

REVIEW

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Research Progress on Improving the Water Resistance of Magnesium Oxychloride Cement (MOC)

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Abstract

Magnesium oxychloride cement (MOC) is a promising alternative to Portland cement due to its superior mechanical strength and lower carbon footprint. However, its poor water resistance remains a major barrier to widespread use. This review critically evaluates recent and emerging modification strategies to overcome this limitation, with a specific focus on improving water durability through chemical and physical enhancements. The novelty of this work lies in the comprehensive analysis of synergistic effects from compound additives, particularly combinations of organic acids and phosphates, on MOC performance. For example, integrating 1% tartaric acid (TA) and phosphoric acid (PA) was found to increase compressive strength to 87 MPa and 100 MPa, respectively, while significantly improving the softening coefficient and reducing degradation under prolonged water exposure. The study also highlights the role of nano-modifications, fiber reinforcements, and polymer emulsions in densifying the microstructure and enhancing long-term durability. These insights offer a quantitative and practical roadmap for optimizing MOC formulations and advancing its use in sustainable construction applications.

Keywords Magnesium oxychloride cement, Water resistance, Strength, Microstructure, Concrete, Energy

1 Introduction

Magnesium oxychloride cement (MOC) is a type of non-hydraulic cement with superior strength and durability properties, high thermal resistance, and rapid setting time (Failed, 2024; Yu et al., 2020). These properties make MOC a desirable material for different applications,

such as flooring finishes, abrasion resistance (He et al., 2020a), temperature resistance (He et al., 2019), thermal stability (Huang et al., 2022), fire protection (Zhou et al., 2023), and industrial flooring (Maier & Manea, 2022). As reported by Liu et al. (2020), the appropriate characteristics of MOC make it suitable for use in several applications, such as lightweight panels (Zhou & Li, 2012), fire protection panels (Pivák et al., 2020a), and industrial flooring (Pivák et al., 2020b). MOC was discovered by Sorel in 1867, and it is one of the hardening gel material types that can be found in lightly burned magnesium oxide, magnesium oxide, and water (Yu, 1993). MOC is a cementing material that has a high quantity of magnesia, micro-expansive properties, and is air-hardened (Wei et al., 2018). Numerous benefits can be obtained from the use of MOC as compared to Ordinary Portland cement (OPC), such as fire resistance, good thermal insulation, fast setting time, and high strength; therefore, it was used extensively in different areas, such as biological materials,

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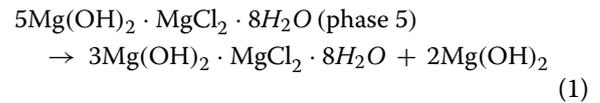
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construction materials, and thermal insulation materials (Yunsong, 2002; Zhou & Li, 2012). Simultaneously, MOC is a saving for energy, an extensive source of raw materials, and, a lower cost (Jianli et al., 2010; Li et al., 2003). The outstanding properties of MOC make it a widespread and environmentally friendly material (El-Gamal et al., 2015). Many factors can affect the hydration products and process, and adjust the production of high-performance hydrated crystals, namely, the ratio and quality of raw materials, and additional modifiers (Beskopylny et al., 2022). Humidity and temperature rates have a clear influence on the curing development (Blom et al., 2014).

The properties of high early strength and rapid hardening made MOC an optimum material for fast maintenance (Chau et al., 2009). MOC is generally applied for door frames because of the high resistance to abrasion, low thermal conductivity, and increasing fire resistance (Zhou & Li, 2012). Recently, Xie et al. (2024) studied the potential of additional biochar for improving the water resistance of lightweight MOC. They tested the compressive and flexural strengths after 28 and 56 days for water curing. They observed that the compressive and flexural strengths of MOC increased due to the addition of 5 and 10% biochar, after immersion for 56 days. Therefore, they concluded that biochar can be a possible additive to improve the water resistance and mechanical properties of MOC. MOC is also suitable for use with different organic and inorganic waste materials (Li et al., 2003). It is essential to keep the curing room in dry conditions to avoid the decomposition of the crystalline phases because of the existence of high water, which leads to evaporation to their evaporation into the air, and the occurrence of halogenation as a result (Jianli et al., 2010). The crystal phase increases gradually due to the low-temperature rate. While the high-temperature phases will be produced and the products are easy to be damaged due to the increase in temperature (Dinnebier et al., 2010). Numerous studies have been conducted to overcome the deficiencies and investigate the products of MOC with outstanding performance (Wu et al., 2013). Li et al. (2020) investigated the effect of improvement methods that have been conducted in enhancing water resistance through improving MOC. They examined the macro and micro properties of MOC, such as microstructure, softening coefficient, and strength. They observed that the multiple additives comprising polymer and phosphate materials have a good result in enhancing water resistance. He et al. (2017a) conducted many experimental works to enhance MOC's water resistance by adding incinerated sewage sludge ash (ISSA). They added Aluminum nitrate nonahydrate ($\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$) and Sodium metasilicate nonahydrate ($\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$) to the cement paste and mortar to replace ISSA to react

with MOC. They observed that the decreased expansion and improved water resistance are directly associated with the reduction in MgO content of the paste and an enhanced consistency, as shown in Formula 1.



Cao et al. (2023) used a new technique to improve the water resistance of MOC to enhance the pore structure and mechanical properties by incorporating highland barley straw ash (HBSA). They found that the addition of 10% HBSA improved the properties of the mechanical and microstructure of MOC.

Although numerous studies have been conducted to show the effect of different additives on the water resistance of MOC. However, further studies are needed to compile the latest advancements in enhancing the water resistance of MOC. Only a few studies, such as Maier and Manea (2022), investigated the potential use of MOC as cement replacement in the mix of wood–cement composite. They concluded that MOC can be used as a cement replacement at certain levels. Therefore, this study was introduced to close this gap and show the new results obtained from the latest studies related to the materials and methods applied in improving the water resistance of MOC. The properties of MOC were also enhanced due to the addition of different additives were also discussed. This study aims to address this gap by providing a comprehensive review of the previous studies on enhancing the water resistance of MOC. In addition, this study recommends some suggestions for future studies to find potential areas for future research, highlighting the need for innovative solutions that reduce the cost and environmental issues, thus enhancing eco-friendly construction practices.

2 Methodology of Study

The Scopus database was selected as the main data collection to download and collect the essential data related to the water resistance of MOC from the literature. The keywords inserted in the engine search were “water resistance” AND “magnesium oxychloride cement”. Scopus database was selected as the main database for the data collection, 188 documents were downloaded, and the search was conducted on 11 November 2024. The screening process was conducted to collect only the significant papers based on many criteria, such as papers related to the use of MOC as a cement, materials used in enhancing MOC, and strategies applied in enhancing MOC. These criteria include, but are not limited to, the effect of MOC on the environment and economic

aspects. Therefore, only 116 papers were adopted and discussed the results, while other papers were neglected either out of scope or did not match the criteria identified. This encourages direction and represents a significant matter in the adoption of new treatment methods for MOC and exploring the characteristics of MOC, and its effect on the mechanical, durability, and microstructure properties of MOC composite.

As shown in Fig. 1a, it was focused only on the new papers published after 2010. The main reason is that most studies were published after 2010, and few papers have been published before that time, as observed in the Scopus database. A significant increase in the publication of papers occurred after 2018, and 34 papers were published in 2022, to is the highest publication number. China, the Czech Republic, and the USA recorded the highest number of countries in the world in the publishing of papers with 144 papers for China and 14 for each of the Czech Republic and the USA. Iraq, Russia, South Korea, and Tunisia recorded the lowest publication rates with one paper for each, as shown in Fig. 1b. In terms of the type of paper, the article research constituted more than 90% of the documents collected, as shown in Fig. 1c, while the conference papers were only 11 came in the second stage after the research article.

3 Water Resistance of MOC

The water resistance of magnesium oxychloride cement (MOC) is a critical aspect in assessing its durability and suitability for various applications (Aiken et al., 2022a; He et al., 2019). MOC, renowned for its exceptional strength and rapid setting properties, undergoes a complex interaction with water molecules that influences its long-term performance. Understanding the mechanisms governing water resistance is pivotal for optimizing MOC formulations in construction materials and chemical industries. Research endeavors have focused on elucidating the interplay between water ingress, hydration kinetics, and microstructural evolution within MOC matrices. Furthermore, advancements in additive technologies and surface treatments have been explored to enhance its resistance to water penetration and subsequent degradation. Numerous studies investigated the physicochemical characteristics of MOC in aqueous environments to develop resilient and sustainable construction materials. For instance, He et al., (2019) conducted a comprehensive study on the durability and mechanical of MOC boards combining waste wood. They reported that the flexural strength retention was reduced due to increased wood content, which can be attributed to the softening of the wood fibers with water immersion. Deng (2003) showed that the water resistance of MOC could improve due to the incorporation of some soluble phosphates

into MOC. They concluded that the soluble phosphates could enhance the water resistance of MOC; thus, the strength retention coefficients of hardened MOC pastes are increased with the increase of the mass fraction of the phosphates added into the MOC pastes. Chen et al. (2019) investigated the influence of tartaric acid and phosphoric acid on the water resistance of MOC paste. They found that the addition of 1% tartaric acid and phosphoric acid can reduce thermal stability and enhance the water resistance of MOC paste.

