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# Preparation and characteristics of magnesium phosphate cement based porous materials

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## HIGHLIGHTS

- Preparation of high strength porous MPC materials with compressive strength 2–15 MPa.
- Chemically foaming process was adopted for preparing of MPC based porous materials.
- Metallic zinc powder was used as the air entraining agent.

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## ABSTRACT

Magnesium phosphate cement based porous materials (MPCPM) were prepared by means of a chemical foaming process using zinc powders as foaming agent. The influence of the zinc content, W/S ratio and particle size of ammonium dihydrogen phosphate (ADP) on the viscosity, temperature evolution, compressive strength, flexural strength and thermal conductivity of the MPCPM was investigated. The results indicate that with higher content of zinc powder and W/S ratio, a longer hardening time of slurry, higher viscosity values, lower hydration temperature, less mechanical strength and lower thermal conductivity of the MPCPM can be obtained. The effects of the particle size of ADP on the properties of MPCPM are analogous to those of the content of zinc powder and W/S. Strong linear relationships can be found between the dry density or porosity and the compressive strength or thermal conductivity of prepared porous materials. The results also show that the MPCPM has good potential to be used for fireproofing doors and high temperature furnace insulation lining due to its light weight, high strength, and thermal and acoustic insulation.



## 1. Introduction

As is well known, cement based porous materials have network systems made up of pores and the walls beside them, and mainly include cellular aerated concrete, foam concrete and other porous cement pastes or mortars [1]. Due to their light weight, saving in materials, good heat insulation, sound absorption, and seismic resistance, porous cement based materials have been widely used in civil infrastructures for thermal insulation, noise absorption and heavy metal removal from industrial waste water [2,3]. Cement based porous materials are prepared by either a pre-foaming process or a gas-foaming process. The pre-foaming process, which is also called a physical foaming process, involves producing a base mixture and stable preformed aqueous foam separately and then stirring fast and thoroughly to blend the foam into the base mixture [4,5]. In addition, the physical foaming process requires the use of a compressed air machine to create pre-formed air bubbles that are added to freshly mixed concrete to create a cellular structure. In general, this process is simple to conduct, standardized and widely used, but the porous materials tend to have low strength [6]. In the gas-foaming process, often called the air-entraining process, gas-foaming chemicals are mixed into slurry during the liquid or plastic stage and then hydrogen, oxygen and acetylene are generated, which leads to a considerable increase of volume when aluminum powder, hydrogen peroxide and calcium carbide react with the slurry, until finally a porous structure is obtained after the gas has escaped [7]. In this method, metallic powders such as Al, Zn or liquids like $H_2O_2$ are the most common air entraining agents [8].

Magnesium phosphate cement (MPC) is a type of chemically bonded ceramic, as these are high-strength materials formed through a solution acid based reaction between dead burnt

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magnesia and phosphate at low temperature [9]. MPC shows many superior properties compared with Portland cement, such as faster setting time, stronger bonding strength with other materials [10], higher early strength [11,12,10,13], lower drying shrinkage [14] and excellent frost resistance [15]. It has thus been widely used in many fields for many years, such as the repair and rehabilitation of damaged structures, physical solidification or stabilization of heavy metallic ions and nuclear waste, or bone restoration [16–19]. In recent years, more and more interest has focused on the magnesium phosphate cement based porous material. Li and Chen prepared MPC foam concrete by a pre-foaming process, where the dry density, compressive strength and thermal conductivity of porous materials ranged from 210 to 380 kg/m$^3$, from 1.0 to 2.8 MPa and from 0.049 to 0.070 W/m K, respectively [20]. Liu et al. also prepared high porosity magnesium phosphate paste (HPMPP) via the pre-foaming method, where the bulk density, maximum compressive strength and the porosity of the HPMPP reached 464.00 ± 5.00 kg/m$^3$, 0.30 ± 0.05 MPa and 83.75%, respectively, according to the water to solids ratio (W/S) of 0.32 [21].

In the current study, a special magnesium phosphate cement based porous material (MPCPM) with high strength was prepared by the chemical foaming process, and zinc powder was selected as the gas-foaming agent. Compared to the traditional Portland cement based porous material, MPCPM has many advantages such as faster strength development, higher final strength, better resistance to high temperature and so on. As a result, MPCPMs have the potential to be used as a core material for fireproofing doors and high-temperature furnace insulation lining.

The effects of the zinc powder content, water to solid ratio (W/S) and particle size distribution of ammonium dihydrogen phosphate on fresh mortar, the mechanical properties, porosity and thermal conductivity of the MPC based porous material, as well the optical micrographs of the porous materials were all systematically investigated in this paper.

