its application in cementitious materials and stated that MgO can decrease the compressive strength, flexural strength, tensile strength, and modulus of elasticity of cementitious materials, especially at high replacement ratios and low curing ages. This is mainly attributed to the increased porosity and the formation of low strength magnesium silicates hydrate. Sonat *et al.*, 2017 [8] investigated the performance and thermal decomposition of MgO and MgO-SiO<sub>2</sub> formulations. Overall, the literature suggests that MgO can improve the durability and performance of cementitious mortars, and further research is needed to optimize its use in different applications. Additionally, Chen *et al.*, 2022 [9]. found that the addition of nano-MgO increased the mechanical strength of cement mortar blocks, with the strengthening effects being most significant in the early stages of maintenance.

In addition to its potential benefits, the use of MgO in cementitious mortars may also have implications for the behavior of other materials in the mortar. For example, Murphy *et al.*, 2017 [10] found that the addition of clay to sand-cement mix exposed more ion exchange sites and altered pH, enhancing the uptake capacity of cadmium via ion exchange of iron, magnesium, and aluminum oxides bound in cement. Furthermore, Gonçalves *et al.*, 2019 [11] noted that MgO can participate in the cement's hydration reactions and presents enhanced carbon capture ability during its life cycle, making it a promising alternative to traditional cement. Overall, the use of MgO in cementitious mortars has the potential to improve their properties and reduce their environmental impact, but further research is needed to fully understand its effects on other materials in the mortar

## 2. Materials and Methods

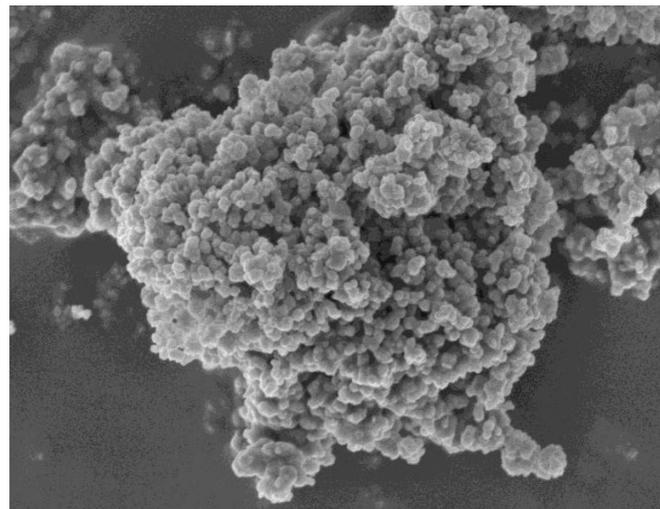
### 2.1 Cement and MgO

The cement that was used was Portland ordinary cement and its chemical composition is presented in Table 1. The cement has an initial setting time of 161 minutes and a final setting time of 232 minutes. Every single specimen was made with drinkable tap water, and that water was employed in the production process. MgO samples chemical composition also are presented in Table 1. The micrographs taken with a scanning electron microscope (SEM) and displayed in Figure 1 allow

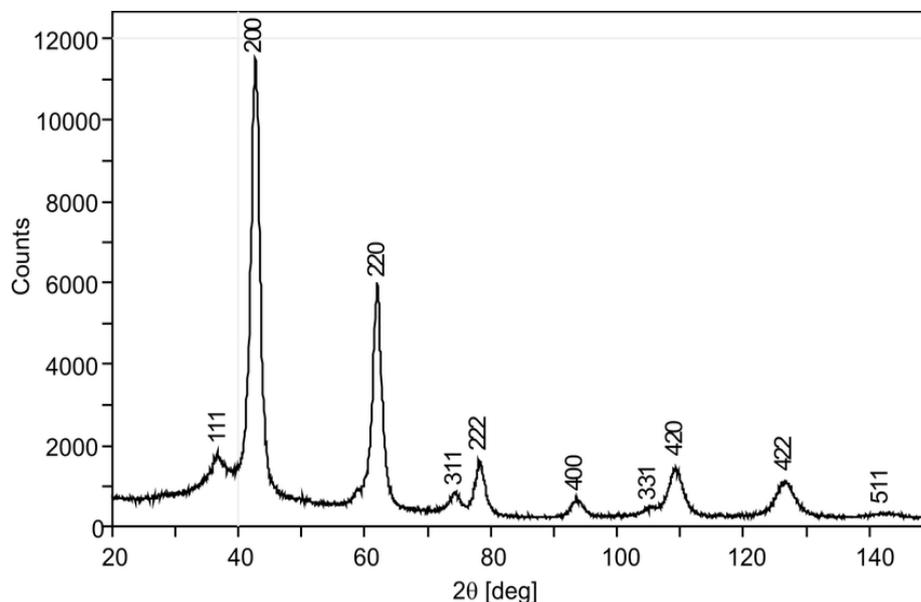
one to examine the morphology of MgO samples. Figure 2 displays the findings from the XRD analysis that were conducted. The pattern of MgO demonstrates that the primary phase was periclase (MgO) and the crystallinity of the substance is inferred from the peak's extreme narrowness. There are other peaks that are apparent for MgO that correspond to the presence of dolomite, calcite and talc.

