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Review

A Review of Recent Advances in MgO-Based Cementitious Composites for Green Construction: Mechanical and Durability Aspects

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Abstract

The construction industry, as a major contributor to greenhouse gas emissions, urgently requires sustainable development solutions to achieve the Net Zero Emission Goal. Magnesium oxide (MgO)-based cementitious composites have emerged as promising alternatives due to their ability to reduce environmental impact and their potential to enhance structural integrity. Despite these advantages, limitations such as poor resistance to harsh environmental conditions and concerns over long-term durability continue to restrict their broader application. To better understand these strengths and limitations, this review investigates the influence of MgO; supplementary cementitious materials (SCMs) such as fly ash, silica fume, and rice husk ash. It also examines fibers, including polyethylene (PE), polypropylene (PP), polyvinyl alcohol (PVA), glass, sisal, and cellulose, and their effect on the mechanical and durability properties of MgO-based composites. Mechanical performance is assessed through compressive and tensile strength, while durability is evaluated in terms of porosity, permeability, water absorption, shrinkage (autogenous and drying), and carbonation resistance. Key challenges and future research directions to promote the use of MgO composites in sustainable construction are also identified.

Keywords: magnesium oxide (MgO); natural fibres; supplementary cementitious materials (SCMs); synthetic fibres; mechanical properties; durability

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1. Introduction

The global demand for cement and concrete continues to rise with rapid urbanisation, expanding infrastructure, and population growth [1]. Ordinary Portland Cement (OPC) remains the backbone of construction, but its production comes at a high environmental cost, contributing nearly 8% of global CO_2 emissions and releasing around 0.66–0.82 tonnes of CO_2 per tonne of clinker. This adds up to over 2.6 billion tonnes of emissions annually, placing the cement industry among the top industrial polluters [2]. The emission from the cement industry primarily results from the calcination of limestone in kilns at high temperatures (1400–1500 °C) [3]. In response, researchers have been exploring sustainable alternatives to reduce CO_2 emissions. One such option is Magnesium Oxide (MgO)-based cementitious composites, which are gaining attention due to the various benefits. Light burned MgO (also known as reactive MgO) can be produced at a lower calcination

temperature (650–800 °C), making the process less energy-intensive, resulting in lower CO_2 emissions compared to Ordinary Portland Cement (OPC). Additionally, its ability to compensate for shrinkage (expansive agent), CO_2 sequestration, high surface area, and reactivity also makes it an attractive choice as a binder or partial replacement of OPC in sustainable cementitious systems [4,5].

Due to the advantages mentioned above, the demand for magnesium oxide (MgO)-based cementitious composites is steadily increasing. The global MgO market is expected to rise from USD 4.6 billion in 2025 to nearly USD 8.9 billion by 2033, reflecting a compound annual growth rate (CAGR) of 6.6%. This upward trend highlights the material's expanding role in greener construction solutions [6,7]. Magnesite is the primary raw material used for producing magnesium oxide (MgO), though its reserves are unevenly distributed worldwide. As shown in Figure 1a, Russia and Slovakia lead with 30.1% and 15.7% of the world's reserves, respectively. They are followed by China (7.6%), Australia (3.7%), Brazil (2.6%), and Greece (3.7%). Other notable contributors include the United States (0.5%) and Austria (0.6%) [8–10]. Within Australia, most magnesite deposits are found in Queensland, which holds a dominant 83.3 % share, followed by the Northern Territory (8.2%), New South Wales (5.1 %), and South Australia (3.4 %) [11,12], as shown in Figure 1b.

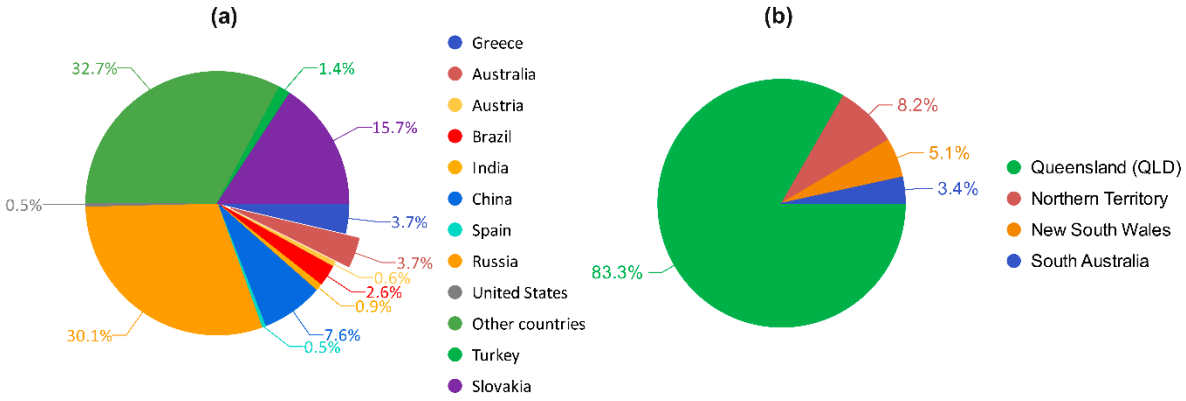

Figure 1. Distribution of magnesite reserves: (**a**) Global distribution; and (**b**) Distribution in Australia.

In the construction industry, magnesium oxide (MgO) serves multiple functions. It acts as a primary binder in alternative cements such as magnesium oxychloride (MOC), magnesium oxysulphate (MOS), and magnesium phosphate cement (MPC). Additionally, it is used as a partial replacement for OPC or as an expansive agent to mitigate shrinkage. MgO-based composites are featured for rapid setting, early strength gain, and low shrinkage [13,14], which makes them suitable for use as precast elements, repair mortars, and refractory applications [15,16].

However, these advantages are tempered by ongoing debates and limitations. Concerns remain about long-term durability, particularly under aggressive environments, where brucite leaching and phase instability can reduce performance. High MgO dosages may also increase porosity and permeability, raising questions about strength retention over time. Furthermore, while MgO can sequester CO_2, excessive carbonation depth may compromise durability by altering the pore structure and accelerating degradation in reinforced systems [17,18]. To improve their properties, researchers have incorporated supplementary cementitious materials (SCMs) such as fly ash (FA), silica fume (SF), and rice husk ash (RHA) [19,20]. These SCMs react with MgO to form magnesium silicate hydrate (M-S-H) and magnesium calcium (alumino)-silicate hydrate (M-A-S-H) gels, improving matrix density and reducing porosity [21,22]. Studies have confirmed the positive effects of SCMs. Xu et al. [23] found that silica fume improved workability, delayed setting, and increased strength at 15% replacement. Zhou et al. [24] reported a 28-day compressive

strength of 39.2 MPa for a mix with 10% silica fume, outperforming the control mix. Fly ash was also found to have enhanced workability and long-term strength. Zhang et al. [25] observed that 20% fly ash improved 90-day compressive and flexural strength by 23.3% and 18.4%, respectively, while Vo et al. [26] achieved 56.5 MPa compressive strength at 91 days using 15% fly ash and 5% MgO in recycled aggregate concrete. Rice husk ash (RHA), with its high silica content, was found to have enhanced chemical resistance [27]. For example, Amran et al. [28] found that RHA reduced calcium hydroxide content, leading to additional C-S-H formation and a denser matrix. Neri Jr et al. [29] reported a 9.8% strength gain at 28 days with 10% RHA and admixtures.

