

## Thermal properties of nano-SiO<sub>2</sub> optimized aluminate cementitious composite Cu powders

Yu Shi<sup>1,a</sup>, Yi Wang<sup>1,b</sup>, Gaoming Wang<sup>1,c</sup>, Wei Li<sup>1,d</sup>, Tao Yu<sup>1,e</sup>, Chunhua Lu<sup>2,f</sup>

<sup>1</sup>Jiangsu Arit New Materials Co. Ltd., Nanjing 210000, China;

<sup>2</sup>Nanjing Tech University, Nanjing 210009, China;

<sup>a</sup>aritsy@163.com, <sup>b</sup>aritwy@163.com, <sup>c</sup>aritwgm@163.com, <sup>d</sup>aritlw@163.com, <sup>e</sup>arityt@163.com, <sup>f</sup>shy19653@163.com

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**Abstract.** One of the most accepted thermal storage system of solar thermal power for balancing energy considers the use of cementitious/concrete materials. We report the preparation of nano-SiO<sub>2</sub> optimized aluminate cementitious pastes as thermal storage materials with mass fractions of 0, 5, 10 and 15% Cu powders and the influence of Cu additives on thermal and mechanical properties of the composite pastes. The specimens were heated at 105, 350, and 900 °C. When 15% Cu powders were added, the properties of the composite pastes were significantly modified at corresponding heat-treatment temperature. This paper also deals with the heat evolution of the composite pastes in the early 48 h, observing the double effects of nano-SiO<sub>2</sub> and Cu powders in the hydration process.

### Introduction

The increasing demand of energy for recent development of the society is fulfilled by a variety of energy sources. Solar energy as renewable energy offers a promising and viable option for electricity generation for the present and future[1]. Integration of thermal energy storage (TES) technology can facilitate a continuous generation of power from solar thermal power plants[2]. Sensible heat storage material with some advantages including simplicity of design and construction, ease of control and hence lower loss is considered as a promising thermal storage material at high temperature[3].

From the literature[4] it appears that cementitious materials have been widely researched for sensible heat storage applications in solar thermal power plants. It has been reported that certain reactions and transformations occur in the cementitious materials with the increasing operating temperature, which influence their thermo-physical properties[5]. Sharper strength loss and cracking are observed when exposed to heat[6]. Nanoparticles are good candidates for improving the mechanical performance of cementitious materials, due to their multiple mechanisms of action, not the least their high pozzolanic activity[7]. Metal Cu powders have high thermal conductivity of 390 W·m<sup>-1</sup>·K<sup>-1</sup> and volume heat capacity of 3.395 MJ·m<sup>-3</sup>·K<sup>-1</sup>[8]. The aim of the present work is to investigate the thermal and mechanical performance of nano-SiO<sub>2</sub> optimized aluminate cement pastes incorporated with Cu powders at heat-treatment temperatures of 105, 350, and 900 °C. The required matrix structure is estimated by addition of nano-SiO<sub>2</sub> while the thermal performances are enhanced by addition of Cu powders.

### Materials and specimen preparation

Aluminate cement performing better corrosion resistance than Portland cement was used as cementing agent. Nano-SiO<sub>2</sub> (NS) particles were supplied by Aladdin Reagent Database Inc., China. Cu powders were used to improve thermal properties of composite materials. High-performance polycarboxylate numbered for ART-JR2 supplied by Jiangsu Arit New Materials Co. Ltd. in China was used for reducing water consumption and improving the dispersion of the fresh paste.

The composite pastes were all mixed with 1 wt% NS. A reference paste named OCS, without Cu powder, was also prepared. The four mix designs are designated as OCS, 5CS, 10CS, and 15CS representing NS optimized cement pastes incorporating Cu powders with mass fractions of 0%, 5%,

10%, and 15%, respectively. The water to binder ratio was uniformly set at 0.22. The pastes cast for volume heat capacity (thermal conductivity) and thermal expansion coefficient were performed with moulds of 48 mm× 20 mm× 80 mm and 5 mm× 5 mm× 50 mm, respectively. The moulds were covered with plastic wrap in order to limit the water evaporation and moistened for 24h. Then the specimens were demoulded and cured in water at the temperature of 25 °C for 7 days. Then the specimens were separately exposed to 105, 350, and 900 °C for 6h. Comparison of the results about thermal properties at these three temperatures was listed in the present paper.