**Table 1**  
 Chemical composition of cement and MgO (% by mass)

Component	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	CuO	Fe <sub>2</sub> O <sub>3</sub>	SO <sub>3</sub>	ZnO	C <sub>3</sub> S	C <sub>2</sub> S	C <sub>3</sub> A	C <sub>4</sub> AF
Cement	19.5	5.0	63.5	1.3	—	3.3	3.3	—	57.7	16.5	4.3	11.2
MgO	4.6	—	5.5	78.6	2.8	7.4	—	1.1	—	—	—	—



**Fig. 1.** SEM micrographs of MgO



**Fig. 2.** XRD patterns for MgO

## 2.2 Characterization of Aggregates

The particle-size distribution of the sand was determined in line with the EN 1015-1 standard [12]. The water absorption and apparent density were measured in accordance with EN 1097-6 [13], whereas the bulk density was measured in accordance with EN 1097-3 [14]. The classification of the

fine particles content was established in accordance with EN 13139 [15]. Table 2 outlines the various physical characteristics as well as the particle-size distributions of both fine and coarse sand, with corresponding sizes of 0.2 and 0.4 millimetres.

**Table 2**  
 Characteristics of fine and coarse sand

Properties	Fine sand	Coarse sand
Nominal size ( $d/D$ )	0/2	0/4
Apparent density ( $\text{g}/\text{cm}^3$ )	2.62	2.63
Oven-dry density ( $\text{g}/\text{cm}^3$ )	2.60	2.61
Saturated and surface-dry density ( $\text{g}/\text{cm}^3$ )	2.61	2.62
Water absorption (%)	0.23	0.25
Fine particles content	Category 1	Category 1
Chloride content (%)	$\leq 0.01$	$\leq 0.01$
Particle-size distribution (mm)	Cumulative retained material for fine and coarse sand (%)	
4.0	100	
2.0	93.2	
1.0	77.4	
0.5	50.9	
0.25	15.6	
0.125	1.4	
0.063	0.0	

### 2.3 Mix Design

The method that was proposed by Nepomuceno *et al.*, 2012 [16] was used to determine the composition of the mortar, and Table 3 details what was included in the mixture. Mortars that exhibit characteristics and performance equivalent to those of a concrete counterpart can be produced thanks to the method that was adopted for the mix design. This is in contrast to the mortars that are normally used in rendering and masonry. Every batch of mortar was mixed with a binder-to-aggregate ratio of exactly one third by volume. The control mixes (CMs) had a water-to-binder (w/b) ratio that started at 0.50, which allowed the spread of the mixes to be held constant at  $200 \pm 15$  mm. This was accomplished by adjusting the amount of water used to bind the binder. The cement was partially replaced by the three different types of MgO in the following weight-based ratios: 10%, 15%, and 20%. The difference percentages of MgO is to provide varying levels of strength, durability and other desirable properties.