Recent studies on durable concrete and cement provide useful comparisons for MgO-based systems. For example, Hosseinzadehfard et al. [30] reported new approaches to improving resistance to environmental degradation by combining alternative binders with microstructural optimization and performance-based design. These findings demonstrate how durability can be enhanced through both material development and design practice. In addition, methods such as life-cycle assessment (LCA), integrated design, and performance-based durability frameworks have been proposed to guide the development of sustainable buildings. Placing MgO in this wider context highlights its role not only as a binder but also as part of broader strategies for green construction. Fibre reinforcement, both synthetic and natural fibres, has emerged as an effective strategy to improve the performance of cementitious composites. Most cement-based composites are inherently brittle and possess low tensile strength and strain capacity [31,32]. The incorporation of fibres helps overcome these limitations by improving ductility, toughness, and crack resistance. Synthetic fibres such as PE, PVA, and PP fibres are widely used due to their durability, chemical stability, and strong mechanical properties. PE fibres demonstrate exceptional performance in OPC-based Engineered Cementitious Composites (ECC), achieving tensile strain capacities of up to 6–8% at a 2% fibre dosage [33]. In PE fibre-reinforced MgO composites, Wei et al. [34] reported 5–7% tensile strain, and Wang et al. [35] observed strain hardening and multi-cracking behaviour with tensile strength of 7 MPa and strain capacity of 8%. Yu et al. [36] further confirmed these results, reporting compressive, tensile, and flexural strengths of 127.4 MPa, 11 MPa, and 29.8 MPa, respectively, after 28 days of curing, along with a strain hardening capacity of 8%. These improvements are attributed to the high tensile strength and hydrophobic nature of PE fibres, which effectively resist water ingress and crack propagation [37]. PVA fibres, known for their high modulus and strength, also contribute to better flexural and tensile performance [38]. Noushini et al. [39] found that the axial tensile strength of PVA-reinforced concrete reached 2.66 MPa, 4.29 times greater than the control specimen, and increased further to 3.09 MPa at 400 °C. Polypropylene fibres, which form a random 3D network within the matrix, can block microcrack growth and reduce ion penetration, thereby enhancing durability in pavements, buildings, and hydraulic structures [40,41]. Hassan et al. [42] demonstrated that using hybrid macro- and micro-PP fibres reduced shrinkage by up to 15% and enhanced both flexural and splitting tensile strength in alkali-activated slag concrete. Natural fibres like sisal and cellulose are also gaining interest as eco-friendly alternatives. Sisal offers high strength and durability, helping control cracking and improve toughness. Cellulose fibres, derived from wood pulp or agricultural waste, are flexible, biodegradable, and enhance ductility and crack resistance [43]. These studies highlighted the potential benefits of fibres in enhancing the properties of MgO-based cementitious composites.

Given the growing interest in the role of MgO in sustainable construction, a detailed review is essential to analyse existing research and provide a clear and systematic understanding of the current state-of-the-art knowledge. No comprehensive review has yet been reported that critically analyses the mechanical properties and durability performance

of MgO-based cementitious composites. This review addresses this gap by conducting a systematic and bibliometric analysis of recent studies published between 2010 and 2025. This review is outlined with 6 main sections. Section 2 describes the methodology used to select and analyse relevant literature. Section 3 discusses the effect of MgO on the mechanical and durability properties of cementitious composites, covering compressive and tensile strength, as well as durability aspects such as porosity, water permeability, water absorption, carbonation, volumetric autogenous shrinkage, and drying shrinkage. Section 4 reviews the effects of SCMs, especially fly ash, silica fume, and rice husk ash, on improving MgO-based composites. Section 5 examines the impact of different fibres, including synthetic, natural, and glass, on the mechanical performance and cracking behaviour of MgO composites. Finally, the review concludes with key findings and outlines future research directions for researchers, engineers, and policymakers.

2. Methodology

This review follows a systematic approach to identify and evaluate existing research on magnesium oxide (MgO)-based cementitious composites. The search focused on peer-reviewed journal articles and reviews published between 2010 and 2025, using databases including Google Scholar, Scopus, and Web of Science. Specific keywords such as "magnesium oxide in cementitious composites", "MgO with supplementary cementitious materials", "durability of MgO composites", and "mechanical performance of MgO systems" were used. A total of 974 records were initially identified: 422 from Google Scholar, 271 from Scopus, and 281 from Web of Science. After removing 405 duplicates, 569 records remained for screening. Based on title and abstract relevance, 388 articles were excluded. The remaining 181 full-text papers were assessed for eligibility, and 70 were excluded due to a lack of access.

Only peer-reviewed journal articles were included in the final selection, with conference papers, theses, and technical reports excluded to ensure reliability, quality, accessibility, and consistency. Finally, 111 peer-reviewed studies were selected for detailed analysis in this study. The selection process is summarised in Figure 2.

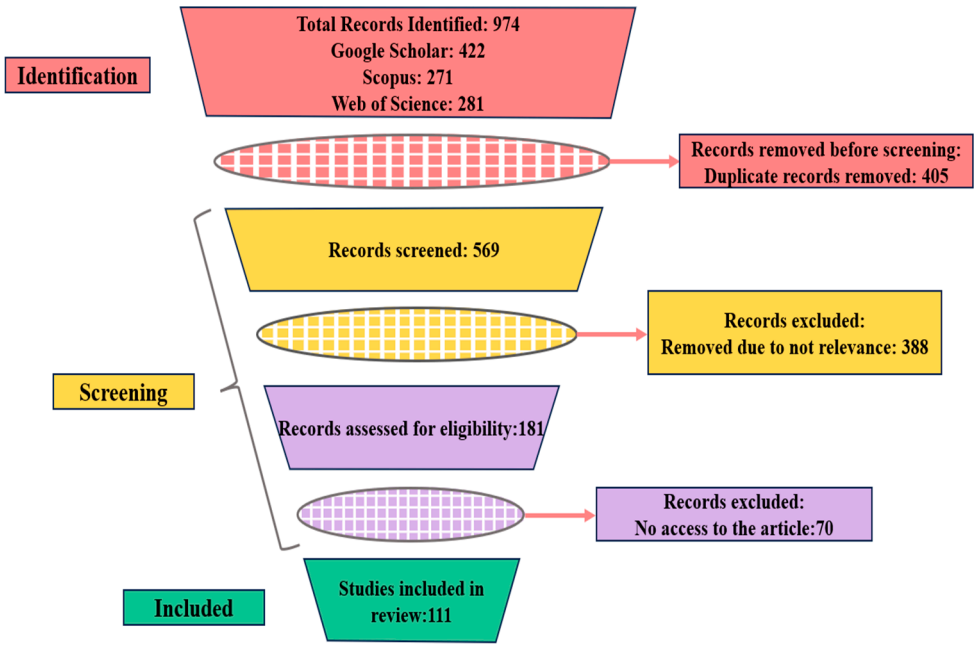

Figure 2. Methodology adopted for the current review work.

To assess research development, a bibliometric analysis was conducted using VOSviewer (v1.6.20). Publication and citation trends were mapped to quantify research growth over time. As shown in Figure 3, research on MgO composites increased steadily after 2016 and peaked in 2024, reflecting both rising interest and impact. The upward trend suggests that MgO is no longer just an alternative and it is becoming a major focus in sustainable construction research.