Other studies reported that the soluble phosphates and Phosphoric acid (H_3PO_4) were used to improve the water resistance of MOC (Góchez et al., 2019; Tan et al., 2014). The compressive strength of MOC pastes was developed to 0.8 due to the addition of 0.5–1.0% soluble phosphates into the MOC mix and saturated in water at room temperature for 60 days (Deng, 2003). A small decrease in compressive strength was observed in MOC mixed with phosphates (Tan et al., 2014). The phosphates have a positive effect on the increase of water resistance for MOC mixed, as reported by the previous studies (Li et al., 2016; Sun et al., 2024). Nevertheless, there is still a lack of comprehensive studies and details on the development of water resistance of MOC mix due to the incorporation of some additives. Guo et al., (2022a) concluded that the water resistance and flexural strength are increased considerably due to the addition of phosphates into the MOC paste, but the volume change, compressive strength, and density are reduced. Numerous studies investigated CO_2 curing to increase the water resistance of MOC mixtures (He et al., 2017b). The water resistance of MOC pastes containing incinerated sewage sludge ash was high (around 80% strength retention), consequently, the samples including incinerated sewage sludge ash were not exposed to CO_2 curing (He et al., 2017a).

3.1 MOC is an Eco-Friendly Material

MOC with lower CO_2 emissions compared to Portland cement can be considered as an eco-friendly material (Wang et al., 2017). Zhong et al. (2023) detected that the carbon emissions of MOC are lower than those of the production of normal cement. Jankovský et al. (2020) reported that the MOC composite has a significant role in the ability to capture CO_2 , thus making it an eco-friendly material besides its ability to enhance its durability and strength. They also indicated that the use of MOC as a construction material, MOC as a low-energy building composite material, will contribute to reducing the energy consumption required for the construction industry, thus reducing CO_2 emissions and climate change. The production process does not require the high-temperature calcination of limestone, as required in the process of cement production (Jiang et al., 2019). Furthermore,

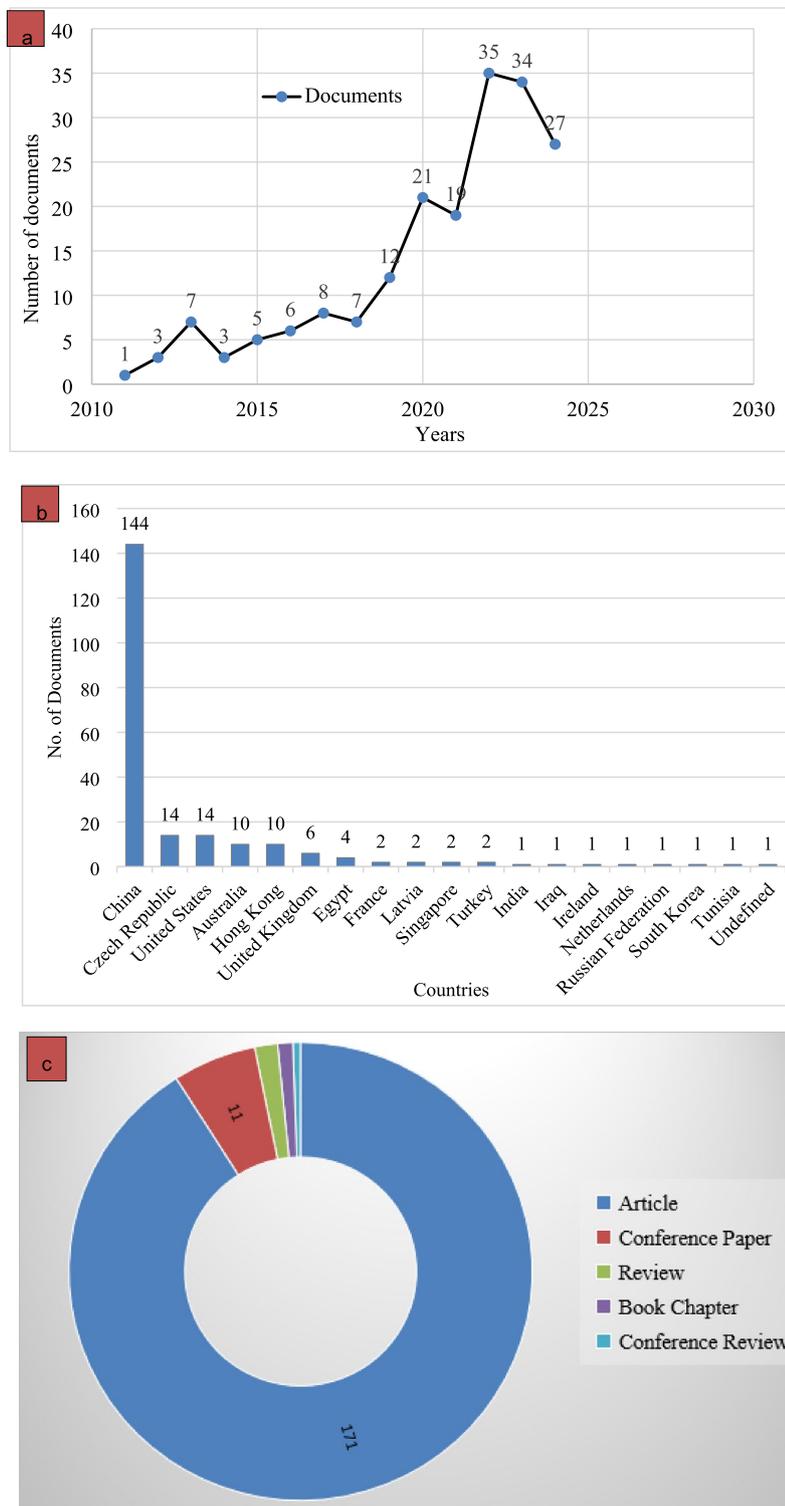


Fig. 1 a Number of papers published versus years, b papers published versus countries, and c type of papers versus number of papers

MOC requires less energy during synthesis, as its formation relies on the reaction between magnesium oxide and magnesium chloride solution at ambient or moderately elevated temperatures, eliminating the need for energy-intensive clinker production (Kara et al., 2021; Walling & Provis, 2016).

In addition to that, unlike Portland cement, which has strict compositional requirements that limit the integration of industrial by-products, MOC has demonstrated compatibility with various waste materials (Khan et al., 2024a, 2024b), such as fly ash (Guo et al., 2020), silica fume (Nasir et al., 2025), and other pozzolanic additives (Ahmad et al., 2024a). For instance, Zheng et al. (2024) used fly ash as an SCM with MOC to enhance the workability of the slurry in replacement levels of 20, 30, 40, and 50%, by MOC weight. They observed that the optimal FA content was between 20 and 30%, which led to improved mechanical properties and setting time, and the fluidity of the MOC mortar increased from 206 to 297 mm. This capacity for waste utilization not only reduces environmental impact but also enhances resource efficiency, aligning with circular economy principles.

4 Approaches to Improve the Water Resistance of MOC

Several approaches have been proposed to enhance the water resistance of MOC, aiming to improve its durability and performance in various applications. The following sub-sections are the most common approaches used.

4.1 Inorganic Additives

Inorganic additives are one of the most common additives in the improvement of the water resistance of MOC. Inorganic additives such as nitrates, chlorides, and metal fluorides are usually used to enhance MOC composites' water resistance (Kalidasan et al., 2023). MOC has been given considerable consideration, since numerous methods exhibit properties higher than standard Portland cement. It sets rapidly to allow quick restoration and displays a higher strength at an early age. Although the numerous benefits of using MOC in construction materials it is still not widespread and decreased strength quickly on protracted exposure to water is one of the reasons (Beaudoin & Ramachandran, 1975). The addition of different additives can improve the durability of MOC (Misra & Mathur, 2007; Yunsong, 2001). Phosphoric acid (H_3PO_4) is one of the additives that could increase the water resistance of MOC considerably (Deng, 2003; Huang et al., 2019a). Guan et al. (2022) prepared MOC using fly ash and hexa-decyltrimethoxysilane (HDTMS). They observed that the addition of 3% HDTMS and 20% fly ash enhances the water resistance of MOC, and this

improvement is due to the increase in the amount of the gelling 5-phase of MOC, as shown in Fig. 2.

Moreover, the incorporation of H_3PO_4 results in decreased compressive strength and delays the hydration process. Luo et al. (2020) studied the influence of hydroxyacetic acid (HA) on the water resistance of MOC and its effect on the light-weight, fire resistance, and mechanical strength. They observed that HA-modified MOC has a considerable increase in the softening coefficient but has an insignificant influence on compressive strength. Consequently, from the analysis by scanning electron microscope (SEM), thermogravimetric-differential scanning calorimetry (TG-DSC), and X-ray diffraction (XRD), it becomes considerably stable $5Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$ (phase 5) in water by the absorption and coordination effect. They observed that the use of HA led to obvious modification in the MOC crystal morphology, as shown in Fig. 3.

Figure 3 shows that phase 5 forms a high-aspect ratio (length: diameter) with a needle-like crystal, and the $Mg(OH)_2$ forms flaky crystals that cross with each other in the matrix. Zhang et al. (2017) investigated the impact of synthesizing 5-phase seed crystals on the microstructure, reaction process, and compressive strength of the two types of MOC. They observed that the incorporation of 5-phase seed crystals can considerably increase the production of 5-phase in the MOC, resulting in to increase in the early compressive strength of MOC. In terms of the five phases, the authors revealed that the addition of seed additives results in an important increase in the early curing age-compressive strength of MOC samples. In addition, the formation rate of 5-phase can be enhanced due to the use of seed crystals. In contrast, the microstructure of MOC can be affected significantly due to the use of seed crystals in MOC. Li et al. (2013) conducted an experimental study to determine the compressive strength of granite waste fly ash MOC (GFMOC) with a replacement level of granite fly ash of 40% magnesia weight. They observed that the filling role and water absorption of the fine particles of granite waste in GFMOC slurry are favorable for phase 5, and the microstructure is denser.

