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Synergistic effects of curing conditions and magnesium oxide addition on the physico-mechanical properties and firing resistivity of Portland cement mortar

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H I G H L I G H T S

- Cement mortars with or without MgOs were cured in different conditions.
- Different curing media were used, i.e. Tap water, normal, and accelerated carbonations.
- The performance of cement mortar depends on synergistic MgO and curing conditions.

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An experimental investigation was performed to evaluate the impact of curing conditions on the physico-mechanical properties and firing resistivity of cement mortar (CM) containing reactive magnesium oxide (MgO). Three different curing media including Tap water (TW), normal carbonation (NC) and accelerated carbonation (AC), have been applied. Two MgOs with different reactivity were used (MgO550 and MgO1250); where, 550 and 1250 are referred to the calcination temperatures applied on hydromagnesite. 10 mass % of MgO550 as well as MgO1250 were individually added to CM. The cured CMs were exposed to different elevated temperatures (250, 500 and 750 °C) for 2 h soaking time. The phases composition and microstructure of CMs were investigated via Fourier transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD), thermogravimetric analysis (TGA) and scanning electron microscopy (SEM) techniques. The results proved that the physico-mechanical properties and firing resistivity of control CM without MgOs cured in TW were superior to those exposed to NC and AC. The MgOs have detrimental impact on the properties of TW-cured-CM, due to the formation magnesium silicate hydrate with lower binding capacity compared to calcium silicate hydrate. Interestingly, the CM-MgOs cured in AC or NC showed the highest mechanical properties as well as firing resistivity compared to control sample at the same curing media, respectively. In AC and NC, the MgO1250 has a higher impact on compressive strength development and firing withstanding of CM compared to MgO550. The optimum curing condition and MgO type, which gave the highest engineering properties and the highest resistivity to elevated temperature were AC and MgO1250.

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1. Introduction

Concrete is widely distributed as important structural material in construction due to several advantages including strength,

durability, ease of production, and firing resistivity properties. Concrete was found to have higher sensitivity to curing conditions, affecting its physico-mechanical properties [1,2]. Curing conditions and temperature are delicate parameters affecting the concrete performance. The application of water curing has potential effect on the compressive strength development of cementitious materials compared to water and air curing [3–5]. Other researchers [6–8] found that the concretes containing nano sized materials cured in $\text{Ca}(\text{OH})_2$ saturated-media have higher engineering properties compared to those cured in water.

Although concrete, in general, has a high resistance to fire, its mechanical properties such as strength and elastic modulus decrease when subjected to high temperatures. The exposure of cement concrete to elevated temperatures leads to a significant variation in its microstructure [9,10]. Free water starts to evaporate when concrete subjected to temperature of 105 °C. The dehydration of hydrated products (ettringite and gypsum) takes place in the temperature range of 80–170 °C [11]. At 300 °C, the chemically combined water begins to dissociate which in turn leads to compressive strength regression. Further increase in temperature up to 600 °C causes the dehydroxylation of portlandite. Evidently, the compressive strength rapidly decreased when the concrete exposed to temperature beyond 400 °C, illustrating the calcium silicate hydrate (CSH) decomposition. The second CSH phase decomposes at the temperature range of 600–800 °C, yielding $\beta\text{-C}_2\text{S}$ [11]. A complete degradation of CSH was recorded at 900 °C. This leads to thermo-mechanical damage, weight loss, spalling and cracking [12–18]. The firing resistivity of concrete can be enhanced by the addition of some additives [19,20]. Supplementary cementitious materials such as silica fume and slag have a positive impact on the microstructure densification caused by the interaction of silicate with portlandite (CH) (liberated during cement hydration) leading to form additional CSH yielding low permeable concrete. This contributes in the enhancement of concrete performance under elevated temperatures [10,21–31]. As stated by Heikal et al. [32], the addition of 1% nano-alumina has a positive effect on the firing resistivity of cement mortar. Other researchers [33] found that the addition of 1% nano-iron oxide enhances the resistivity of cement pastes towards firing up to 450 °C. As extension research, no spalling detected after the exposure of $\text{Ca}(\text{OH})_2$ -sludge-silica fume-nano silica-cement paste composites to fire up to 800 °C [34].