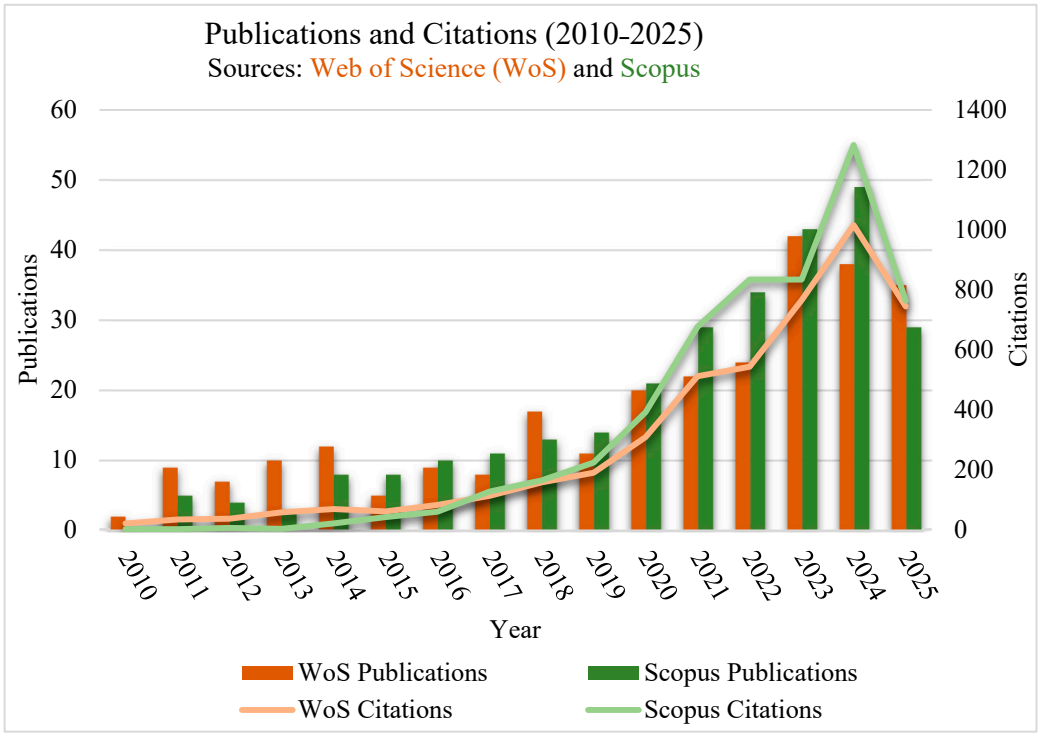

Figure 3. Annual publication trend and citation count (2012–025) for Magnesium Oxide (MgO) based Cementitious Composites [Sources: Web of Science (WoS) and Scopus].

3. Effect of MgO on Mechanical and Durability Properties of Cementitious Composites

The mechanical properties discussed in this section include compressive and tensile strength, both essential indicators of a material's load-bearing capacity and overall structural performance [44]. In contrast, durability-related properties such as porosity, permeability, water absorption, shrinkage (both autogenous and drying), and carbonation resistance are critical for assessing long-term performance, especially in real-world applications [18]. These factors influence how well MgO-based composites resist moisture ingress and maintain dimensional stability under varying environmental conditions. As such, durability plays a vital role in determining the suitability of these materials for infrastructure projects where extended service life and sustainability are key requirements.

3.1. Compressive Strength

Compressive strength is a key performance indicator of cementitious composites, influencing both structural integrity and long-term durability [45]. The effect of MgO on the compressive strength of cementitious composites varies depending on dosage, reactivity, and curing conditions [46]. As illustrated in Figure 4, Liu et al. [47] designed four curing regimes, labelled G1–G4, where specimens underwent carbonation curing for 12, 24, 36, and 48 h, respectively, followed by standard curing up to 28 days. Each group also included mixes with 0%, 10%, 20%, and 30% reactive MgO. Their results indicate that 10% MgO consistently improved compressive strength (47.6–57.42 MPa),

whereas 20% MgO achieved slightly lower values (37.58–53.06 MPa), and 30% MgO led to the weakest performance (32.38–37.38 MPa). Importantly, strength generally increased from G1 to G4 as longer carbonation curing enhanced hydration and densification of the matrix. Rawat et al. [48] Observed that blended systems labelled PC30–BFS60–M10, where "PC30" represents 30% Portland cement, "BFS60" represents 60% ground granulated blast-furnace slag, and "M10–M30" denotes reactive MgO dosages of 10%, 20%, and 30%. These high-slag mixes achieved superior performance, reaching 63.2 MPa at 10% MgO and peaking at 66.6 MPa at 20% MgO, before dropping to 55.34 MPa at 30% MgO after 28 days. The improvement at moderate MgO levels highlights the beneficial synergy between MgO and slag in forming dense hydration products, while excessive MgO still caused strength reduction due to delayed hydration and porosity development. These results align with other studies, Jin et al. [49] achieved strength gains with 7.5% high-reactivity MgO via accelerated hydration, while Wu et al. [50] recorded ~55 MPa using 15% MgO + 30% fly ash + 2% PVA in ECC. In contrast, high MgO levels (≥60%) often limit strength development due to delayed hydration and increased porosity [51–53]. The data indicate that moderate MgO additions (10–20%), especially when combined with supplementary materials like GGBFS or fly ash, can significantly enhance compressive strength compared to higher dosages.

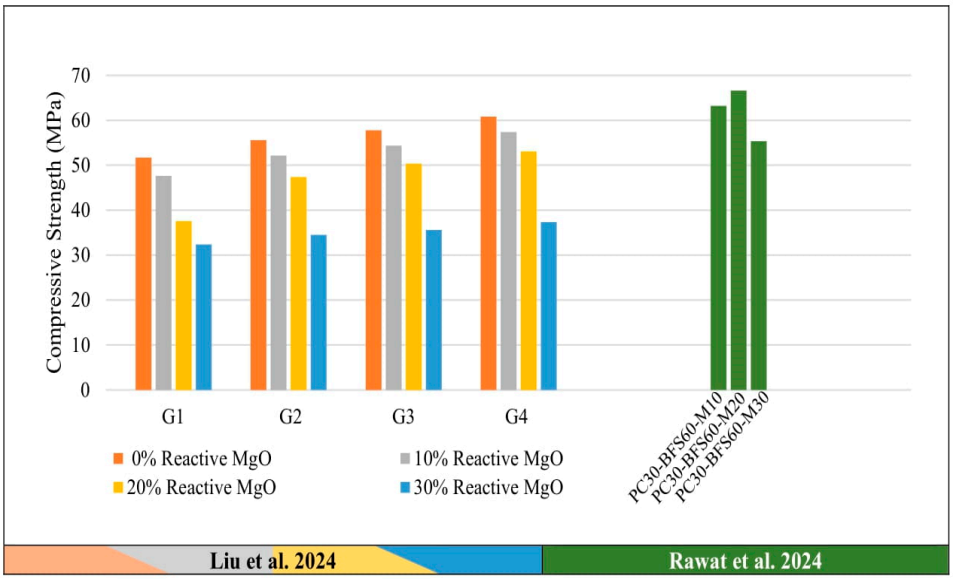

Figure 4. Compressive strength of mixes with different MgO replacement levels. Strength decreased with higher MgO content, while slag-blended mixes (PC30–BFS60) achieved the highest values [47,48].

3.2. Tensile Strength

Tensile strength is essential for evaluating a material's resistance to cracking under tension As shown in Figure 5, Forero et al. [54] tested mortars where OPC was partially replaced with MgO at 5%, 10%, and 20%, labelled C5:C, C10:C, and C20:C, alongside a reference mix (RC). In RC, the mix contained 300 g of cement, 174 g of water, and constant fine (883 kg/m^3) and coarse aggregates (997 kg/m^3). In C5:C, cement was reduced to 285 g with 15 g MgO added, while C10:C and C20:C contained 270 g cement + 30 g MgO, and 240 g cement + 60 g MgO, respectively, with water adjusted from 179 g to 188 g to ensure workable mixes. Results showed a consistent reduction in splitting tensile strength from 3.58 MPa in RC to 2.29 MPa in C20:C after 28 days, mainly due to reduced clinker hydration and brucite formation, which acted as a weak filler without sufficient pozzolanic reaction. Wu et al. [55] evaluated engineered cementitious composites (ECC) incorporating MgO at 0–10% by weight of cement. The mixes were labelled as 0%E1.2, 4%E1.2, 6%E1.2,

8%E1.2, 10%E1.2, and their corresponding E2.2 variants, where the percentage denotes MgO replacement of cement, and E1.2 and E2.2 represent different fly ash levels (1.2 and 2.2 relative to binder). All mixes maintained a low water/binder ratio of 0.25, sand/binder ratio of 0.36, polycarboxylate-based superplasticizer, and 2% PVA fibers. With these proportions, tensile strength improved from 5.37 MPa in the control to a maximum of 6.41 MPa at 10%E1.2, demonstrating that moderate MgO levels enhance fiber–matrix bonding and crack-bridging, leading to improved strain hardening and ductility. Wang et al. [56] studied low-heat Portland cement concretes with 0%, 4%, and 8% MgO, labelled LC0, LC4M50, and LC8M50, respectively. LC0 was the control with 313 kg/m^3 cement, while LC4M50 and LC8M50 contained 300 kg/m^3 and 288 kg/m^3 cement, alongside MgO additions. All mixes included 1330 kg/m^3 coarse aggregate, 626 kg/m^3 sand, 125 kg/m^3 water, and water-reducing agents between 2.8–3.1 kg/m^3, with slump values ranging from 65 mm in LC0 to 51 mm in LC8M50. At 28 days, tensile strength decreased from 2.18 MPa in LC0 to 1.99 MPa and 1.84 MPa in LC4M50 and LC8M50, respectively. However, by 90 days, LC4M50 achieved 2.77 MPa, suggesting that longer curing can partially recover early-age strength losses in MgO-modified concretes. These studies demonstrate that while higher MgO contents in conventional mortars and low-heat concretes reduce tensile strength, carefully optimized dosages of 4–10% in fiber-reinforced ECC significantly improve performance.

