



Research Paper

Influence of Fe powders replacing Cu powders on the thermal and mechanical properties of aluminate cementitious thermal energy storage materials at high temperature



Aihong Du, Huiwen Yuan, Wei Liao, Haobo Zhou, Chunhua Lu^{*}, Zhongzi Xu

Jiangsu National Synergetic Innovation Center for Advanced Materials (SICAM), State Key Laboratory of Materials-Oriented Chemical Engineering, College of Materials Science and Engineering, Nanjing Tech University, Nanjing 210009, China

HIGHLIGHTS

- Fe powders replacing Cu powders is first proposed.
- The optimal results are gained when the content of Fe powders substitution is 10 wt%.
- Fe powders replacing Cu powders is more effective especially at high temperature.

ARTICLE INFO

Article history:

Received 18 June 2016

Revised 17 November 2016

Accepted 19 November 2016

Available online 21 November 2016

Keywords:

Cementitious materials

Thermal energy storage

Fe powders

Cu powders

Properties

ABSTRACT

Cost-effective thermal energy storage materials are vital to the application of solar thermal power plants. One focus of this paper is improving thermal and mechanical properties of the thermal energy storage materials; the second focus lies in reducing the investment cost. On the basis of aluminate cementitious composites with 1 wt% nano-SiO₂, 1 wt% nano-Cu and 15 wt% Cu powders, we introduced different wt% (0, 5, 10, and 15) of Fe powders to gradually replace 15 wt% Cu powders. The samples were heated at 105, 350, and 900 °C, respectively. As a result, when the content of Fe powders substitution was 10 wt%, volume heat capacity, thermal conductivity and compressive strength of the composites after heat-treatment at 900 °C were up to 2.38 MJ m⁻³ K⁻¹, 1.45 W m⁻¹ K⁻¹, and 73.8 MPa respectively, which were 26.6%, 26.1%, and 24.0% higher than those of the composites with 15 wt% Cu powders. At the same time, the investment of the composites with 10 wt% Fe powders substitution was reduced almost 62.0%, compared with that of the composites with 15 wt% Cu powders. In addition, XRD and MIP were employed to characteristic the mineral phases and the pore structures of the aluminate cementitious composites, respectively.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Nowadays, the energy crisis and environmental pollution have caused extensive concern. As a clean and renewable energy, solar is researched to relieve the energy and environmental problems [1–3]. We are making use of solar energy in many fields, mainly in power generation. Solar thermal power is currently regarded as an attractive technology to generate electricity without any pollution [4–7]. However, the limitations of solar technology have seriously hindered the application of solar. Firstly, solar technology is easily affected by weather conditions and the change of day and night. Secondly, the investment cost is so high that solar cannot be

applied widely [8–10]. Therefore, thermal storage technology becomes an excellent and necessary measure to ensure the safe and stable operation of electrical power system [11,12]. Of course, thermal storage materials, as the core of thermal storage technology, becomes the object of this paper to be researched for speeding up the application of solar thermal power plants.

Among previous numbers of solutions to preparing thermal storage materials, using concrete/cement as solid thermal storage materials is most promising just due to its advantages of low-cost and good thermal stability [13–15]. In particular, aluminum cement has strong corrosion and thermal shock resistance. While the volume heat capacity and thermal conductivity of aluminum cement cannot meet the application requirement [16,17]. Some efforts have been made to improve the efficiency of energy storage by incorporating functional materials such as nano-particles

^{*} Corresponding author.

E-mail address: chhlu@njtech.edu.cn (C. Lu).

[16,17], metal powders [18,19], fly ash [20,21], fibers [22,23] and so on. At present, it is considered that the usage of metal powders is an effective method to improve the performance of solid thermal storage materials, because the thermal properties of metals is excellent. In the previous research, incorporating different wt% (0, 5, 10, and 15) of Cu powders based on the content of nano-SiO₂ and nano-Cu particles respectively remaining a constant at 1 wt% has been studied. Meanwhile, it showed that volume heat capacity and thermal conductivity both increased with the content of Cu powders increasing and the optimum thermal properties were acquired at 15 wt% [18]. Unfortunately, though the addition of Cu powders in the previous research has achieved better effects, the investment cost of thermal storage materials will be much high in the practical engineering. This is not conducive to promoting the widely application of solar power plants. What is more, the properties of thermal storage materials need to be further improved. Besides Cu, Fe is also available to the further research. First of all, volume heat capacity of Fe powders is about $3.52 \text{ MJ m}^{-3} \text{ K}^{-1}$, which is higher than that of Cu powders. Volume heat capacity of Cu powders is about $3.45 \text{ MJ m}^{-3} \text{ K}^{-1}$. Furthermore, volume heat capacity of Cu₂O and CuO is about 2.72 and $3.33 \text{ MJ m}^{-3} \text{ K}^{-1}$, respectively. And that of Fe₂O₃ and Fe₃O₄ is 3.43 and $3.32 \text{ MJ m}^{-3} \text{ K}^{-1}$, respectively. In addition, Fe/Cu oxidized can provide a volume compensation effect, thereby improving the density of the composites. What is more, the cost of Fe powders is nearly one tenth of Cu powders.