## 2. Experimental details

### 2.1. Materials and mix proportions

In this work, the raw materials for the MPC based porous material preparations were dead burnt magnesia (MgO), analytical reagent ammonium dihydrogen phosphate (ADP), quartz powder (as filler material), zinc powder, borax and water. Dead burnt magnesia powder was obtained by calcining magnesium carbonate at 1700 °C, and was supplied by Liaoning Xinrong Mining Co., Ltd., China. The chemical composition of the dead burnt magnesia is shown in Table 1 and its median diameter is 29 μm. ADP was provided by Jinshan Chemical Reagent Co., Ltd. of Chengdu, China. The median diameters (d50) of the ADP are 600 μm ($d_{0.6}$), 100 μm ($d_{0.1}$) and 60 μm ($d_{0.06}$). Quartz powders were prepared by ball-milling quartz and the median diameter of the powder is 20 μm. Borax ($Na_2B_4O_7{\cdot}10H_2O$) was used as a retarder in this study. The mix proportions of the prepared MPCPM are given in Table 2. As listed in the table, the zinc powder and W/S ratio ranged from 0.3% to 0.8% and from 0.14 to 0.18, respectively. It should be pointed out that M/P and M/F represent the mass ratio of magnesia to ADP, and magnesia to quartz powder, respectively. Besides, the borax and zinc powder were weighed by the mass of the magnesia and all the solid powders, respectively.

### 2.2. Testing methods

MPCPM was prepared according to the mix proportions listed in Table 2. The mixing procedure is conducted in a vertical-axis planetary mixer. Dead burnt magnesia powder, ADP powder and quartz powder were mixed for 1 min at first, and then water was added and stirred for 1 min, and finally zinc powder was mixed with them and stirred rapidly for 90 s. After mixing, specimens were cast immediately into steel moulds with a size of 40 × 40 × 160 mm. The as-prepared samples were cut and demoulded after 1 h, then cured in the lab at a temperature of 20 ± 2 °C and a relative humidity of 60 ± 5%. The compressive strength was tested at 1, 7, 14 and 28 days by a microcomputer controlled universal testing machine (CMT5105, Shenzhen SANS Testing Machine Co., Ltd, China) with a loading rate of 2.4 kN per second according to Chinese standard GB17671-1999. The temperature evolution of the fresh MPCPM was measured through a miniature temperature recorder (RC-4, Elitech, China). The viscosity of the fresh specimens was measured by a rotational viscometer (NDJ-8S, Jingtian Electronic Instrument Co., Ltd., China). Thermal conductivity was measured by a thermal conductivity meter (JW-III, ORIENT ODA, China) and panel-shaped specimens with size

**Table 1**
Chemical composition of dead burnt magnesia/%.

| MgO | $Al_2O_3$ | $SiO_2$ | $P_2O_5$ | $SO_3$ | CaO | $Cr_2O_3$ | MnO | $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|---|
| 91.70 | 0.53 | 4.18 | 0.29 | 0.02 | 2.20 | 0.04 | 0.04 | 1.01 |

**Table 2**
Mix proportions of MPCPM.

| Mix no. | M/P | M/F | $d_{50}$ of ADP (μm) | Borax (%) | Zn (%) | W/S |
|---|---|---|---|---|---|---|
| $M_{I\text{-}1}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.3 | 0.16 |
| $M_{I\text{-}2}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.4 | 0.16 |
| $M_{I\text{-}3}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.5 | 0.16 |
| $M_{I\text{-}4}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.6 | 0.16 |
| $M_{I\text{-}5}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.7 | 0.16 |
| $M_{I\text{-}6}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.8 | 0.16 |
| $M_{II\text{-}1}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.5 | 0.14 |
| $M_{II\text{-}2}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.5 | 0.15 |
| $M_{II\text{-}3}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.5 | 0.16 |
| $M_{II\text{-}4}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.5 | 0.17 |
| $M_{II\text{-}5}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.5 | 0.18 |
| $M_{III\text{-}1}$ | 1 | 1/2 | 600 ($d_{0.6}$) | 10 | 0.5 | 0.16 |
| $M_{III\text{-}2}$ | 1 | 1/2 | 100 ($d_{0.1}$) | 10 | 0.5 | 0.16 |
| $M_{III\text{-}3}$ | 1 | 1/2 | 60 ($d_{0.06}$) | 10 | 0.5 | 0.16 |