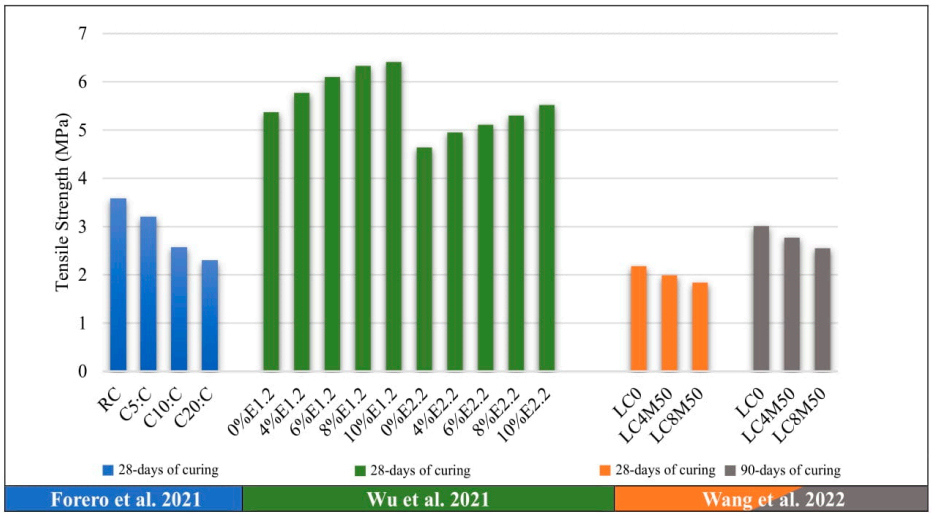

Figure 5. Tensile strength of mixes with different MgO and binder proportions at 28 and 90 days. Strength improved in optimized MgO–binder systems but decreased at higher MgO contents [54–56].

3.3. Water Absorption and Permeability

Water absorption and permeability are two important indicators of concrete durability. Absorption refers to the uptake of water through capillary pores without applied pressure [57]. Permeability measures the movement of water through connected pores under pressure [58]. Both properties are strongly influenced by the pore structure, hydration behaviour, and binder composition. The incorporation of MgO affects these characteristics depending on its reactivity, dosage, and interaction with supplementary cementitious materials (SCMs). Mavroulidou et al. [59] found that adding 5% MgO to concrete containing fly ash and metakaolin reduced water absorption due to improved pore refinement. However, at 10% MgO, absorption increased slightly but remained below the reference. This was linked to reduced compaction and higher water demand. Moradpour et al. [60] observed a 7–33% reduction in water permeability in mortars with nano-MgO, especially at lower dosages. Dung et al. [61] reported a 2–42% reduction in permeability using hydration and dispersion agents along with MgO. A moderate MgO content can improve water resistance by refining the pore network. Higher contents may have the opposite effect due

to increased porosity. These findings indicate that MgO dosages around 5% can effectively reduce water absorption and permeability by up to 33–42%, while higher contents may increase porosity and negatively impact durability, emphasizing the need for careful dosage control to optimise performance.

3.4. Porosity

Porosity is a decisive factor in shaping both the durability and mechanical performance of cementitious composites [62]. It was found that a lower total pore volume restricted permeability and limited crack propagation, while a finer, well-distributed pore network promoted matrix densification [47,63]. Recent findings, as illustrated in Figure 6, revealed that distinct variations in cumulative pore volume were influenced by mix composition and curing conditions. Mo et al. [52] studied fly ash–MgO–Portland cement blends with different proportions. The mixes were labelled M20F40, M40F20, and M60F30, corresponding to 20%, 40%, and 60% MgO, with Portland cement contents of 40%, 40%, and 10%, and fly ash contents of 40%, 20%, and 30%, respectively. After 28 days of curing, pore volume decreased markedly with higher MgO replacement: M20F40 recorded 0.211 mL/g, M40F20 dropped to 0.105 mL/g, and M60F30 achieved the lowest value of 0.066 mL/g. This reduction was attributed to brucite formation, refining the pore network, and enhancing matrix compactness.

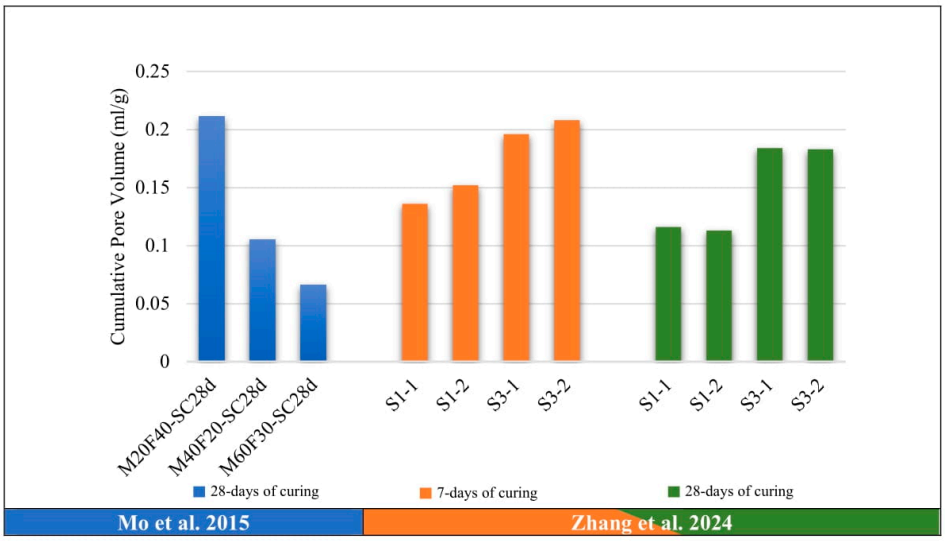

Figure 6. Cumulative pore volume of mixes under varying curing conditions. High-reactivity MgO significantly reduced pore volume, leading to a denser matrix compared to low-reactivity MgO [52,64].

Zhang et al. [64] evaluated systems incorporated light-burned magnesia (LBM) with two levels of reactivity (80% and 50%), different Mg/Si ratios (1.25 and 1.0), and a constant w/c ratio of 0.55. The mixes were labelled S1-1, S1-2 (high-reactivity MgO, 80% LBM) and S3-1, S3-2 (low-reactivity MgO, 50% LBM). Each mix also included silica fume (SF, 40–44%), additives (2%), water (55%), and sand (100%) per 100 g of cement. At 7 days, pore volumes ranged from 0.136 mL/g (S1-1) to 0.208 mL/g (S3-2), reflecting the combined effects of MgO reactivity, silica fume, and Mg/Si ratio. After 28 days, high-reactivity MgO mixes (S1-1, S1-2) recorded the lowest pore volumes of 0.116 and 0.113 mL/g, whereas low-reactivity mixes (S3-1, S3-2) remained higher at 0.184 and 0.183 mL/g, indicating a less dense structure. This data confirms that higher MgO reactivity, optimized Mg/Si ratio, and silica fume addition are key to reducing cumulative pore volume. This refinement of pore

structure enhances durability and mechanical performance, demonstrating the importance of tailored binder design in MgO-based composites.