Recently, Li et al. (2025) investigated the effect of inorganic and organic materials on the water resistance of MOC composite. They developed a new material from acorn powder (AS) and Tannic acid (TA) as organic components to offer extra active sites for Mg^{+2} ions in MOC. The water resistance of the MOC composite improved by 57.8% compared to the control sample and the compressive strength of the MOC composite increased by 14% to reach up to 109.7 MPa, as shown in Fig. 4.

Guo et al., (2022a) studied the influence of sodium mono-fluoro-phosphate (MFP) as a modifier to improve

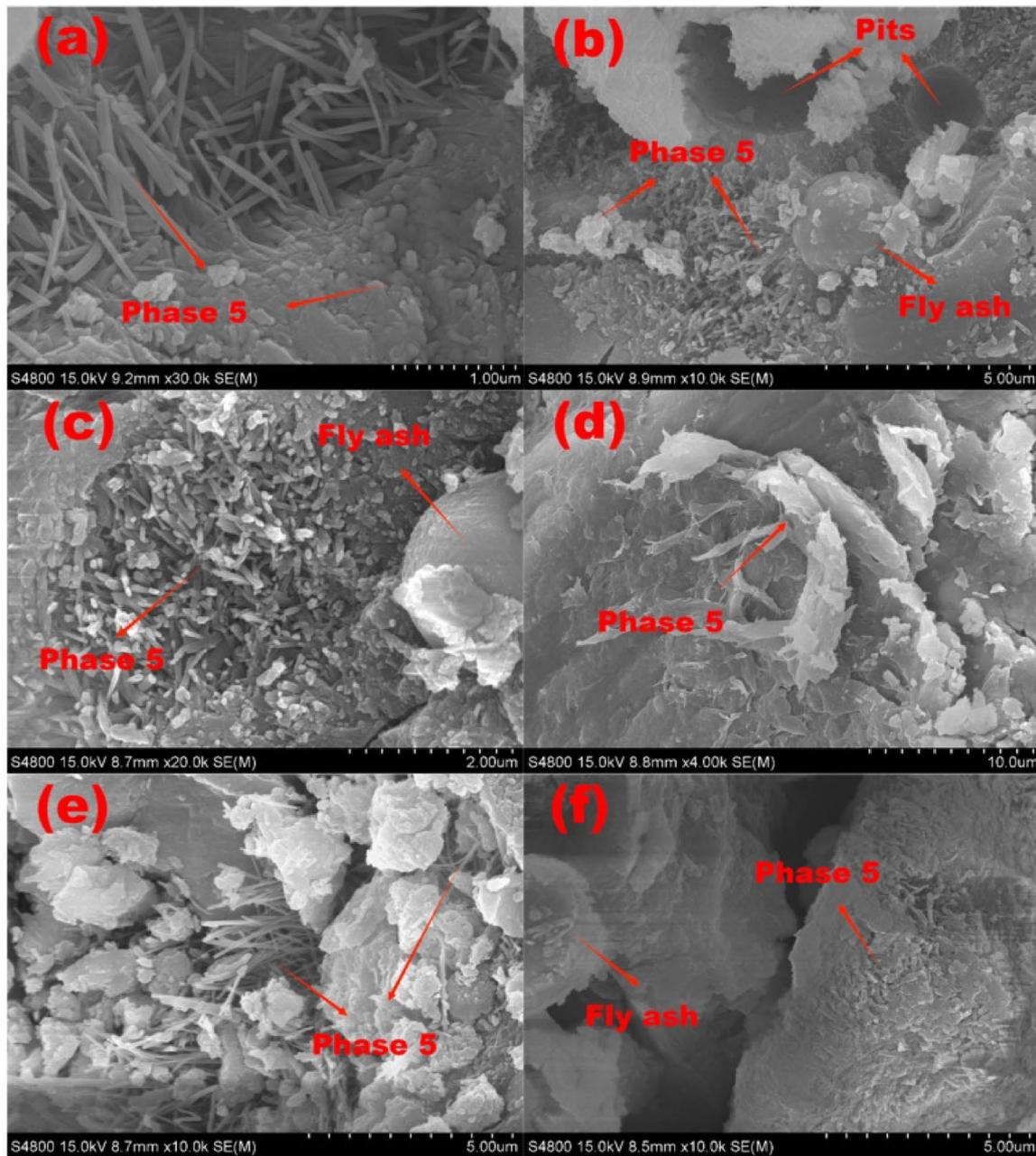


Fig. 2 SEM images of improved MOC due to the use of fly ash and hexa-decyltrimethoxysilane (HDTMS)

the water resistance of MOC. They investigated the influence of phosphates, including soluble phosphates (KH_2PO_4) and phosphoric acid (H_3PO_4) with different dosages, on the water resistance of MOC properties, such as compressive and flexural strengths, fluidity, and setting times. The results obtained from that study showed that the setting times and fluidity of the MOC pastes mixed with phosphates showed an obvious increase from 68 to 118 mm, while the initial and final setting times were

delayed and extended due to the addition of H_3PO_4 or KH_2PO_4 . Nevertheless, the addition of MFP to the paste leads to a delay influence to is more noticeable. For example, the increase in MFP content from 0.5 to 1% leads to a delay in the initial and final setting times from 8.7 h to 10.4 h and from 10.9 h to 12.3 h, respectively.

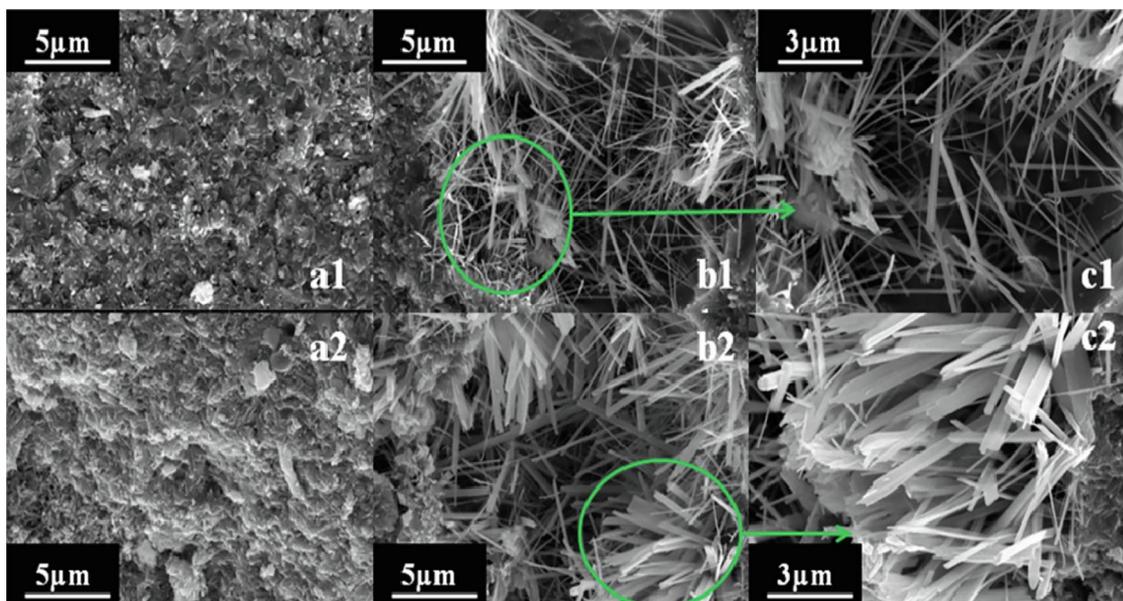


Fig. 3 SEM of MOC modified with 2% HA (a2, b2 and c2) and unmodified MOC (a1, b1 and c1) (Luo, et al., 2020)

4.1.1 Chemical Additions

Chemical additives represent a pivotal approach in enhancing the water resistance of magnesium oxychloride cement (MOC) (Chen et al., 2019; Luo, et al., 2020). These additives play a crucial role in modifying the hydration process and microstructure of MOC, thereby improving its resistance to water ingress (Guo et al., 2018). Various chemical additions, such as organic and inorganic compounds, have been investigated for their effectiveness in enhancing MOC's water resistance. Moreover, these additives can also improve the mechanical properties of MOC, making it a viable option for sustainable construction practices. For instance, Ya et al. (2021) studied the chemical composition and thermal stability of the MOC. The main composition of the MOC specimens was examined by SEM/EDS. The results obtained showed that the pH value of the MOC slurry mix increased from 7.08 to 7.40 because of increasing the curing age from 5 to 120 min. The MOC composites included lesser alkalinity compared to MOC-0 due to the integration of phytic acid, displaying a better perspective to incorporate with an extensive variety of fillers, including plant fibers and wood wastes (Zhou & Li, 2012). Table 1 shows the chemical composition of MOC components as reported by the previous studies. The table of the chemical composition of MOC is created to establish a baseline reference for understanding how various chemical additives interact with and modify their composition.

As shown in Table 1, the MgO is the highest percentage among other MOC components ranging between 80.20 and 94.37%. While second highest percentage was

the silica oxide (SiO_2) which ranged between 0.21 and 12.88%, and these different proportions in MOC components affect their properties. In addition, the difference in chemical composition of MOC depends on numerous factors, such as the treatment methods, source of materials, and others.