**Table 3**  
 Composition of mortar

Mix	Cement ( $\text{kg}/\text{m}^3$ )	MgO ( $\text{kg}/\text{m}^3$ )	Water ( $\text{kg}/\text{m}^3$ )	Sand ( $\text{kg}/\text{m}^3$ )	w/b ratio
Control	560.7	—	280.3	1406.9	0.50
Mg10%	504.6	56.1	280.3	1406.9	0.50
Mg15%	476.6	84.1	294.3	1406.9	0.52
Mg20%	448.5	112.1	304.3	1406.9	0.54

### 2.4 Test Methods

Samples containing MgO were tested with compressive strength, water absorption and carbonation resistance tests. A total of 105 specimens were tested in a chamber with 5% carbon dioxide concentration, 60% relative humidity, and a temperature of 23°C.

### 3. Results and Discussion

#### 3.1 Compressive Strength

The compressive strength of all mixes at 7, 14, 28, and 56 days is presented in Figures 3. The findings indicate a correlation between increasing MgO content and a decrease in strength, which is consistent with the observations made by other researchers who examined lower replacement levels [17]. The observed reduction in strength is particularly prominent in specimens of MG. The observed decrease can be attributed to two primary factors: firstly, the necessity to augment the water-to-binder ratio, and secondly, the dilution of cement due to the escalation of MgO content. The incorporation of excess water resulted in a heightened porous microstructural morphology in the samples comprising of 15% and 20% MgO. In the latter scenario, the introduction of MgO as a substitute for cement results in a reduction of the available C2S and C3S, and subsequently, the C-S-H phases, despite the formation of  $Mg(OH)_2$ . This has been reported in previous studies [18]. The findings suggest that the introduction of amorphous  $SiO_2$  may lead to an increased rate of strength development due to pozzolanic reactions with  $Mg(OH)_2$ . This is evidenced by previous research [19]. The formation of  $Mg(OH)_2$  plays a crucial role in enhancing the strength of cementitious materials during the early stages of curing. However, it is the subsequent formation of M-S-H that primarily contributes to the improvement of these materials when MgO is incorporated. This finding has been reported in literature [20]. Additionally, the presence of alumina resulting from the inclusion of aluminosilicate minerals may confer a benefit with respect to the mechanical properties of the material. The potential interaction between the substance and  $Mg(OH)_2$  could result in the formation of a hydrotalcite-like phase [21] that is capable of enhancing the overall mechanical performance through improved bond with the cementitious matrix and due to the hydrate's ability of decreasing the porosity of the resulting composite [22].