3.5. Autogenous Shrinkage

Autogenous shrinkage refers to the volume reduction that occurs in cementitious materials when cured under sealed or thermally insulated conditions. This phenomenon primarily results from chemical shrinkage and self-desiccation during hydration [65]. If not properly controlled, autogenous shrinkage can induce internal tensile stresses and lead to early-age cracking, particularly in high-performance or mass concrete applications [66]. MgO-based expansive agents reduce this risk by forming brucite [Mg $(OH)_2$] during hydration, which generates internal expansion and compensates for volume loss [67]. Gao et al. [68] reported that concrete with high-reactivity MgO (E1) at dosages of 6%, 8%, and 10% exhibited progressive expansion of about 40×10^{-6}, 50×10^{-6}, and 55×10^{-6}, respectively, compared with -20×10^{-6} shrinkage for the reference mix, with most of the expansion occurring in the first 180 days. In contrast, Wang et al. [56] observed that low-heat Portland cement blends with MgO (LC4M50 and LC8M50) experienced negative autogenous strain (shrinkage), though the magnitude was lower than in the control. To illustrate these differences, data from both studies have been combined in Figure 7. The comparison shows that high-reactivity MgO promotes early and sustained expansion, while lower-reactivity systems may still shrink but at a reduced rate. This trend was further confirmed by Chen et al. [69] through autoclave expansion tests, where MgO content consistently produced higher expansion, regardless of the powder's size or type. These findings underscore MgO's ability to compensate internal shrinkage in mass concrete. Similarly, Polat et al. [70] investigated early-age volumetric shrinkage in high-performance cement pastes incorporating nano-MgO. Under sealed curing for 48 h, the control showed a maximum shrinkage of 0.91%. Replacing cement with 2.5%, 5.0%, and 7.5% nano-MgO reduced shrinkage to 0.87%, 0.75%, and 0.68%, respectively. Mehmood et al. [71] also observed that MgO-based expansive agents effectively reduced early-age shrinkage by introducing controlled internal expansion during hydration. Collectively, these studies confirm that MgO can mitigate autogenous shrinkage, with its performance governed by dosage, chemical reactivity, particle size, and curing conditions.

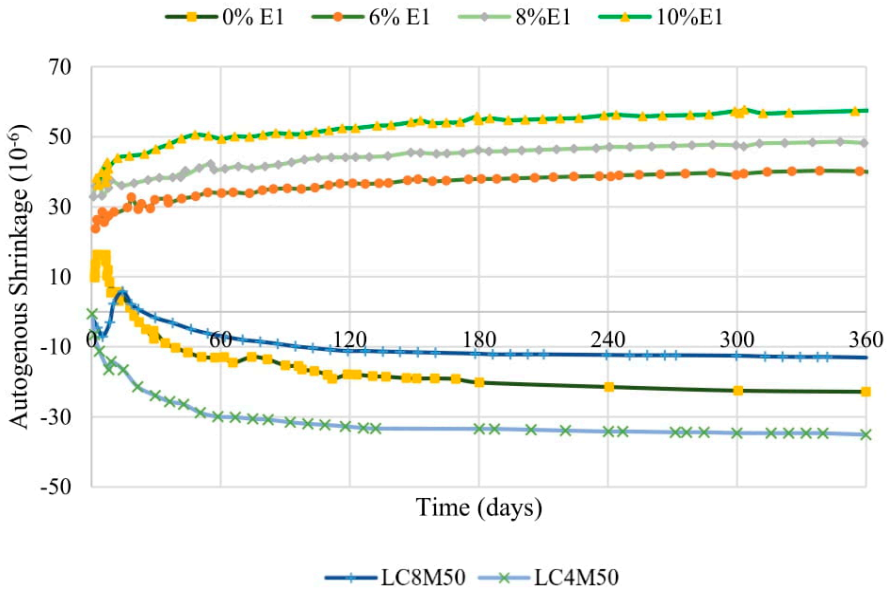

Figure 7. Autogenous shrinkage of mixes with varying MgO contents over 360 days. Higher MgO replacement reduced shrinkage, showing improved dimensional stability [56,68].

3.6. Drying Shrinkage

Drying shrinkage refers to the unrestrained volume reduction of hardened cementitious materials due to moisture loss to the surrounding environment [72]. It usually appears as a linear strain and is most noticeable during the early stages of exposure [73]. If not controlled, excessive shrinkage can lead to micro-cracking, greater permeability, and ultimately, lower durability [74]. The influence of MgO on drying shrinkage has been investigated in several studies. Wang et al. [65] examined drying shrinkage in low-heat MgO cement composites exposed to 20 °C and 50% relative humidity for 360 days. Without MgO, the reference mix shrank by 0.56%. High-reactivity MgO caused early-age expansion. At 4% dosage, it offset 12% of the shrinkage, at 8%, the reduction reached 13.5%. Zhang et al. [68] studied MgO–SiO_2 mortars under similar conditions over 28 days. Mixes with high-reactivity MgO (S1-1, S1-2) recorded the highest shrinkage, up to 1.07%, whereas mixes with low-reactivity MgO (S3-1, S3-2) showed significantly lower shrinkage values of 0.88% and 0.86%, respectively, representing an 18% reduction relative to S1-2 as shown in Figure 8. Shrinkage rates peaked around the third day, with higher reactivity leading to more rapid deformation. Lower reactivity delayed the shrinkage peak and reduced the total deformation, likely due to slower hydration kinetics and a more stable internal matrix. Similarly, Hu et al. [73] assessed drying shrinkage in MgO-modified geopolymer coatings over a 90-day period. The control mix (0% MgO) exhibited rapid shrinkage, while the addition of 0.2% and 0.4% MgO reduced final shrinkage by 8.9% and 15.1%, respectively. The most notable improvement was observed with 0.8% MgO, which reduced shrinkage by 61% at 7 days and 55% at 28 days, respectively. This behaviour is attributed to the formation of brucite, which fills pore spaces, restricts moisture loss, and introduces internal resistance to capillary tension. As evidenced by the results, low to moderate dosages of MgO, typically between 0.4% and 8%, depending on the binder type, have been most effective in reducing drying shrinkage by promoting internal expansion and stabilizing the microstructure.

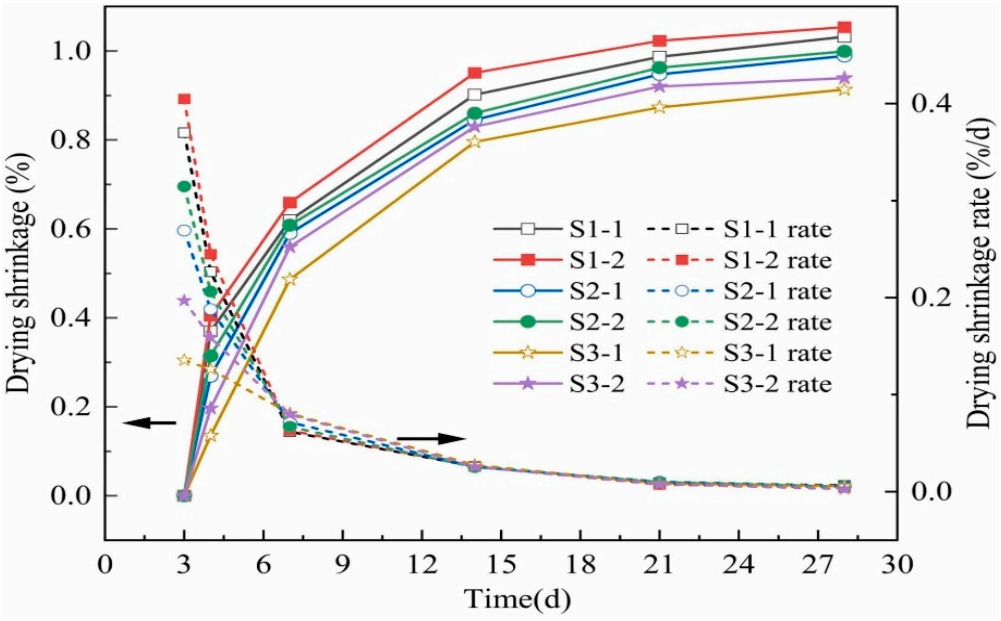

Figure 8. Drying shrinkage and shrinkage rate of mixes over 27 days. High-reactivity MgO lowered shrinkage and reduced drying shrinkage rate, indicating better resistance to cracking [64].