Another study by Tan et al., (2014), used MOC with added the H_3PO_4 to control the degradation process of MOC. They evaluated the effect of H_3PO_4 on the hydration, degradation, mechanical properties, and microstructures of MOC, and they observed that the addition of H_3PO_4 did not impact the crystalline phases in MOC. Huang et al. (2019b) reported that the addition of phosphoric acid into MOC led to the decomposition of the components into PO_3^{4-} , HPO_2^{4-} , and $\text{H}_2\text{PO}_4^{4-}$ in MOC paste. The existence of these ions plays an important role in decreasing the dissolution of phase 5. Zhou et al. (2024) prepared interfacial functionalized graphite with tartaric acid, and milling graphite flakes and utilized it to improve the water resistance of MOC. They observed that the addition of 1.5% BM-graphite into the MOC composite showed an important development in compressive strength and water resistance. Table 2 shows the effect of chemical additives on the water resistance of the MOC composite.

4.1.2 Supplementary Cementitious Material (SCM)

The addition of supplementary cementitious materials (SCM) into MOC mortar has a significant effect in enhancing their properties. Lauermannová et al., (2021a) conducted a study that deals with the analysis

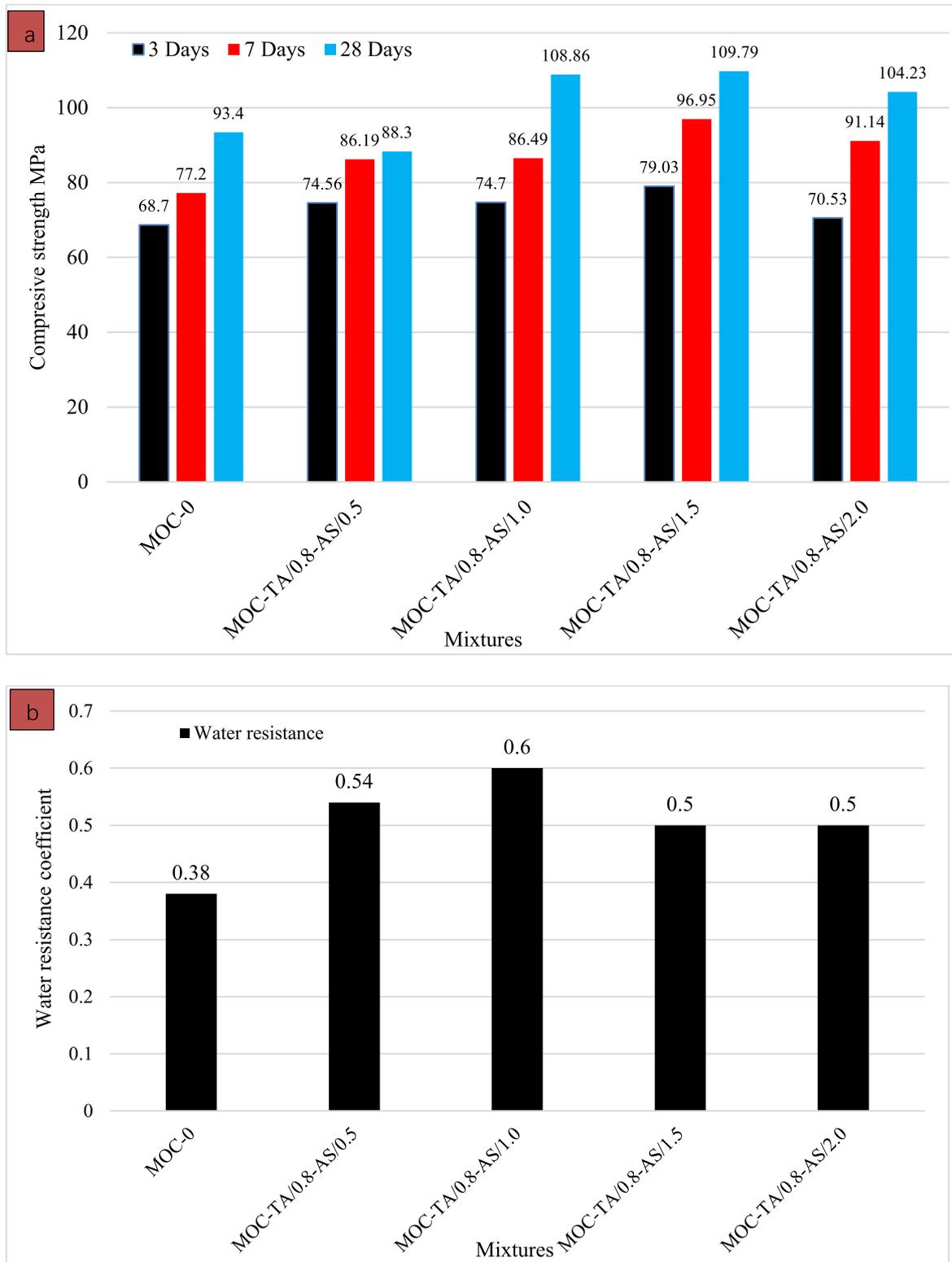


Fig. 4 Effect of inorganic and organic additives on the **a** compressive strength and **b** water resistance of MOC composite (Li et al., 2025)

and synthesis of the composite of MOC with diatomite in three phases with different quantities of diatomite using different analytical techniques, namely, SEM/EDX, XRF, and XRD. The results obtained show that the spread diameter is reduced due to an increase in the

diatomite content in the composite mix. This reduction can be attributed to the high specific surface and high fineness of variable-formed diatomite particles compared to that of quartz sand. The phase composition was determined using XRD, as shown in Fig. 5. It shows

Table 1 Chemical composition of MOC

Reference	SiO ₂	Al ₂ O ₃	MgO	Fe ₂ O ₃	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	Others	LOI
Guo et al., (2017a)	0.21	0.07	91.75	0.07	0.07	0.25	<0.01	–	<0.01	–	7.18
Li et al., (2013)	6.07	0.15	80.20	0.41	1.30	–	–	–	–	11.87	–
Guo et al., (2022a)	0.21	0.07	91.75	0.03	0.50	0.25	<0.01	0.01	<0.01	–	7.18
Luo et al., (2020)	2.95	0.28	94.37	0.34	2.95	–	–	–	–	–	0.97
Wei et al., (2018)	12.88	0.07	84.46	0.60	0.04	–	0.04	–	0.03	0.13	–
Huang et al., (2021a)	6.03	1.28	85.96	0.57	1.29	–	0.04	–	0.04	–	–
Feky et al., (2022)	0.21	0.07	91.75	0.03	0.50	0.25	0.01	0.01	0.01	–	7.15
Zhou et al., (2022)	6.78	0.83	87.94	0.54	2.05	–	–	–	–	1.86	–
Yang et al., (2022)	5.857	0.63	90.76	0.345	1.958	0.168	–	–	–	0.212	–

Table 2 Effect of chemical additives on the water resistance of MOC composite

References	Chemical additives	Effect on the water resistance of MOC composite
Chen et al. (2019)	Tartaric acid (TA) and phosphoric acid (PA)	Adding 1% of PA or TA to MOC considerably enhances the water resistance of paste specimens. This enhancement is due to the production of gels such as phase 5 with low crystallinity
Deng et al. (2003)	Soluble phosphates	The soluble phosphates considerably enhance the water resistance of MOC when added in a certain amount
Ye et al. (2020)	Hydroxyl groups	The addition of hydroxyl groups aligned with rice husk ash mainly contributed to enhancing the water resistance of MOC due to integrating an anionic polymer
Li et al. (2008)	phosphate, stearic acid–styrene acrylic acids' copolymer emulsion	The chemical additives decreased the warp distortion and water absorption, as well as importantly enhanced the interlocking coefficient and ameliorated the degree of magnesium salt out of magnesium oxychloride cement floor tile

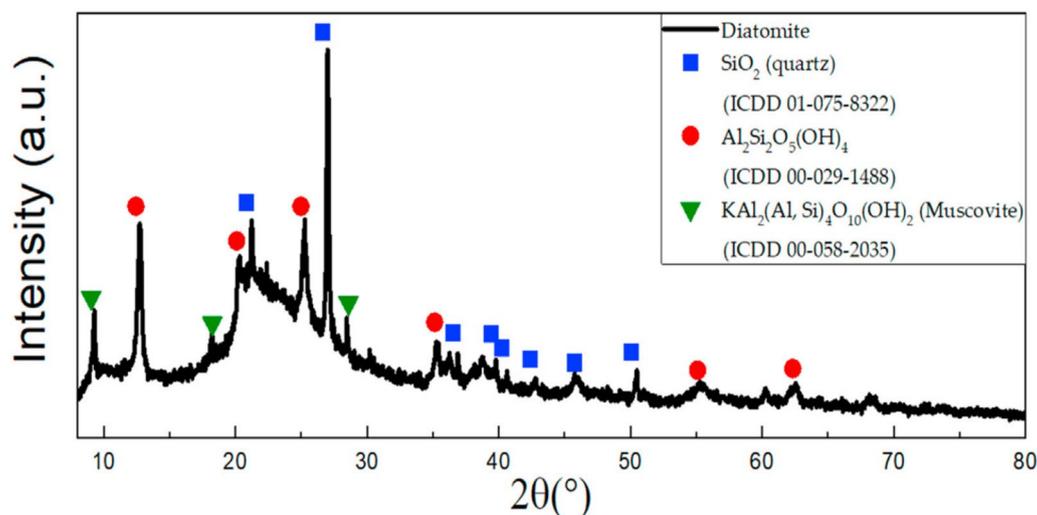


Fig. 5 Diffraction pattern of the diatomite powder (Lauermannová et al., 2021a)

the alumino-silicate phase, the quartz (SiO_2) represents the crystalline phases and the muscovite. The diversion configuration also presented fair quantities of amorphous phases.