Dead burnt magnesium oxide (MgO) regarded as the harmful ingredient for Portland cement (PC), due to its lower hydration rate compared to cement phases. Where it hydrates at later age of hydration after cement hardening, forming brucite or expansive magnesium hydroxide $\{\text{Mg}(\text{OH})_2\}$, which results in 118% volume increase [35], causing cracks formation [36]. The hydration reactivity and expansive property of MgO mainly depends on the calcination temperature [37]. Where, the light burnt MgO possess higher hydration property comparing with dead burnt MgO [38]. The addition of reactive MgO does not causes soundness or cracks formation in concrete [39], referring to the hydration of light burnt MgO at early age with the main cement phases [39]. A reduction in compressive strength was detected in MgO-cement, due to the formation of $\text{Mg}(\text{OH})_2$ and magnesium silicate hydrate with lower binding capacity comparing with calcium silicate hydrate [38–41]. A significant enhancement in compressive strength have been

recorded after exposure cement mortar-MgO to accelerated carbonation [42,43]. Up till now there is no study dealt with the impact of curing conditions and MgO reactivity on the mechanical properties and firing resistivity of cement mortar.

So, the present work aims at studying the synergistic impact of curing media and MgOs addition on physico-mechanical properties and firing resistivity of cement mortar have been evaluated. The MgO with different reactivities were individually added to cement mortar namely MgO550 and MgO1250. Cement mortars with or without MgOs were cured in three different media such as Tap-water, atmospheric air (normal carbonation) and 100% CO_2 (accelerated carbonation). After 28-days of curing, cement mortars were exposed to elevated temperatures such as 250, 500 and 750 °C. Different experimental and instrumental methods were applied to elucidate cement mortar with high engineering properties as well as high firing withstanding.

2. Experimental program

As main raw materials, ordinary Portland cement (OPC), sand and hydromagnesite (HM) were used in this investigation. OPC was brought from Benisuif Cement Company, Benisuif, Egypt, HM was purchased from El-Gomhouria Chemical Company, Cairo, Egypt, and sand was obtained from El-Wasta Area, Benisuif, Egypt. The chemical compositions of OPC, sand and HM are given in Table 1. The X-ray diffractograms (Fig. 1) shows that the OPC is mainly composed of crystalline peaks related to clinker minerals such as di- and tri-calcium silicate (C_2S , C_3S and tetra-calcium ferroaluminate (C_4AF) as well as anhydrite (CaSO_4); meanwhile sand is completely composed of quartz. The MgO was prepared by the calcination of hydromagnesite (HM) at 550 and 1250 °C for 2 h soaking time, producing two-MgOs with different reactivities which labeled as MgO550 and MgO1250. As shown in Fig. 2, the intensity of the crystalline MgO1250 peak is found to be higher than that of MgO550. Also, the broadness of MgO550 peak is greater than that of MgO1250. Scanning electron microscopy (SEM), proved the calcination of HM at 550 °C leads to form

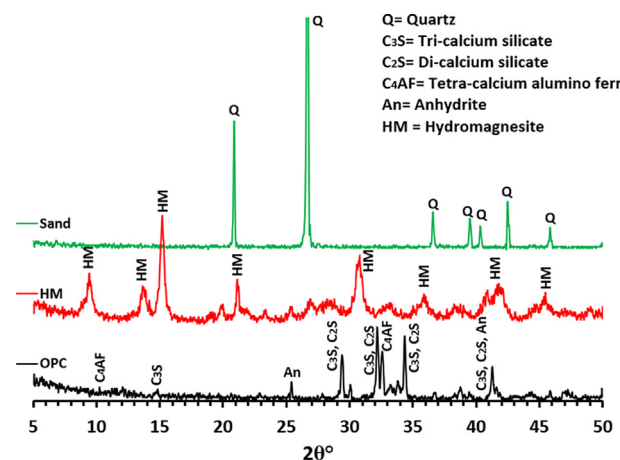


Fig. 1. XRD-patterns of sand, HM and OPC.

Table 1
Chemical composition of ordinary Portland cement and hydromagnesite.

Oxide, %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	TiO_2	P_2O_5	L.O.I	Total
OPC	20.51	4.86	3.72	62.80	2.35	0.12	0.08	2.14	0.04	0.05	2.35	99.92
Hydromagnesite	0.09	0.08	0.01	0.40	42.95	–	0.18	0.04	–	0.03	56.19	99.94

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