3.7. Carbonation

Carbonation is a key durability concern in cement-based materials, and it lowers the pH value, changes the pore structure, and can eventually lead to corrosion of reinforce-

ment [75]. Researchers have studied how MgO affects carbonation, and the findings are summarised in Table 1. Mo et al. [52] found that carbonation depth increased with both higher CO_2 pressure and longer exposure times. They also observed that mixes containing more fly ash and MgO had deeper carbonation under a CO_2 pressure of 0.10 MPa. In contrast, Choi et al. [76] reported no noticeable effect of MgO in concrete cured for 28 days in water. However, in 360-day cured composites, MgO reduced carbonation due to a filler effect that helped lower porosity. Similarly, Pu et al. [76] noted that MgO-concrete reached 45% carbonation in just 14 days, compared to 22% in OPC mixes, with the effect more prominent near the surface. Gonçalves et al. [77] found that incorporation of MgO increased carbonation depth due to higher porosity and reduced Ca $(OH)_2$ content. At 91 days, mixes with 10%, 15%, and 20% MgO showed increases of 1.2 mm, 2.6 mm, and 4.1 mm, respectively. Overall, these findings suggest that MgO's influence on carbonation depends heavily on factors like curing duration, CO_2 exposure, and the overall binder composition.

Table 1. Summary of research on Carbonation.

Reference	MgO Content (%)	Curing Age (Days)	Key Findings
[52]	20–60	28 (after CO_2 exposure of 3 h to 14 days)	Under 0.10 MPa CO_2, cement pastes were partially or fully carbonated. Higher CO_2 pressure accelerated carbonation. Mixes with higher FA and MgO showed deeper carbonation.
[76]	5	28–180	MgO addition (with 20% FA) did not affect carbonation in 28-day water-cured mixes. However, it reduced carbonation in 360-day cured mixes due to a filler effect, reducing porosity.
[78]	5–10	1–14	MgO-concrete showed 45% carbonation at 14 days vs. 22% in the OPC mix. Carbonation increased with time and depth, being higher near the surface.
[77]	0–20	1–91	Carbonation depth increased with MgO content. At 20% MgO, carbonation depth increased by 1.2–4.1 mm under accelerated carbonation over 28 days.

4. Effect of Supplementary Cementitious Materials (SCMs) on MgO-Based Cementitious Composites

Supplementary Cementitious Materials (SCMs) have been used in construction since ancient times, dating back to the Greeks between 750 B.C. and 600 B.C., and later by the Romans, who blended volcanic ash with lime to build long-lasting structures [79]. Today, SCMs play a critical role in sustainable concrete development by improving strength and durability while reducing the carbon footprint of cement production by reducing the amount of OPC needed [80]. Based on their origin, SCMs are classified as natural or artificial, as shown in Figure 9. Natural SCMs come from volcanic sources like ash and pumice, or sedimentary materials such as clay and diatomaceous earth. Artificial SCMs include industrial by-products and agricultural wastes like fly ash, silica fume, slag, metakaolin, and rice husk ash. The geological or industrial origin of each SCM determines its chemical composition, particle size, and amorphous content, all of which govern its pozzolanic reactivity and influence its effect on the mechanical and durability performance of cementitious composites [81]. This section summarises how fly ash, silica fume, and rice husk ash affect the properties of MgO-based cementitious composites.

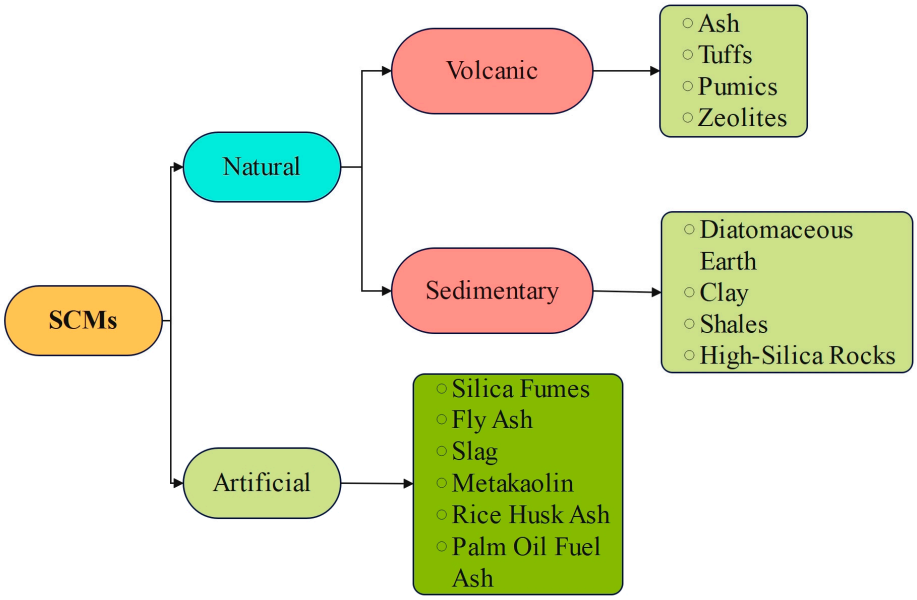

Figure 9. Classification of Supplementary Cementitious Materials (SCMs).

4.1. Fly Ash (FA)

Fly ash, a byproduct of coal-fired power plants, has emerged as a key supplementary cementitious material in sustainable construction [82]. Its pozzolanic reactivity contributes to long-term strength development, reduced permeability, and improved durability of cementitious composites [83]. Literature reported the effect of FA on MgO cementitious composites on mechanical properties and durability. Shah et al. [84] reported that incorporating fly ash with MgO in cementitious composites resulted in the formation of brucite and Mg-S-H phases led to a slight improvement in early-age compressive strength. Ye et al. [85] further examined the performance of nano-MgO in composites with 30% fly ash, highlighting that the pozzolanic activity of fly ash supported the delayed hydration of nano-MgO, resulting in a denser microstructure and enhanced long-term volume stability. This combination significantly improved both flexural and compressive strengths after extended curing, indicating its suitability for large-volume concrete applications with shrinkage compensation requirements. From a durability perspective, Sequeira et al. [86] demonstrated that incorporating 15–30% fly ash in MgO-based systems densified the matrix, reduced water absorption, and limited chloride ingress. These findings make it clear that combining fly ash with MgO in cementitious composites enhances both mechanical and durability performance, improving compressive and flexural strength over time, refining the microstructure, reducing shrinkage, and increasing resistance to water absorption and chloride ingress.

4.2. Silica Fume (SF)

Silica fume is a by-product of silicon or ferrosilicon alloy production, formed when silicon monoxide vapours oxidize in air during the high-temperature reduction of quartz with coal [87]. The resulting ultrafine amorphous silica particles are captured from furnace exhausts using filters [88]. Silica fume is known for its high pozzolanic reactivity and significantly enhances the mechanical and durability properties of cementitious composites [89]. Rawat et al. [48] observed that silica fume improved early strength and spalling resistance of MgO-based composites up to 400 °C. However, at 800 °C, thermal stability declined due to the decomposition of silica-rich phases and the formation of microcracks, compromising structural integrity. Li et al. [90] found that incorporating 5–15% silica fume with MgO in the composite slightly improved compressive strength due to the micro-filling

effect. At 400 °C, the 5% SF mix reached 105.4 MPa, attributed to M-S-H gel formation. Strength remained higher than the control even at 600 °C and 800 °C, supported by sintered forsterite and reduced brucite content. Tuxworth et al. [91] reported that silica fume, combined with light-burned MgO, refined the pore structure by reducing capillary pores (0.03–0.3 μm). This lowered permeability and improved resistance to chloride ingress, and sulphate attack. The denser matrix also reduced shrinkage and cracking. These results demonstrate the effectiveness of silica fume in improving thermal and durability performance of MgO-based composites.