The SEM image of MOC includes diatomite, as shown in Fig. 6. The high enlargement enables us to see the interconnecting of diatomite particles in MOC in cement paste. An increase in interconnected phase-5 crystals over the pores created in composites was likewise well obvious.

Guo et al., (2022b) studied the effect of sodium mono-fluorophosphate (MFP) on the improvement of the poor water resistance of MOC. Cao et al. (2023) they used highland barley straw ash to enhance the water resistance and mechanical properties of MOC. They found that the working and physical properties improved, and the compressive and flexural strengths of MOC increased. The enhancement in performance of MOC might be due to the formation of further magnesium–silicate–hydrate gels, which closed open-pore spreaders along the MOC matrix.

In addition to that, several material wastes are used to enhance the MOC matrix. For instance, Xe et al. (2022) used dredged sediment (DS) resulting from several processes in the MOC matrix to enhance sustainability, and

found that the water resistance of the MOC pastes significantly enhanced as compared mix without DS. Sun et al. (2024) investigated the influence of red mud (RM) and phosphate (KH_2PO_4) on the water resistance of MOC. They observed that RM and KH_2PO_4 considerably extended MOC's setting time. Finally, they suggested benefiting from RM in enhancing the properties of MOC by reducing the environmental effects.

4.2 Organic Additives

Numerous organic additives such as styrene–acrylic emulsion polymers, epoxy resins, and phytic acid can be used to improve the water resistance of the MOC matrix. For instance, Stearic Acid is an organic additive that can be used to reduce permeability, improve adhesion, and enhance the water resistance of MOC (Li et al., 2020). Ye et al. (2020) showed that the materials, especially the cornstarch/sodium polyacrylate (PAAS) MOC composites, improve the water resistance and compressive strength of MOC. Furthermore, the bio-mineralization method enhances the alignment and growth of phase-5 crystals by hydroxyl groups with a cornstarch template. The water resistance of MOC can be considerably improved by the removal of heavy magnesium ions and the conversion of the phase-5 crystal structure by

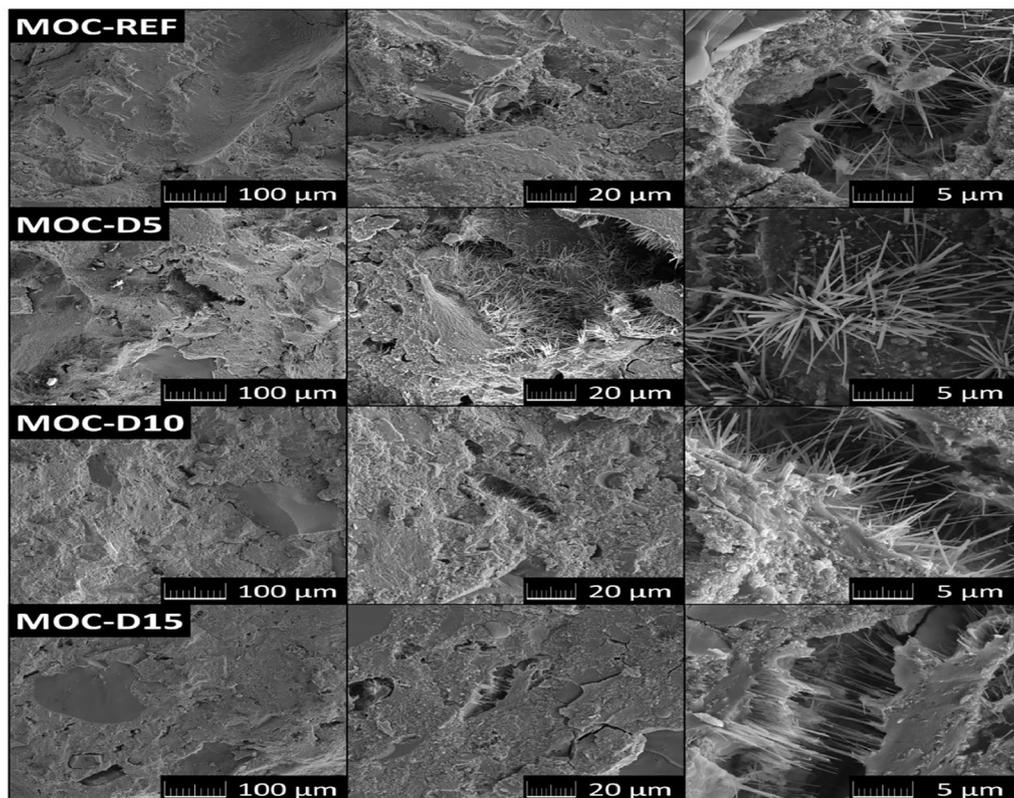


Fig. 6 SEM images of MOC containing different content of diatomite (Lauermannová et al., 2021a)

PAAS. Therefore, the composite strength increased by about 21%. Another study by Ye et al., (2021) studied the potential of using acid radicals in improving the water resistance of MOC. The strength retention coefficients, hardness, compressive strength, and flexural strength were tested to determine the variations in the mechanical properties of the MOC composites. They observed that the water resistance and compressive strength of MOC were considerably improved. This improvement was linked to the high tension and coordination bonds of the stiffness rings in phytic acid. In the crystallization process, numerous phosphate ions on phytic acid were removed with magnesium ions (Ye et al., 2021). The strength retention coefficients, hardness, compressive strength, and flexural strength were tested to determine the variations in the mechanical properties of the MOC composites. Nevertheless, the compressive strength of 7 and 28 days reduced to 43.8 MPa and 63.6 MPa, respectively. The compressive strength increased due to the addition of phytic acid up to 51.6 MPa and 71.5 MPa for 7 and 28 curing ages, respectively.

Recently, Yi et al. (2024) examined the effect of phytic acid on the water resistance and mechanical properties of MOC in different macroscopic characterization methods. They observed that the phytic acid has a significant effect on the improvement of water resistance and mechanical strength of MOC. Luo et al. (2014) reported that the MOC has numerous advantages, such as light weight, fire resistance, and better mechanical strength. However, the poor water resistance of MOC prevented it not spreading widely; the addition of organic acid can improve the water resistance of MOC. Therefore, they investigated the influence of hydroxyacetic acid on the water resistance of MOC. They observed that the hydroxyacetic acid has remarkably increased the softening coefficient and has an insignificant influence on the compressive strength, while in the setting times of MOC were also affected due to exposure of the MOC to hydroxyacetic acid in different concentrations. Hydroxyacetic acid

has a significant effect on the setting times of MOC. The increase of HA content from 0 to 2.4% resulted in to increase in the final setting time of MOC from 4.1 h to 8.5 h. As reported before, increasing the tartaric acid ratio in MOS likewise considerably increases the setting times, which can reduce the hydration reactions and hydration heat rate (Wu et al., 2017). Abd-El-Raouf et al., (2022) studied the effect of the incorporation of vinyl versatile and copolymer emulsion [copolymerization of vinyl acetate in different contents as a bonding copolymer to reduce the CO₂ emissions and energy consumption. They observed that the early curing-compressive strength values up to 50 MPa were achieved due to the use of the polymer-modified MOC pastes. Table 3 shows some of the effects of organic additives on the water resistance of MOC composites.

Zhou et al., (2021) reported that the poor water resistance and low initial viscosity of MOC have restricted their use in plywood production. The usage of MOC is useful for the conservation of fossil resources and the protection of human health. Nevertheless, Zhou et al., (2021) added sodium polyacrylate (PAAS) and polyacrylamide (PAM) to the adhesive as organic agents to create wood-based composites by the inorganic-organic hybrid approach. Chen et al. (2019) investigated the influence of the additions of tartaric acid and phosphoric acid on the water resistance of MOC pastes. They observed that the addition of these acids led to a decrease in the setting time and compressive strength of MOC paste, besides increasing the total porosity.

Chen et al., (2019) reported that the MOC with low density, low thermal conductivity, and high early strength is still not extensively used in construction applications because of its poor water resistance. Therefore, they investigated the influence of additions of tartaric acid (TA) and phosphoric acid (PA) on the pastes of water resistance of MOC. They observed that the thermal stability of MOC pastes was reduced, and the water resistance of MOC pastes was improved due to the addition

Table 3 Effect of organic additives on the water resistance of MOC composites

References	Organic additives	Effect of organic additives on the water resistance of MOC composites
Huang et al. (2021b)	Waterborne epoxy resin	The addition of Waterborne epoxy resin to the MOC composites led to enhancing the water resistance, mechanical strength, viscosity, and thermal stability of MOC composites. The water absorption was reduced up to 8.7%
Zhou et al. (2021)	Polyacrylamide (PAM) and sodium polyacrylate (PAAS)	The addition of PAAS enhanced the water resistance of MOC, while the addition of PAM effectively enhanced the strength and processability of MOC
Zhou et al. (2022)	hydroxyapatite (HA)	The hybrid effect of organic and inorganic materials has a significant effect on the water resistance of MOC. The water resistance and mechanical strength were somewhat improved
Mohsen et al. (2024)	Polyurethane (PU) or epoxy (EX)	The use of EX led to enhanced water resistance compared to PU. The addition of both PU and EX resulted in a reduction in the workability and 28-day compressive strength of MOC composites by 32.6% and 26.1%, respectively

of 1% of tartaric acid and phosphoric acid, due to the production of gel-like $5\text{Mg}(\text{OH})_2 \cdot \text{MgCl}_2 \cdot 8\text{H}_2\text{O}$ (phase 5). Furthermore, increased the total porosity, delayed the setting times, and reduced the compressive strength due to the use of these additives. The compressive strength was reduced due to adding some additives, as shown in Fig. 7.