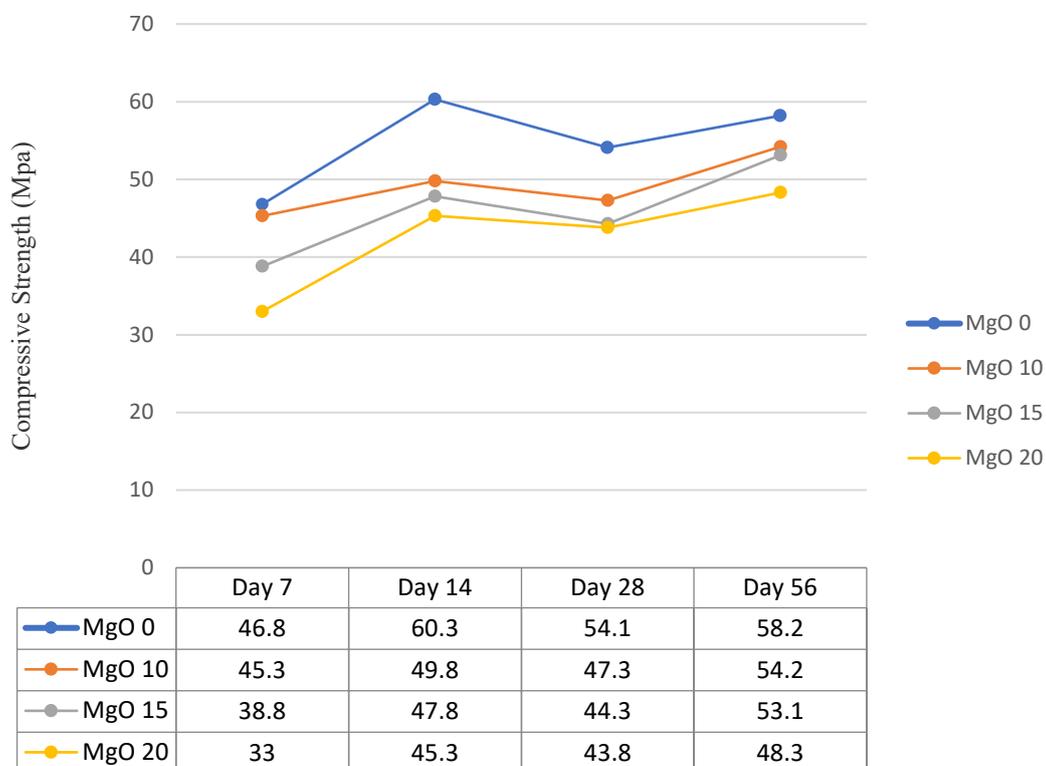


Fig. 3. Compressive strength of mortars

### 3.2 Water Absorption

The water absorption exhibited a marginal rise with the increase in MgO content, as anticipated as shown in Figure 4. The hydration of MgO can lead to the creation of a phase with a greater volume than the original components. However, if a portion of the cement is substituted, it will directly reduce the quantity of C-S-H that can generate a less connected and more complex porous structure [23]. This is particularly true after the specimen has undergone carbonation [24]. Over time, the occurrence of carbonation reactions and the formation of more magnesium carbonate hydrates may result in a decrease in total pore volume and water absorption, as indicated by previous studies [23].