4.3. Rice Husk Ash (RHA)

Rice husk ash (RHA), produced by controlled burning of rice husk, is a supplementary cementitious material rich in amorphous silica [92]. Its use reduces agricultural waste and provides high pozzolanic reactivity [93]. In cementitious composites, the optimum quantity of rice husk ash (RHA) improves durability, reduces permeability, refines the pore structure, and enhances strength through pozzolanic reactions [94]. Jiang et al. [95] showed that adding 10–30% RHA to MgO-based composites improved compressive strength, reaching its maximum value of 24.4 MPa at 20% after 28 days, while water absorption decreased up to 35% RHA addition. The amorphous silica in (RHA) promoted M-S-H gel formation and densified the matrix. Vo et al. [96] reported that partial slag replacement with RHA in MgO-alkali systems decreased workability and strength at early ages due to its porous nature, but 20% RHA with 7.5% MgO improved strength and microstructure. Higher RHA levels increased porosity and reduced performance. Overall, RHA enhances MgO-based composites when used at optimal levels, typically around 20%, while excessive use can impair fresh and hardened properties. A summary of optimum replacement levels, performance gains, and limitations of FA, SF, and RHA in MgO-based composites is presented in Table 2.

Table 2. Optimum levels and effects of SCMs in MgO composites.

SCM	Optimum Replacement Level	Performance Gains	Limitations
Fly Ash (FA)	15–30% with MgO [84–86]	Improves long-term compressive & flexural strength; densifies matrix; reduces water absorption and chloride ingress	Slightly lower early-age strength; performance depends on MgO reactivity
Silica Fume (SF)	5–15% with MgO [48,90,91]	Increases early compressive strength and thermal resistance up to 400 °C; refines pores; reduces shrinkage, chloride, and sulphate attack	At high temperatures (>800 °C),the decomposition of silica phases reduces stability
Rice Husk Ash (RHA)	~20% with MgO [94–96]	Enhances strength, lowers permeability, densifies microstructure, reduces water absorption	Excess (>30%) increases porosity, reduces early strength and workability

5. Effect of Fibres on MgO-Based Cementitious Composites

Cementitious composites such as concrete (OPC-based), a cornerstone of construction, are inherently brittle, with low tensile strength and strain capacity compared to their compressive strength, making them prone to cracking [97]. Cracks compromise the serviceability and durability of concrete structures over time [98]. Similarly, MgO-based cementitious composites also exhibit brittleness and limited crack resistance [46]. In MgO-based cementitious composites, a variety of fibres have been used to enhance mechanical performance, crack resistance, and durability. These include natural fibres such as cellulose and sisal, which are biodegradable and derived from plant-based sources, and synthetic fibres. Basalt fibres, classified as natural inorganic fibres, offer high thermal stability and are suited for high-temperature applications. Synthetic polymeric fibres such as PP, PE, and PVA provide good ductility and crack control [99]. While alkali-resistant

glass fibres are known for their high tensile strength and compatibility with cementitious matrices. Figure 10 summarises the roles of various fibres used in MgO-based cementitious composites, as discussed in this paper.

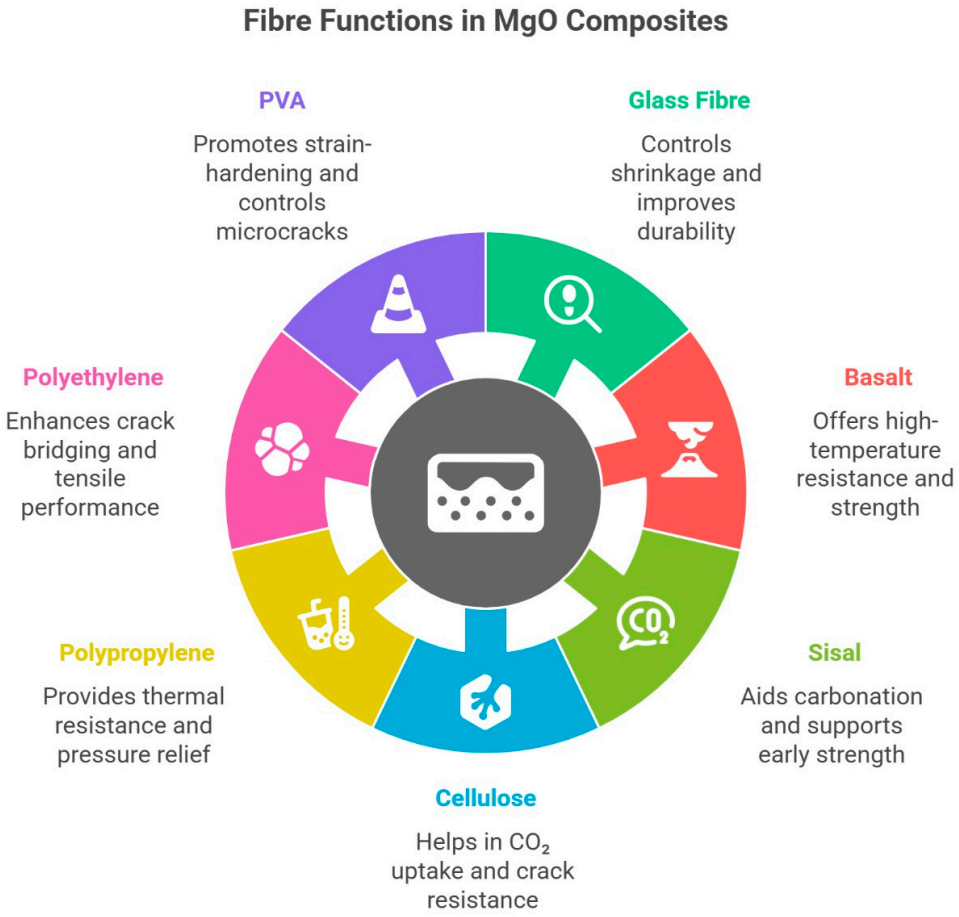

Figure 10. Fibre Functions in MgO Composites.

5.1. Natural Fibres

As shown in Table 3, natural fibres such as jute, sisal, ramie, cotton, and bamboo have gained attention in cementitious materials due to their low density, high tensile strength, and renewable nature [100]. Composed mainly of cellulose, hemicellulose, and lignin, these fibres offer mechanical strength and moisture responsiveness that vary with type and treatment. Their tensile strength ranges from 140 to 1000 MPa, and their modulus of elasticity spans from 5 to 130 GPa [101]. When incorporated into cement-based systems, they effectively bridge cracks, enhancing post-cracking performance and overall toughness [102]. Among them, sisal fibres have been explored in magnesium oxide systems. Wu et al. [103] found that adding 1–2 vol% sisal fibres improved compressive strength (~90 MPa at 28 days) and first-crack tensile strength by enhancing matrix densification and fibre–matrix bonding. Their hollow lumens and porous walls facilitated CO_2 diffusion, promoting uniform carbonation. Similarly, Mármol et al. [104] reported that incorporating jute and sisal fibres in MgO-based mortars increased flexural strength by up to 84% and 73%, respectively. Tensile strength improved by 40–56%, with jute performing better due to its higher aspect ratio and crack-bridging ability. Cellulose fibres have also shown encouraging results. Mármol et al. [105] evaluated MgO–SiO_2 cement reinforced with cellulosic fibres and observed excellent durability. Flexural strength increased from 9.23 MPa to 10.36 MPa after 200 ageing cycles, while specific energy remained stable (5.40 to 5.07 kJ/m^2), indicating minimal degradation and strong fibre matrix interaction. Hay et al. [106] further

explored cellulose fibres in MgO-based composites and reported improvements in crack resistance, internal curing, and CO_2 sequestration. Their porous structure helped retain moisture and supported CO_2 transport, which contributed to matrix densification. The optimal content was 0.25 vol%, which yielded the highest compressive strength in their study. These findings highlighted the potential of natural fibres, particularly sisal, jute, and cellulose, to improve both the mechanical performance and durability of MgO-based cementitious composites.