4.3 Fiber Modification

The addition of different fiber types into MOC composite is one of the innovative solutions for enhancing the water resistance of MOC. For instance, He et al. (2022) studied the influences of wood fiber size and content, admixtures, and extrusion force on the mechanical and physical properties of MOCB. They adopted a new strategy of recycling construction waste wood to produce MOCB, which is a high-performance and eco-friendly strategy. They observed that the flexural strength and density of MOCB increased significantly due to a suitable increase in the wood fiber content. The SEM test was conducted to find out the influence of wood fibers on the microstructure of MOCB, as presented in Fig. 8. Therefore, the use of MOC to prepare cement is more economically related to reducing CO_2 emissions, fire resistance, and density than OPC (He et al., 2020b). While the compressive strength of MOC at early ages improves quickly (Gu et al., 2021). Nevertheless, the integration of wood fibers leads to the enhancement of its toughness and the crack resistance of MOC (Wang et al., 2016). He et al. (2020b) observed that the use of high-volume wood fiber resulted in to increase in the flexural strength of the MOC and a decrease in the

heat insulation. Table 4 shows the effect of fiber types on the water resistance of MOC composites.

Ahmad et al. (2025) investigated the effect of metakaolin (MK) and ground granulated blast furnace slag (GGBFS) on the ductility and strength of MOC-based hybrid polyethylene and basalt-fiber-reinforced cementitious composite. They detected that the addition of 1.25% polyethylene and 0.75% basalt fibers with 30% GGBFS increases compressive and tensile strengths up to 73.9 MPa and 8.52 MPa, respectively. Rawat et al. (2024) examined the mechanical properties of fiber-reinforced MOC at elevated temperatures and ambient curing. They concluded that compressive strength was significantly reduced up to 87% due to the increase in temperature up to 800 °C (Failed, 2024; Rawat et al., 2024). While the concrete samples with 0.5 PP and 1.5% basalt fibers exhibited lower reduction compared to the samples without fibers (Failed, 2024).

4.4 Curing Strategy

The water resistance of MOC can be improved and its applications can be increased, it is essential to comprehend the influence of molar ratios and curing regimes on the water resistance of MOC. Aiken et al., (2022b) studied the influence of curing conditions and molar ratios on the properties of MOC pastes. The results obtained indicated that the use of suitable molar ratios can considerably develop the water resistance of MOC under suitable curing conditions. For instance, the compressive strength of MOC paste samples was reduced by 40–90% of their strength according to the molar

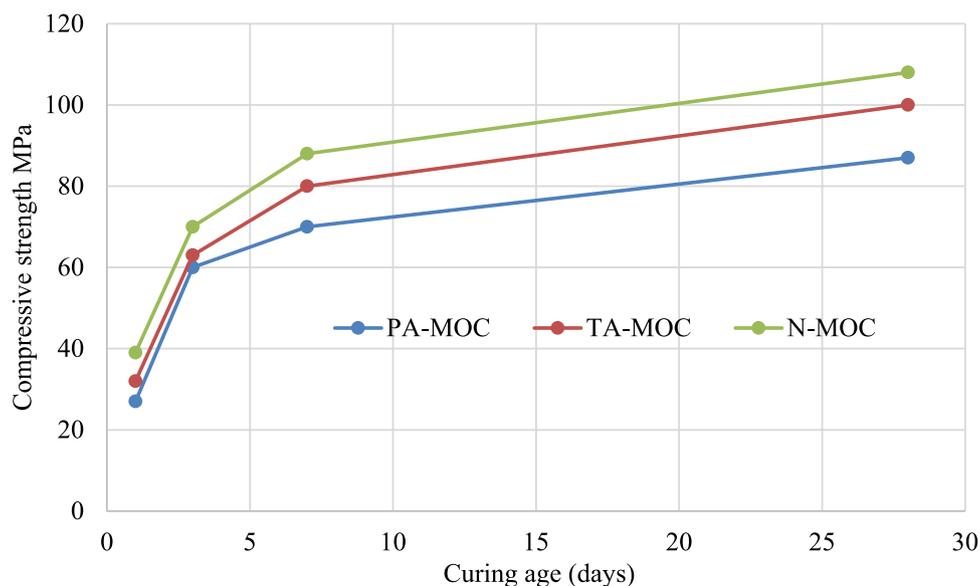


Fig. 7 Compressive strengths of MOC with and without additives (Chen et al., 2019)

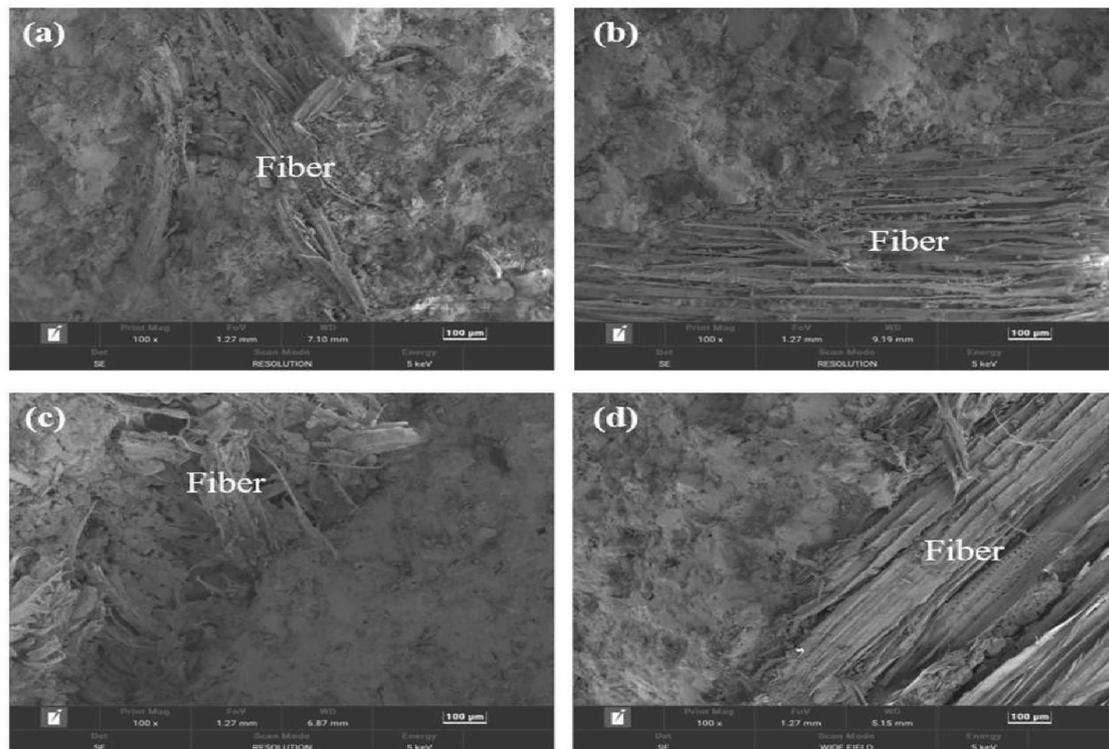


Fig. 8 SEM images of MOCB with various with different sizes of wood fiber (He et al., 2022)

Table 4 Effect of fiber types on water resistance of MOC composites

References	Fibers used	Effect on the water resistance of MOC
Li et al. (2023)	Polyformaldehyde (POM) fiber	The addition of POM fibers presented an excellent bonding effect with the MOC matrix, because the nanoscale cement crystal could grow in the micron-level pores of the fibers that were generated during the plasma treatment
Han et al. (2024)	Inorganic fibers	The addition of inorganic fiber improvement and several reinforcement networks not only reinforces the cohesive properties but also improves the chemical reactions and physical anchorage at the bonding interface
Shuiping et al. (2006)	Glass fiber	Glass fiber and Treatment of EVA improves the soft coefficients, namely, the improved water resistance and aging resistance while reducing the initial flexural strength of GF/MOC composites
Zhang et al. (2018)	Glass fiber and polypropylene fiber	The addition of polypropylene fiber with 0.37, 0.4, and 0.25% enhanced 7-day compressive strength and the softening coefficient up to 64.3 MPa and 0.93, respectively. Thus, enhancing the water resistance of MOC composites
Zhao et al. (2024)	Alkaline-resistant glass fiber (AR-GF)	The addition of alkaline-resistant glass fiber (AR-GF) into MOC composites shows a significant improvement in early mechanical strength and water resistance of MOC composites

ratio after 28 days of immersion in water. The lower alkalinity and high chloride content of MOC compared to the conventional concrete binders made it not widely used in concrete structures. It is not suitable for the protection of steel reinforcement against chloride and other aggressive environment (Wei et al., 2018). The different curing methods can affect the performance of cement-based materials (Sglavo et al., 2011; Silva

et al., 2013). Sglavo et al. (2011) stated that MOC pastes under ambient curing had higher compressive strength than those under low-temperature curing, such as 5 C or 10 C. Xia et al. (1991) reported that phase 5 might misplace two water molecules at about 72 C. Runc̆evski et al. (2014) stated that the dehydration of phase 3 happening nearby 80 C. Furthermore, Li et al. (2014) used the hot water immersion method, where

Table 5 Curing conditions used in the enhancement of water resistance of MOC composite

References	Curing conditions used	Effect on the water resistance of MOC composite
He et al., (2017b)	CO ₂ curing	The use of CO ₂ curing further enhances the properties of the MOC composite because of the production of a large quantity of amorphous gels
He et al. (2018)	Air and CO ₂ curing	The MOC composite content fly ash and glass powder treated by CO ₂ curing showed a high-water resistance because of creating amorphous gels mainly for the GP-blended MOC
Xu et al. (2016)	Ambient and high-temperature curing	The high-temperature curing resulted in micro-characteristic changes in the MOC composites and enhanced the water resistance more than that of ambient curing
Ye et al. (2018)	8 °C, 25 °C, 40 °C, and 55 °C	The curing temperature has a significant effect on the phase structure and mechanical strength of the MOC composites. As well as enhancing the water resistance of MOC
He et al. (2020b)	CO ₂ and air curing	The use of CO ₂ curing enhanced the water resistance and flexural strength of the MOC composite more than that of air curing

the water temperature was up to 75 °C for rapid assessments of the water resistance performance of MOC pastes, since the minor effect of temperature lowers 75 °C on crystalline construction of phase 5. Table 5 shows the curing conditions used in the enhancement of water resistance of MOC composite.

