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# Compressive strength of fly ash magnesium oxychloride cement containing granite wastes

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## HIGHLIGHTS

- Granite waste and fly ash are incorporated into magnesium oxychloride cement (MOC).
- The water absorption of granite waste from the slurry results in increased hydration product of $5\,Mg(OH)_2{\cdot}MgCl_2{\cdot}8H_2O$.
- The excess water absorption of granite waste from low-concentration brine leads to compact microstructure of GFMOC, whereas from the high concentration of brine leads to porous microstructure.
- The sound composition and compact microstructure of the hydration product lead to high compressive strength of GFMOC.
- Incorporated granite waste can increase the compressive strength of fly ash MOC.

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## ABSTRACT

This paper presents the results of an experimental investigation on compressive strength of granite waste fly ash magnesium oxychloride cement (GFMOC). Various GFMOC specimens were prepared with 23°Bé or 25°Bé brine and different proportions of granite fragment (GF) or granite sludge (GS) ranging from 0% (for the control mixture) to 40% of magnesia weight. Compression tests were conducted at the age of 3, 7, and 28 days. The hydration products and paste microstructure were analyzed by XRD and SEM, respectively. The results demonstrated that the water absorption and filling role of the fine particles of granite waste in GFMOC slurry are favorable for $5\,Mg(OH)_2{\cdot}MgCl_2{\cdot}8H_2O$ (P5) and dense microstructure, respectively. The quantity ratio of P5 to $Mg(OH)_2$ (MH) and microstructure are important factors responsible for the compressive strength of GFMOC. The incorporation of granite wastes as aggregate can increase the compressive strength of fly ash magnesium oxychloride cement (FMOC).



## 1. Introduction

Magnesium oxychloride cement (MOC) is an air-dried, magnesia-based cementitious material developed not long after the invention of Portland cement (PC) [1]. MOC is used extensively in residential and industry applications due to its advanced performance compared with PC. The characteristics of quick hardening and high early strength make MOC an ideal material for quick repairs [2]. Due to its qualities of fire resistance, low thermal conductivity, and good resistance to abrasion, MOC is commonly used for door frames [3], beams [4], fireproof materials [5], thermal insulation materials [6], floor tiles [7,8], and grinding wheels [9,10], among others. MOC is also suitable for incorporation in a variety of organic and inorganic aggregates, which enables it to be able to solidify municipal waste [7] and fix sewage sludge [11]. The ability of MOC to manage solid wastes facilitates recycling and reduces the cost of MOC products.

MOC is obtained by mixing magnesia powder with brine (magnesium chloride solution). MOC is a by-product of hardened neat cement slurry of the $MgO–MgCl_2–H_2O$ ternary system; however, it has high water solubility and bad dimensional instability [2,12,13]. It is necessary to add various additives and fillers into the MOC neat cement slurry to improve water resistance and to avoid expansion-related problems [2–4,14]. For instance, the addition of a small quantity (for example, 1% by weight of magnesia) of phosphoric acid or soluble phosphates ($NaH_2PO_4{\cdot}2H_2O$ or $NH_4H_2PO_4$) can greatly improve the water resistance of MOC [14]. According to Li et al. [2], the incorporation of fly ash into

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MOC can enhance the workability or fluidity, retard the setting time, and improve the water resistance while unexpectedly reducing the final compressive strength of the MOC mortars. In the MOC mortars, the more fly ash is added, the lower the compressive strength [2]. The compressive strength of MOC mortar has been found to decrease by about 35% when 30% of fly ash by weight of magnesia is incorporated [2]. However, there has been no explanation why this phenomenon happens [2]. Obviously, the physical and chemical properties of MOC, such as compressive strength, volume stability, and water resistance, are modified by various chemical or/and physical effects of the additives and fillers in the hydration processes.

Granite have diverse applications because of its versatile characteristics, such as high durability and resistance to scratches, stains, cracks, spills, heat, cold, and moisture. Unfortunately, a considerable and increasing amount of solid wastes from granite industries are generated in cutting and polishing [15]. These wastes are currently disposed in landfills with increasing cost and negative environmental impact, which affects the economic and environmental sustainability of such industrial productions, as well as public health [16].

In recent decades, environmental considerations have become a main concern, and efforts to reuse granite wastes have been undertaken. A number of previous studies have shown that granite residues have high potential as raw materials in the ceramic industry [15,17–19] and as aggregates in the building material industry [20–22]. For example, red clay roof tiles incorporated with granite wastes can reduce water absorption without increasing sintering temperature and pyroplastic deformation [15]. According to Binici et al. [20], granite residues as aggregates can be applied to improve the mechanical properties, workability, and chemical resistance of conventional concrete mixtures. Granite wastes are effective fillers and pozzolanic materials for mortars and concrete due to the ability to ameliorate the mechanical properties and corrosion resistance of mortars and concrete by improving compactness [20,21]. To the best of our knowledge, however, the effect of incorporating granite wastes into MOC has not been reported in recent literature.