Table 3. Effectiveness of natural fibers in MgO-based cementitious composites.

Refs.	Fibre Type	Typical Dosage	Effectiveness and Mechanism in MgO-Based Cementitious Composites
[103,104]	Sisal	1–2 vol%	Improves compressive strength (~90 MPa at 28 days) and first-crack tensile strength; promotes uniform carbonation via hollow lumens; enhances matrix densification and fibre–matrix bonding.
[104]	Jute	~1–2 vol%	Increases flexural strength (up to 84%) and tensile strength (40–56%) due to high aspect ratio and crack-bridging ability; improves toughness and post-cracking performance.
[105,106]	Cellulose	0.25 vol%	Enhances crack resistance, internal curing, and CO_2 sequestration; flexural strength improved (9.23 to 10.36 MPa after 200 ageing cycles) with stable energy absorption; maintains durability under ageing.
[100–102]	Other natural fibres (ramie, cotton, bamboo)	Varies	Provide low-density, renewable reinforcement with good tensile strength; potential to enhance toughness, though performance varies with fibre type and treatment.

5.2. Synthetic and Glass Fibres

Synthetic and glass fibres have been investigated to improve the performance of MgO-based cementitious composites. Polypropylene (PP) fibres enhance crack resistance and impact toughness due to their chemical stability and ability to restrain expansion from MgO hydration, leading to refined cracking and reduced porosity [107]. PE fibres offer high tensile strength and ductility, particularly in MgO–silica fume systems. However, achieving uniform dispersion remains critical for consistent results [108]. Rawat et al. [109] reported that 2% PE fibres enhanced the tensile strain of MgO-based ECC to 3.3%, and longer PE fibres (18 mm) improved spalling resistance. PVA fibres are known for controlling crack width and enabling strain-hardening behaviour in MgO-based engineered composites. However, higher MgO content can reduce ductility unless offset by the use of superabsorbent polymers or other admixtures [110]. Another study by Wu et al. [103] found that 2% PVA fibres (12 mm), under carbonation curing, increased tensile strain from 1.18% to 4.93% and tensile strength from 1.46 to 2.68 MPa. Glass fibres (GF), especially alkali-resistant types, improve flexural strength and toughness in MgO-SiO_2-H_2O systems by bridging cracks and bonding chemically with hydration products. At high dosages, fibre agglomeration may increase porosity and diminish mechanical performance [111]. A summary of the performance and mechanisms of these fibres in MgO-based systems is provided in Table 4. Together, these findings suggest that with an appropriate mix design, synthetic and glass fibres can significantly improve the toughness, crack resistance, and long-term performance of MgO-based cementitious composites.

Table 4. Effectiveness and mechanisms of synthetic and glass fibres in MgO-based cementitious composites.

Ref.	Name	Abbreviation	Effectiveness and Mechanism in MgO-Based Cementitious Composites
[110]	Polyvinyl Alcohol fibre	PVA	Polyvinyl alcohol fibres control crack width and enable strain-hardening in engineered cementitious composites. However, a high dosage of magnesium oxide may reduce ductility unless balanced with admixtures such as superabsorbent polymers. When optimised, these fibres improve crack resistance and promote self-healing.
[107]	Polypropylene fibre	PP	Polypropylene fibres improve crack resistance and impact toughness. They restrain expansion caused by magnesium oxide hydration, refine microcracks, reduce porosity, and contribute to better durability and mechanical strength.
[108]	Polyethylene fibre	PE	Polyethylene fibres offer high tensile strength and ductility, especially in magnesium oxide–silica fume matrices. They enhance strain capacity and energy absorption, though careful mix design is needed to ensure proper fibre dispersion.
[111]	Glass fibre	GF	Alkali-resistant glass fibres increase flexural strength and toughness by bridging cracks and bonding chemically with hydration products. At optimal dosages, they improve toughness significantly, but excessive content may lead to fibre agglomeration and increased porosity.

6. Conclusions

This review has primarily examined the role of MgO on the mechanical and durability performance of cementitious composites, while also exploring the influence of SCMs and fibres on their properties. The following key conclusions are drawn from this review:

- Compressive strength in MgO-based composites depends on dosage, reactivity, and curing regime. Strength generally increases with MgO content up to ~60% under favorable conditions (e.g., high-temperature or carbonation curing). Tensile performance also improves at 4–6% dosage, enhancing ductility and strain capacity, while higher contents increase stiffness and reduce flexibility.
- Low to moderate MgO contents (around 5–20%) refine the pore structure, reduce total and harmful pore volumes, and lower water absorption and permeability by up to 33–42%. In contrast, higher MgO dosages (>10%) tend to increase porosity and water transport, lowering durability.
- Autogenous shrinkage is reduced by internal expansion from brucite formation, especially with higher MgO reactivity, which improves dimensional stability under sealed curing. Drying shrinkage is also lower with low to moderate MgO contents, as low-reactivity MgO delays deformation and stabilizes the matrix by reducing moisture loss.
- Supplementary cementitious materials such as fly ash, silica fume, and rice husk ash enhance strength, densify the pore structure, and improve chemical resistance. Their effectiveness is linked to the formation of M-S-H and M-A-S-H gels, which fill pores and strengthen the matrix.
- Synthetic fibers (PP, PE, PVA) and alkali-resistant glass fibers improve tensile strength, ductility, and crack resistance by bridging cracks and refining the pore structure. Moderate fiber contents (0.5–2% by volume) show the most reliable improvements. Excessive fiber addition, especially of glass fibers, can lead to agglomeration and higher porosity, reducing overall effectiveness. Natural fibers such as sisal and cellulose also enhance ductility and toughness, offering eco-friendly reinforcement options.

7. Future Research

This review highlights several key areas where further investigation is required to advance the development and practical application of MgO-based cementitious composites. The following recommendations are proposed:

- Despite promising durability results, the long-term performance of MgO-based composites under real-world conditions such as freeze–thaw cycles, sulphate attack, acid attack resistance, and chloride ingress has not been properly explored. Future studies should focus on extended exposure conditions to better evaluate performance.
- Pilot-scale projects and field applications are also needed to validate laboratory findings and demonstrate the feasibility of MgO-based composites in actual construction environments.
- The combined effects of supplementary cementitious materials (SCMs) and their interaction with fibres in MgO-based composites remain underexplored. Further studies are required to evaluate the performance of ternary and quaternary blends for high-performance construction applications.
- It is recommended that future research focus on developing performance-based design specifications for MgO-based cementitious composites. Instead of relying on fixed mix proportions, these guidelines should be centred around key target mechanical and durability properties such as compressive strength, shrinkage control, permeability, and resistance to environmental stresses. This approach would provide greater flexibility in mix design while ensuring reliable performance in real-world structural and exposure conditions.
- The application of MgO-based composites in advanced cement systems such as self-compacting concrete, ultra-high-performance concrete, self-healing concrete, and 3D-printed structures remains largely unexplored. Future research should also integrate digital tools such as artificial intelligence (AI) and machine learning (ML) for mix design optimization, durability prediction, and life-cycle assessment. Coupled with 3D printing technologies, these approaches can accelerate the development of customized, high-performance MgO-based materials.
- A comprehensive life cycle assessment (LCA) of MgO-based composites, considering raw material sourcing, energy input, emissions, and end-of-life recyclability, is necessary to validate their environmental benefits and guide their adoption in sustainable infrastructure.
- The fire performance and thermal behaviour of MgO composites also require further study. This knowledge is essential for applications in fire-sensitive zones and façade elements.
- Future studies should emphasize systematic investigations using standardized durability evaluation methods (e.g., RCM/NTBuild 492 for chloride ion diffusion, gas permeability tests, accelerated/natural carbonation, sulfate resistance, and shrinkage measurements) to ensure more reliable and verifiable results for MgO-based composites.

By addressing these areas, future research can bridge existing knowledge gaps and support the transition of MgO-based cementitious composites from experimental materials to viable, sustainable alternatives in civil infrastructure.

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