As shown in Table 5, the curing factor has an important role in the performance of MOC composites. It has a significant effect on the phase composition, long-term durability, and mechanical strength of MOC. As mentioned before, the different curing conditions, such as moisture-controlled curing, ambient curing, and heat-assisted curing, are important in their effects on hydration degree and strength development. According to previous studies, the optimum curing temperature is different and depends on many factors, such as a source of raw materials, curing conditions, the amounts of materials used, and others. For instance, Ahmad et al. (2024a) reported that for curing MOC composites, the relative humidity of 60 ± 5% and temperature of 24 ± 1 °C are the most appropriate. Han et al. (2022) concluded that an increase in curing temperature led to an increase in volume shrinkage compared with samples cured at 25 °C.

Xu et al. (2016) investigated the effect of the curing regimes, including various temperatures, on the mechanical characteristics of the MOC composite. They observed an important increase in the early age-compressive strength of MOC composite samples due to exposure to high-temperature curing. He et al. (2017b) investigated the effect of the use of pulverized fuel ash (PFA) on the water resistance of MOC in terms of volume stability and Strength retention coefficients. They observed that the use of PFA leads to an increase in the amorphous phase quantity, namely, magnesium–chloride–hydrate (M–Cl–H) gels and magnesium–chloride–silicate–hydrate (M–Cl–S–H) gels using air curing. During air curing, the addition of PFA to the MOC mortar can increase the expansion, while the addition of PFA

might reduce the expansion of cement mortar. Furthermore, the improvement of the MOC performance containing PFA could be obtained with a higher content of amorphous gels during the CO₂ curing. The compressive strengths of the MOC paste with various quantities of PFA in different curing ages have also been investigated. The author reported that the compressive strength values have been developed due to the increase in curing ages. The 14-day compressive strength obtained at air curing was 152.3 MPa, 124.3 MPa, and 118.5 MPa for MOC pastes containing 10, 20, and 30% of PFA, respectively. They concluded that the compressive strength of MOC samples cured with CO₂ was somewhat lower than that of samples cured without CO₂. Góchez et al. (2017) studied the conversion of MOC to chlorartinite and showed enhanced water stability of the cement. The MOC specimens have been exposed to hassled CO₂ to quicken the creation of chlorartinite on the cement surface. They observed that the untreated specimens convert to magnesium hydroxide (MgOH) due to exposure of the specimens to the deionized water. He et al., (2018) investigated the effect of pulverized fuel ash (PFA) and glass powder (GP) with and without CO₂ curing on the volume stability and strength retention coefficient. They observed that the use of PFA and GP in MOC pastes leads to an increase the water resistance after exposure to CO₂ curing due to the high amounts of amorphous gels.

In general, the curing process plays a significant role in the hydration and performance of MOC, directly influencing its mechanical strength, dimensional stability, and long-term durability, particularly water resistance (He et al., 2017b; Li et al., 2020). To achieve optimum performance, MOC requires a controlled curing strategy that balances moisture retention for phase development while avoiding prolonged water exposure. Dry curing in a controlled humidity environment (typically 50–60%) at ambient or moderately elevated temperatures (25–40 °C) has been identified as an effective approach

for promoting stable phase formation and minimizing the risk of water-induced degradation (Jing et al., 2024). Accelerated curing techniques, such as low-temperature heat curing or sealed curing, have also shown promise in enhancing early strength and reducing porosity. However, the ideal curing method may vary depending on additive types (such as phosphates and polymers) and mix composition.

4.5 Nanomodification

Regardless of all the advantages desired from using MOC, however, numerous issues are preventing to use of it as a structural material. Initially, MOC is not an appropriate medium for steel reinforcement because of its chemical nature has free or high content of chloride ions and low alkalinity with pH between 10 and 11. The high chloride content and low alkalinity will result in serious corrosion problems (Li & Chau, 2007; Maravelaki-Kalaitzaki & Moraitou, 1999). Recently, numerous efforts were conducted to increase the engineering and chemistry properties as well as the reaction mechanisms of MOC. Pang et al. (2022) used inorganic cementitious material to replace MOC because of its poor water resistance, which results in the migration of Cl^- to the surface. They used layers of magnesium aluminum to release the free Cl^- in MOC paste. The compressive strength increased by about 13–118% due to an increase in the $\text{Mg}_2\text{Al-LDH}$ content from 0.5 to 2.0%, and after that reduced by 24% due to an increase in the $\text{Mg}_2\text{Al-LDH}$ content to 2.5% compared to the control specimen. Consequently, the optimal $\text{Mg}_2\text{Al-LDH}$ content is 2% due to achieving the highest compressive strength and increasing it significantly up to 118%. Huang et al. (2021a) studied the effect of nano-silica, phosphoric acid, and FA additives on the thermal stability, water resistance, hydration process, setting time, and compressive strength of MOC in different

contents. They used X-ray diffraction (XRD), thermogravimetry analysis (TGA), Fourier-transform infrared spectroscopy (FTIR), and scanning electron microscopy (SEM) to examine the hydration products and microstructures. They observed that the compressive strength of MOC increased, and thermal stability decreased with a decrease in setting times due to the use of nano-silica in the MOC mixtures with phosphoric acid and FA. In addition, the combined usage of additives leads to important improvements in the water resistance of MOC mixtures. The development of amorphous gels generated by nano-silica addition leads to significant improvement of water resistance because of the secondary hydration of the $5\text{Mg}(\text{OH})_2 \cdot \text{MgCl}_2 \cdot 8\text{H}_2\text{O}$ (phase 5).

Incorporation of nano-silica into MOC mixtures leads to an acceleration of the setting time and accelerates the hydration of MOC paste, while the fly ash leads to delay it. In terms of water resistance also, they observed that the addition of nano-silica with FA and phosphoric acid to the MOC paste led to obtaining the highest water resistance of MOC after both immersion times. Table 6 shows the effect of nano-modifications on the water resistance of MOC composites.

Another study by Feky et al. (2022), investigated the effect of nano-silica content on the MOC pastes. They observed that the nano-silica as silica fume replacement was very valuable in increasing the MOC strength due to the increase in the quantity of manufactured M–S–H. The use of nano-silica improved the pore structure and compressive strength of MOC pastes. The addition of 5% nano-silica in the MOC mixture leads to an increase in the compressive strengths by 15 and 29% at 7 and 28 days, respectively. Zhou et al., (2022), they studied the effect of polyester (PEs) and hydroxyapatite (HA) to improve mechanical properties and water resistance of MOC. They concluded that a high water-resistant

Table 6 Effect of nano-modifications on the water resistance of MOC composites

References	Nano-modifications	Effect on the water resistance of MOC
Huang et al., (2021a)	Nano silica	The addition of nano-silica to MOC composites comprising phosphoric acid and fly ash enhances the water resistance of MOC paste. It also increases compressive strength and decreases the thermal stability and setting times
Jiříčková et al. (2024)	Nano-dopants	The addition of nano dopants led to the enhancement of the water resistance and mechanical strength of the MOC composites
Guan et al. (2019)	Nano-sized hydroxyapatite (n-HA)	The addition of n-HA to the MOC composites significantly enhances the water resistance of MOC. As well as they affect the strength loss and microstructure of MOC
Pivák et al. (2022)	Graphene nanoplatelets	An excellent improvement in the water resistance of MOC composites was made due to the addition of graphene nanoplatelets to the MOC composites. As well as the mechanical strength and high compactness were also improved
Huang et al. (2019)	Nano silica	The addition of nano-silica with phosphoric acid and silica fume resulted in a significant enhancement of the water resistance of MOC composites. In addition, the strength retention increased by 33.7% due to cured at the water for 56 days

MOC paste was effectively produced via an organic and inorganic hybrid strategy by combining HA and PEs. Meanwhile, the setting time was slightly increased and the mechanical properties of MOC were somewhat increased. Lauermannová et al. (2021b) investigated the influence of graphene's specific surface area on the properties of MOC composites. Their findings, illustrated in Fig. 9, indicate significant enhancements in both the mechanical and durability properties of the MOC–graphene composite. Specifically, the 7-day compressive strength increased by 31.2% for MOC-G300 and 42.7% for MOC-G750. At 14 days, the compressive strength also improved, rising by 14.3 and 26.5% for MOC-G300 and MOC-G750, respectively.