Taking into account all the above-mentioned factors, this paper is dedicated to the investigation of the incorporation of granite wastes in fly ash magnesium oxychloride cement (FMOC) formulations. The effects of brine concentration, granite waste amount, and particle size distribution (PSD) on the compressive strength, hydration products, and microstructure of granite waste fly ash magnesium oxychloride cement (GFMOC) are discussed in detail. The final objective of this work is to examine the feasibility of using granite wastes as aggregate to improve the compressive strength of FMOC.

## 2. Experiments

### 2.1. Raw materials

#### 2.1.1. Light-burnt magnesia

The light-burnt magnesia used in this experiment was produced by Haicheng Magnesium Cement Mining, Ltd. (Liaoning Province, China). The active MgO, which hydrated at 105 °C and 101.3 KPa [23], was 60.0% by weight. The chemical compositions of the light-burnt magnesia by X-ray fluorescence (XRF, Axios PW4400) are summarized in Table 1 and the mineralogical compositions are shown in Fig. 1 by X-ray diffraction (XRD, PANalytical X'PRO Pert). The light-burnt magnesia mixture contains magnesia, magnesite, and minor amounts of quartz and calcite. The crystalline phases identified by XRD are in accordance with the results obtained by XRF (Table 1).

**Table 1**
Chemical compositions of the raw materials, as determined by XRF (wt.%).

| | $Al_2O_3$ | $SiO_2$ | MgO | $Fe_2O_3$ | CaO | $Na_2O$ | $K_2O$ | Others |
|---|---|---|---|---|---|---|---|---|
| Magnesia | 0.15 | 6.07 | 80.20 | 0.41 | 1.30 | – | – | 11.87 |
| Fly ash | 37.70 | 49.90 | 0.54 | 4.38 | 3.74 | – | – | 3.74 |
| Granite sludge | 10.42 | 57.58 | 0.58 | 2.06 | 1.85 | 3.29 | 3.42 | 20.80 |

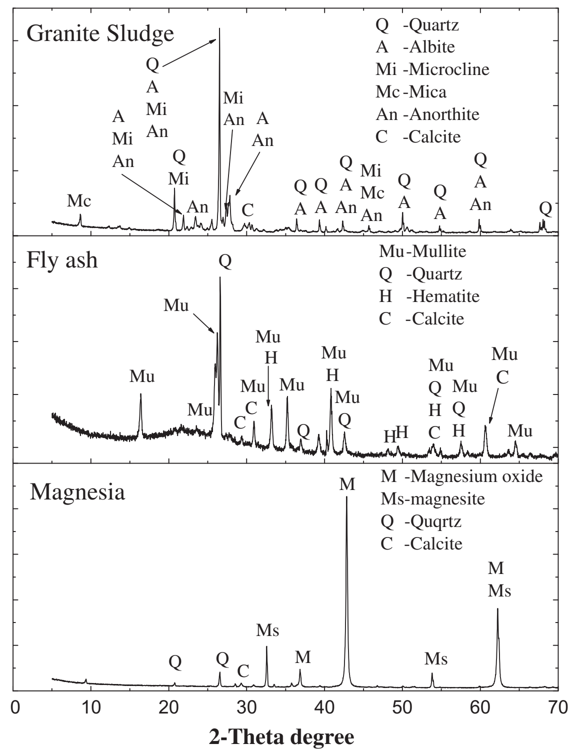


**Fig. 1.** XRD pattern of the raw materials (Cu Kα radiation at 40 kV/30 mA, scan rate: 0.02°/s).

#### 2.1.2. Brine

The brine was prepared by dissolving bischofite in tap water. The bischofite was produced by Jiayoumeiye, Ltd. (Qinghai Province, China) with 98.4% purity.

#### 2.1.3. Fly ash

Fly ash is commonly used as aggregate in MOC [2,3]. In this experiment, 20% fly ash (by weight of light-burnt magnesia) was added into the GFMOC specimens to improve the workability and water resistance of the MOC mortars [2]. However, the workability and water resistance of GFMOC are not reported in this paper. The chemical and mineralogical compositions of fly ash are shown in Table 1 and Fig. 1, as detected by XRF and XRD, respectively. The result of XRF shows that fly ash mainly consists of $SiO_2$ (49.90%) and $Al_2O_3$ (37.70%), together with secondary amounts of $Fe_2O_3$, CaO, and MgO. The mineralogical compositions of fly ash are mullite and quartz mixed with a small quantity of hematite and calcite. The chemical compositions obtained by XRF are in line with the mineralogical compositions by XRD.

#### 2.1.4. Granite waste

Granite fragments (GF) from sawing the block and granite sludge (GS) from polishing the slab were supplied by Lindun Quarry of Changtai County (Fujian Province, China). The as-received GS containing about 40% moisture was sun-dried. The dried GS's