### Characterization methods

Thermal conductivity and volume heat capacity were measured by thermal conductivity constant tester (TPS2500, Hot Disk Ltd., Sweden) with Probe 5465 at 25 °C, and thermal expansion coefficient was measured by thermal expansion coefficient apparatus (RPZ-03P, Institute of refractories Luoyang, China) at a heating rate of 5 °C·min<sup>-1</sup>. In this method, 4 g cement powder or mixture powder was placed in the calorimetric cell, and 2g of deionized water was poured into a solution cell.

### Thermal properties

Thermal conductivity of NS optimized pastes incorporated with Cu powders after heat-treatment at different temperatures are shown in Table 1. It demonstrated that the thermal conductivity significantly increased with the increasing Cu powders contents. The optimal thermal conductivity values were obtained at Cu powders content of 15%, which showed 52%, 11%, and 12% higher than that of pure paste at 105, 350, 900 °C, respectively. At the same time, the rise of heat-treatment temperature also would decrease the thermal conductivity.

Table 1. Thermal conductivity of NS optimized pastes incorporated with Cu powders at different heat-treatment temperatures (W·m<sup>-1</sup>·K<sup>-1</sup>)

Sign	105 °C	350 °C	900 °C
0CS	0.982	0.886	0.856
5CS	0.991	0.969	0.902
10CS	1.386	0.976	0.956
15CS	1.492	0.985	0.962

Volume heat capacity of NS optimized pastes incorporated with Cu powders at different heat-treatment temperatures are shown in Table 2. It indicated that the volume heat capacity increased with the addition of Cu powders contents and decreased with the elevated temperature. After heating at 105 °C, the volume heat capacity value of the pastes incorporating with 15% Cu powders increased to 2.268 MJ·m<sup>-3</sup>·K<sup>-1</sup>, which was 10% higher than that of pure paste. Then further increasing heat-treatment to 350 °C, the volume heat capacity of the pastes decreased compared with the pastes heated at 105 °C. Even so, the highest volume heat capacity of the pastes composite 15% Cu powders at 350 °C still exhibited 17% higher than that of pure paste. Afterwards, the volume heat capacity of the pastes composite 15% Cu powders after heat-treatment at 900 °C was 21% higher than that of pure paste.

Table 2. Volume heat capacity of NS optimized pastes incorporated with Cu powders at different heat-treatment temperatures (MJ·m<sup>-3</sup>·K<sup>-1</sup>)

Sign	105 °C	350 °C	900 °C
0CS	2.057	1.676	1.476
5CS	2.133	1.772	1.569
10CS	2.204	1.846	1.677
15CS	2.268	1.965	1.782

The thermal expansion coefficient curves of NS optimized pastes incorporated with Cu powders at elevated temperature are shown in Figure 1. The measurement temperature ranges from 100 to 900 °C. The results were obtained after preheating at 900 °C for 6 h. It can be noted that when the temperature was up to 400 °C thermal expansion coefficient showed a largely fluctuation. Then the specimens still could keep stable ranging from 500 to 900 °C.

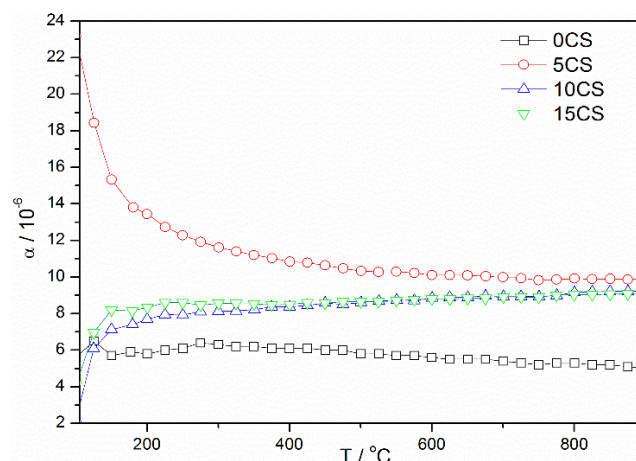


Figure1. Thermal expansion coefficient curves of NS optimized pastes incorporated with Cu powders at elevated temperature

## Conclusions

In this work, we investigate the thermal and mechanical properties of nano-SiO<sub>2</sub> optimized pastes incorporated with Cu powders. Cu powders obviously retard the solid phase formation in the acceleration period. In the heating process, Cu powders are gradually oxidized to CuO, decreasing the mass loss of the composite paste. It is desirable that at corresponding temperature nano-SiO<sub>2</sub> optimized aluminate cementitious storage materials composite metal Cu powders have better thermal properties. On the other hand, the compressive strength still can meet the requirement of thermal storage materials. Consequently, nano-SiO<sub>2</sub> based aluminate cementitious composite material incorporated with Cu powders is available for the further development of thermal storage materials.

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