Based on the optimal experimental ratio of the previous research, this paper mainly discusses about the influence of different wt% (0, 5, 10, and 15) of Fe powders replacing 15 wt% Cu powders on thermal and mechanical properties of the aluminate cementitious composites. As yet, few subjects about Fe powders replacing Cu powders introduced into aluminate cementitious materials have been reported. In this paper, heat-treatment temperature was executed at 105, 350, and 900 °C, respectively. Volume heat capacity, thermal conductivity, thermal expansion coefficient as well as compressive strength were specified in this paper. Moreover, X-ray powder diffraction (XRD) and mercury intrusion porosimetry (MIP) were acquired to characterize the phases and the pore structure of composites, respectively. The optimal properties of the composites with Fe powders substitution will lay foundation for the further research on thermal storage materials and promote the application of solar thermal power plants.

2. Experimental

2.1. Materials and sample preparation

The composites were mixed with aluminate cement, nano-SiO₂, nano-Cu, Fe powders, Cu powders and water-reducing. Aluminate cement supplied by Zhengzhou Yuxiang Special Cement Plant in China was selected as a binding agent. The chemical compositions of aluminate cement were indicated in Table 1. Amorphous nano-SiO₂ particles with the size of about 50 nm were furnished by Aladdin in Shanghai. Nano-Cu particles were offered by Hongwu Nanomaterials Company. Fe powders were purchased from Tianjin Fengchuan Chemical Regent Company and the XRD pattern of Fe powders was shown in Fig. 1. Cu powders were provided by Sino-

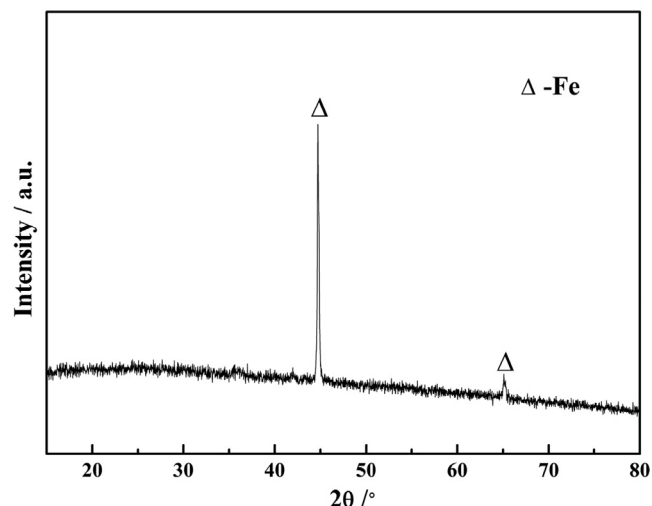


Fig. 1. The XRD pattern of Fe powders.

pharm Chemical Regent Company with an average size of 74 μm. Besides high-performance polycarboxylate superplasticizer (HPPS) named PCA-II (China, Jiangsu Sobute New Materials Limited Company) was applied to reduce water consumption.

The aluminate cement, 1 wt% nano-Cu particles, and Cu/Fe powders were dry mixed for 24 h. 1 wt% HPPS and 1 wt% nano-SiO₂ were dissolved in deionized water and then stirred for 2 min. Then the solution was added to the mixture for hydration reaction. In the experimental process, the total amount of each mixture remained the same and the water to cementitious compound (aluminate cement, nano-particles and metal powders) ratio was set at 0.2 all the time. Mixtures were designed into four groups, namely 15Cu0Fe, 10Cu5Fe, 5Cu10Fe and 0Cu15Fe which represent the substitution of Fe powders by mass of 0%, 5%, 10%, and 15%. 15Cu0Fe was considered as a reference. The samples were performed with moulds of 48 mm × 20 mm × 80 mm, 5 mm × 5 mm × 50 mm, and 20 mm × 20 mm × 20 mm. The moulds were covered with plastic wrap so as to limit the water evaporation and then they were moistened for 24 h. Afterwards, the samples were released from the moulds and cured in water at 25 °C for 7 days. Then the samples were all heated respectively at 105, 350, and 900 °C for 6 h for different performance testing.

2.2. Test methods

Volume heat capacity and thermal conductivity were measured using thermal conductivity constant tester (TPS2500, Hot Disk Ltd., Sweden) with Probe 5465 at 25 °C. The sample size required for testing is 48 mm × 20 mm × 80 mm. In the same experimental conditions, averaging the testing values of repeated measurements was applied in controlling the error within ±0.01.

Thermal expansion coefficient was measured using thermal expansion coefficient apparatus (RPZ-03P, Institute of refractories Luoyang, China) at a heating rate of 5 °C min⁻¹ from 100 °C to 900 °C. The sample size required for testing is 5 mm × 5 mm × 50 mm. In the test process, the error was reduced as much as possible by preheating.

Table 1
Chemical compositions (wt%) of aluminate cement.

Materials	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	R ₂ O	LOI
Aluminate cement	38.79	7.17	51.68	2.07	0.29	0.30

LOI: loss on ignition.

Download English Version:

<https://daneshyari.com/en/article/4991943>

Download Persian Version:

<https://daneshyari.com/article/4991943>

[Daneshyari.com](https://daneshyari.com)