4.6 Joint Improvement Strategy

The joint improvement strategy in MOC aims to improve materials' performance by adding different additives and adjusting their composition. The addition of supplementary cementitious materials (SCMs) such as GGBFS, silica fume, and fly ash is one significant aspect of this strategy (Ahmad et al., 2024a). These by-product materials can partially replace the MOC, reducing shrinkage and increasing compressive strength. The synergistic influences of these wastes lead to a composite that influences the strengths of both MOC and SCMs. Another component of the joint improvement strategy is the addition of nano-materials and fibers into MOC. The use of nano-materials, including carbon nanotubes and nano-silica, can further refine the microstructure of MOC, leading to reduced porosity and better particle packing

(El-Feky et al., 2022; Jiříčková et al., 2023). Fibers such as carbon, basalt, and glass can substantially improve the fracture toughness and tensile strength of MOC, making it more resistant to deformation and cracking (Ahmad et al., 2024b; Yu et al., 2020; Zhao et al., 2024).

Li et al., (2008) used styrene–acrylic acid, stearic acid, copolymer emulsion, and phosphate to improve the physical properties of MOC floor tile. They observed that the materials additives can decrease the warp distortion and water absorption, and highly reduce the magnesium salt ratio in MOC floor tile. Li et al., (2021) suggested a new effective method to improve the water resistance of MOC pastes by taking sandpaper as a model with the alteration of luminescent powders. They found that the superhydrophobic (SHP) adjustment is useful for overcoming the reduced water resistance. They concluded that the composite produced has outstanding properties of established reusability, self-luminescence, and superhydrophobicity. Yang et al., (2022) used several materials to improve the Sawdust–MOC composite (SMOCC) containing modifiers, sawdust, and MOC. These materials are ethylene–vinyl acetate copolymer (EVA) emulsion, sodium phosphate (NaP), sodium hexametaphosphate (SHMP), tartaric acid (TA), and citric acid (CA). The results indicated that the setting times of SMOCC were delayed due to the addition of the modifiers, as well as the water resistance of SMOCC was improved due to inserting the crystal in water. SHMP has a positive effect in terms of improving the microstructure, and water resistance, maintaining the volume stability, and setting times of SMOCC.

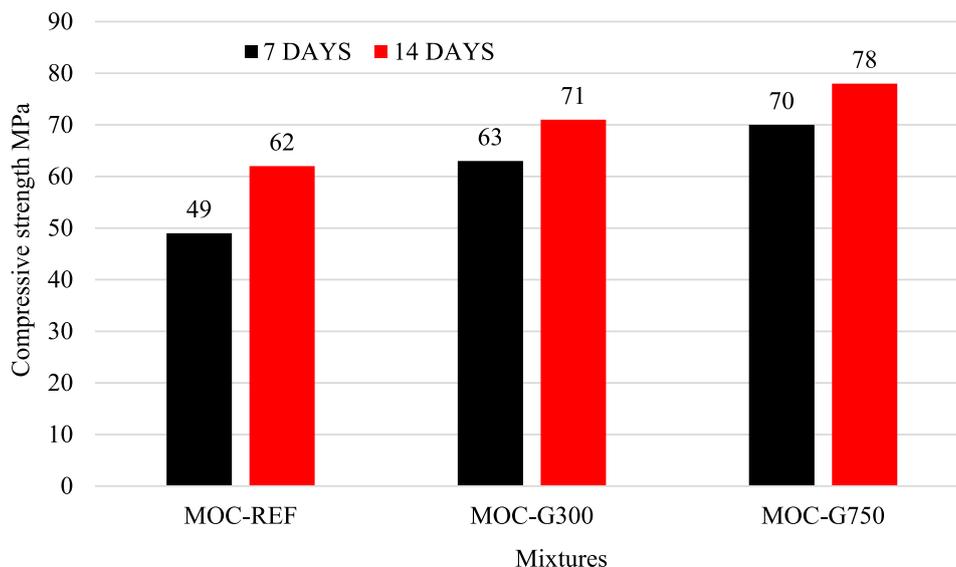


Fig. 9 Compressive strength of MOC–graphene composite at 7 and 14 days (Lauermannová, et al., 2021)

Pavlíková et al., (2020) used light-burned magnesia that was lightened by the expanded glass and granulated scrap tires. They used silica sand as a filler material with different proportions of 70, 80, 90, and 100% of granulated shredded tire replacement. The results obtained indicated that the expanded glass granulate assisted the improvement of lightweight materials with stiffness and adequate mechanical strength, low water permeability, durability, and improved thermal insulation in contact with water. Karimi and Monshi (2011) investigated various MOC pastes with fixed 12 mol of water and 13 mol of magnesium with various moles of magnesium chlorides ranging between 0.5 and 1.9. They adopted the SEM test to find out the microstructure of MOC samples. They observed that the needle-shaped crystals of phase 5 are responsible for the reinforcement of the matrix of these Sorel cements.

5 Future Trends of MOC

Magnesium Oxychloride Cement (MOC) has been explored over the last decade; however, it has not been extensively used as a cement material in the construction industry. The main reason beyond that is low water resistance (Deng, 2003). Therefore, researchers tried to solve this issue and enhance the water resistance of MOC. For instance, Tan et al. (2014) reported that MOC was used in different construction applications but these applications are still limited due to its poor water resistance. They used H_3PO_4 to enhance the water resistance of MOC and its ability to overcome degradation and provide a predictable and clinically appropriate resorption time. They observed that the crystalline phases in MOC before and after adding H_3PO_4 were the same, and the addition of H_3PO_4 considerably enhanced the water resistance of MOC. Even though the previous studies developed some strategies and materials to overcome this issue, the water resistance is still lower than that of cement.

MOC is gaining attention as a sustainable alternative to OPC due to its excellent mechanical properties and low carbon footprint (Jankovský et al., 2020; Maier & Manea, 2022). One of the future trends in MOC research is the exploration of incorporating waste materials and industrial by-products into MOC formulations (Pavlíková et al., 2022; Zhong et al., 2023). By utilizing materials, such as silica fume, GGBFS, and fly ash, researchers aim to enhance the durability and performance characteristics of MOC while also addressing environmental concerns related to waste disposal (Ahmad et al., 2024a). In addition, developments in nanotechnology may enable the incorporation of nanoparticles to improve MOC's mechanical properties, thermal stability, and resistance against chemical attacks (Lauermannová et al., 2022). For

instance, Jiříčková et al. (2024) in an attempt to reduce the global CO_2 footprint emissions and reduce the factors effect of climate change, investigated the effect of MOC as a binder material with different nano-dopants on the physical and mechanical properties of MOC-based composites. They found a significant improvement in mechanical properties due to the addition of nano-dopants. The addition of oxidized multi-walled carbon nanotubes led to the optimum compressive strength of 85.4 MPa of the MOC composite.

Another promising trend is the development of MOC for specialized applications, such as insulating materials and fire-resistant coatings (Ahmad et al., 2024a; Dai et al., 2023). MOC is composed to become a key component in constructing safer, energy-efficient buildings because of its inherent flame-retardant properties and thermal insulation capabilities. Furthermore, with the growing interest in additive manufacturing and 3D printing in construction, MOC's rapid setting time and excellent binding properties make it a suitable candidate for printing complex structures (Cui et al., 2021; Salari et al., 2022). As the construction industry moves towards greener and more sustainable practices, MOC's versatility and eco-friendly attributes are likely to drive its adoption in various applications, paving the way for innovative building solutions.

6 Conclusions and Recommendations

This paper reviewed the results obtained from the previous studies that addressed the materials and methods to improve the water resistance of MOC and examined the alteration methods. The key conclusions were shortened as follows:

1. MOC is a type of high-performance cement; however, it is not widely applied in construction projects due to its water resistance is low; therefore, the modification of water resistance is the most significant issue that needs to be solved.
2. MOC has numerous properties that make it important and suitable for many construction applications, such as an early high strength, rapid hardening, high resistance to abrasion, low thermal conductivity, and increasing fire resistance. For instance, the addition of *D*-gluconic acid sodium salt into MOC mortar increased the compressive strength by 24% and increased the initial and final setting times of MOC mortar.
3. The use of some soluble phosphates in MOC leads to improving the water resistance of MOC. Consequently, the strength retention coefficients of hardened MOC pastes are increased with the increase of

the mass fraction of the phosphates added into the MOC pastes. The phosphates have a positive effect on the increase of water resistance for the MOC mix. For instance, the compressive strength of MOC increased up to 0.8 MPa due to the addition of 0.5–1.0% soluble phosphates into the MOC mix.

4. The addition of different additives can improve the durability of MOC. Phosphoric acid (H_3PO_4) is one of the additives that could increase the water resistance of MOC considerably. The influence of sodium mono-fluoro-phosphate (MFP) as a modifier to improve the water resistance of MOC. The setting times and fluidity of the MOC pastes mixed with phosphates showed an obvious increase from 68 to 118 mm.
5. The compressive strength of MOC increased, and thermal stability decreased with a decrease in setting times due to the addition of nano-silica to the MOC mixtures with phosphoric acid and FA. In addition, the combined usage of additives leads to important improvements in the water resistance of MOC mixtures.

Finally, it is recommended to conduct further investigation by integrating different waste materials to enhance the water resistance of MOC mixtures. Finally, it is recommended to conduct further investigation by integrating different waste materials to enhance the water resistance of MOC mixtures. For instance, it is recommended to insert GGBFS with fly ash at different replacement levels. The use of natural fiber instead of industrial ones, such as cotton fiber and sisal fiber, to improve the performance of MOC composite and enhance sustainability in the construction industry, is also recommended.

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Author contributions

Hussein Hamada wrote the main manuscript, editing, conceptualization, supervision, and investigation. Alyaa Al-Attar supervised and participated in writing the main manuscript. Mand Askar reviewed this paper and edited the final paper. Salmia Beddu funded the work and supervised to writing. Ali Majdi participated in the methodology and data collection sections. Finally, all authors read and reviewed the final article version.

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Availability of Data and Materials

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Declarations

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Competing interests

Not applicable.

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