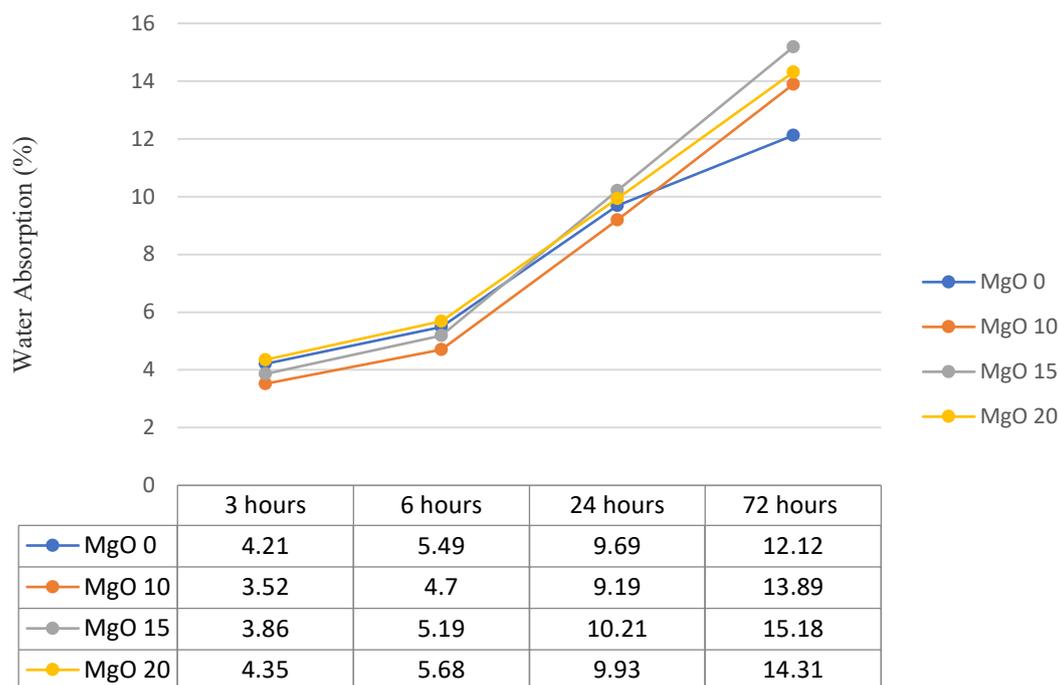


Fig. 4. Water absorption of mortars

### 3.3 Carbonation

The carbonation depth of the specimens containing MgO, following exposure to a CO<sub>2</sub> chamber for 28 and 91 days, is presented in Table 4. The results show greater carbonation depths with increasing MgO content. Previous studies [19] have reported the observation of microstructures with lower porosity that incorporate MgO, indicating a reduction in carbonation. However, contrary to these findings, the present study and others [25] have observed an opposite trend, which is supported by the results presented in Figure 4. Mixes with higher MgO content exhibit increased porosity, which results in a larger surface area within the cementitious microstructure. This increased surface area is available for carbonation in the presence of CO<sub>2</sub>. However, it should be noted that the increased porosity may only be present in the early stages, as subsequent carbonation results in the creation of additional hydration products that decrease the size of the porous microstructure [25]. It is necessary to consider an additional factor, namely the appropriateness of utilising the phenolphthalein test for determining the quantity of CO<sub>2</sub> absorption in mortars that include MgO. The partial replacement of cement with MgO resulted in a decrease in the amount of cement available to generate Ca(OH)<sub>2</sub> [26]. This compound has a higher pH level than Mg(OH)<sub>2</sub>, which is produced from the hydration of MgO. The pH level of Ca(OH)<sub>2</sub> is approximately 12.5, while that of

Mg(OH)<sub>2</sub> is approximately 10.5. Consequently, the overall pH level of the specimens was reduced. The data presented in Figure 4 indicates that there was a slightly higher mass loss observed in the MA20 specimens compared to the CM specimens within the temperature range of 500°C to 850°C. Specifically, the MA20 specimens experienced a mass loss of 3.71%, while the CM specimens experienced a mass loss of 3.34%. This suggests that there was an increase in CO<sub>2</sub> uptake and a subsequent increase in the rate of carbonation for the MA20 specimens.

**Table 4**  
 Carbonation depth of specimens with increasing MgO content

Mix	Carbonation depth (mm)			
	28 days		91 days	
	Avg.	Std.	Avg.	Std.
Control	1.32	1.44	1.76	1.47
MgO10	1.22	1.31	3.00	1.53
MgO15	1.39	1.21	4.38	0.88
MgO20	2.39	1.93	5.83	1.20

#### 4. Conclusions

In this research paper, the impacts of integrating magnesium oxide (MgO) as a cement alternative are discussed with regard to cementitious materials' compressive strength, water absorption by capillary action, and carbonation. According to the findings, an increase in the amount of MgO in a mortars results in a reduction in its compressive strength. This is mostly caused by the requirement to raise the water-to-binder ratio and the resulting dilution of the cement. The addition of MgO causes a reduction in the amount of accessible C2S and C3S, which in turn has an effect on the development of C-S-H phases. On the other hand, the incorporation of amorphous SiO<sub>2</sub> can improve strength development through pozzolanic interactions with Mg(OH)<sub>2</sub>, which are chemical reactions. The early-stage gain in strength is contributed to by the synthesis of Mg(OH)<sub>2</sub>, while the long-term improvement is contributed to by the subsequent formation of Mg(S)H. Because to the presence of alumina and its interaction with Mg(OH)<sub>2</sub>, a phase similar to hydrotalcite may be formed, which improves the mechanical characteristics of the material and decreases its porosity. In terms of water absorption, an increase in MgO content causes a marginal rise in capillary water absorption. The observed phenomenon can be attributed to the hydration process of MgO, which results in the formation of a porous structure that is less interconnected and more intricate in nature. The depth of carbonation is observed to rise due to the heightened porosity resulting from the elevated magnesium oxide (MgO) concentration. Carbonation requires a certain amount of surface area. The ensuing carbonation, on the other hand, causes the development of hydration products, which result in a reduction in pore size. The fall in pH level that results from replacing cement with magnesium oxide has an effect on the phenolphthalein test, which is used to evaluate the amount of CO<sub>2</sub> that is absorbed by mortars that include MgO. In addition, the article stresses the fact that specimens with a greater content of MgO had a higher CO<sub>2</sub> absorption and a faster rate of carbonation. The optimal percentages of MgO in cementitious mortars may vary depending on the intended qualities and applications. In terms of compressive strength, it is more desirable to have lower concentrations of MgO, specifically 10% or less. In the context of water absorption through capillary action, it is advantageous to utilise lower concentrations of MgO (10% or less). In terms of resistance to carbonation, it is advantageous to consider larger concentrations of MgO, specifically at levels of 15% or greater.

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