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Thermal performance and fire resistance of nanoclay modified cementitious materials

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HIGHLIGHTS

- Thermal performance, fire resistance, strengths and microstructure of nanoclay modified cement mortar were investigated.
- Degradation in strengths due to heating was reduced when nanoclay was added.
- Width and density of hairline cracks due to heating were decreased in presence of nanoclay.
- The addition of nanoclay enhanced the thermal behavior of cement mortar.

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ABSTRACT

Thermal performance and fire resistance of nanoclay modified cement mortar were evaluated in this study. To prepare the modified mortar mix, part of the cement was replaced by montmorillonite nanoclay in a range of 0–2% by weight of cement. After a curing period of 28 days, the hardened mortar specimens were exposed to high temperatures of 200 °C, 400 °C, and 600 °C for 2 h. DSC and TGA tests were conducted to examine the thermal performance of the nanoclay modified specimens. The fire resistance was evaluated by comparing the residual mechanical strengths of heated specimens with the strengths of control specimens. The effect of nanoclay on the chemical composition and microstructure of heat-damaged specimens were evaluated using XRD and SEM tests, respectively. Experimental results revealed that the nanoclay modified cement mortar exhibits higher compressive, tensile, and flexural strengths than control specimens, especially at higher temperatures. The addition of nanoclay significantly reduced the degradation in the tensile and flexural strengths of cement mortar due to elevated temperatures exposure. SEM images showed that the presence of nanoclay decreased the density and the width of the hairline cracks that appeared along the cement matrix due to elevated temperature exposure.

1. Introduction

Exposure to high temperatures causes physical deterioration of concrete structures due to the multicomponent nature of concrete that is based on many constituents of different thermal behaviors. High temperature may significantly affect the concrete's strengths, modulus of elasticity and density [1–3]. These detrimental effects of elevated temperatures on concrete may be attributed to many reasons including the degradation of hydration product and increasing of internal vapor pressure [1,4,5]. Practically, the destructive effects of elevated temperatures on concrete can be reduced by using appropriate supplementary cementing materials (SCM) or mineral admixtures. Many studies have shown that adding mineral admixture such as slag, silica fume, and fly ash significantly affect the high-temperature behavior of concrete and enhance its thermal properties [6–11].

On the other hand, nanomaterials with their small size and huge surface area have the potential for tremendous improvement in the overall performance of cementitious materials. Recently, significant numbers of studies were performed to explore the effect of adding various nanomaterials such as carbon nanotubes (CNT), nanosilica, nano titanium, or nano alumina on the behavior of cementitious composites. This research is directed to evaluate the influence of using nanoclay on the performance and characteristics of such materials. Nanoclays are nano-sized particles of

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layered mineral silicates. Based on their chemical composition, nanoclays can be classified into several groups such as montmorillonite, kaolinite, and halloysite [12]. Recent studies have shown that using nanoclay improves cementitious materials mechanical strengths and chloride penetration resistance, reduces its permeability [13–19], and mitigate the alkali-silica-reaction expansion [20]. Moreover, it is speculated that the incorporation of nanoclay alters the microstructure of cement mortar by nucleating the growth of C-S-H [21,22]. Limited studies were performed to investigate the durability issues such as thermal performance of nanoclay modified cementitious materials. Fan et al. [23] investigated the thermal behavior of kaolinite nanoclay modified cement mortar. Their DTA results revealed that adding 5% nanoclay reduce the weight loss of the specimens leading to excellent thermal stability. Hakamy et al. [24] also showed that adding Cloisite 30B nanoclay reduced the weight loss of cement mortar. Gilman et al. [25] showed that adding nano montmorillonite to the cement mortar enhanced its flame retardance and heat resistance. Wang [26] investigated the effect of nanoclay addition on the compressive strength and thermal conductivity of concrete subjected to various high-temperatures. His results showed that the strength and the thermal conductivity coefficient of concrete with nanoclay were reduced with increased temperature. Based on a comprehensive literature review it was found that no enough knowledge about the influence of nanomaterials, such as nanoclay, on the behavior of cement mortar subjected to elevated temperatures. In the present research, the effect of nanoclay addition on the thermal performance and fire resistance of cement mortar was investigated. The nanoclay modified mortar was prepared by partial replacement of cement particles by 1% and 2% of nano montmorillonite. The hardened mortar specimens were exposed to three elevated temperatures of 200 °C, 400 °C, and 600 °C for 2 h. Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) tests were performed to explore the thermal behavior of nanoclay modified specimens. Scanning Electron Microscopy (SEM) and X-ray diffraction (XRD) were conducted to investigate the microstructure and chemical composition of the heat damaged specimens.

2. Research significance

Exposure of concrete to elevated temperatures affects its durability and performance. The destructive effects of elevated temperatures on concrete can be minimized by using appropriate supplementary cementing materials or mineral admixtures. Nanomaterials, such as nanoclay, are promising alternatives to substitute the traditional SCM due to its extraordinary properties. Many studies were conducted to explore the effect of nanoclay on cement based material properties such as its mechanical strengths and microstructure. Limited studies were directed to study the durability issues, in particular, performance of such materials under elevated temperatures. This research will have a significant impact in the scientific community, and it will help to explore the fire resistance and mechanical strength degradation of cement mortar modified with nanoclay due to high temperatures.

3. Experimental details

3.1. Materials

Type II Portland cement, locally available silica sand, tap water, and nanoclay were used to prepare the cement mortar used in this research. The cement is conformed to ASTM C150 standard [27]. The chemical composition of the cement and the physical properties of the silica sand used in this study are summarized in Tables 1 and 2, respectively. The nanoclay was hydrophilic Montmorillonite (Nanocor® Inc., USA) and it was used as received without any treatment. Nano Montmorillonites have a platelet-structure with theoretical formula: $(Na,Ca)_x(Al,Mg)_2(Si_4O_{10})(OH)_2{\cdot}nH_2O$. Although the nanoclay platelet's length and width are measured in hundreds of nanometers, its thickness is only one nanometer. The physical properties and the XRD pattern of nano montmorillonite used in this study are shown in Table 3 and Fig. 1, respectively. Throughout the study, the term nanoclay denotes montmorillonite nanoclay.

Table 1
Chemical compositions of Type II Portland cement used in the study.

Compound	%
CaO	56.02
SiO_2	24.59
Al_2O_3	5.87
Fe_2O_3	4.67
MgO	2.87
SO_3	2.49
Na_2O	0.55
K_2O	0.58
Loss on ignition	0.8

Table 2
Physical properties of silica sand used in this study.

Property		Value
Specific gravity	Dry	2.60
	SSD	2.63
D_{max}		1.18 mm
Absorption (%)		1.5
Fineness modulus		1.72

Table 3
Physical properties of montmorillonite nanoclay used in the study.

Property	
Color	Off white
CEC (meq/100 g) ± 10%	120
Sheet thickness	1 nm
Aspect Ratio	300–500
Specific Gravity	2.6
Maximum Moisture (%)	12
pH (5% dispersion)	9–10

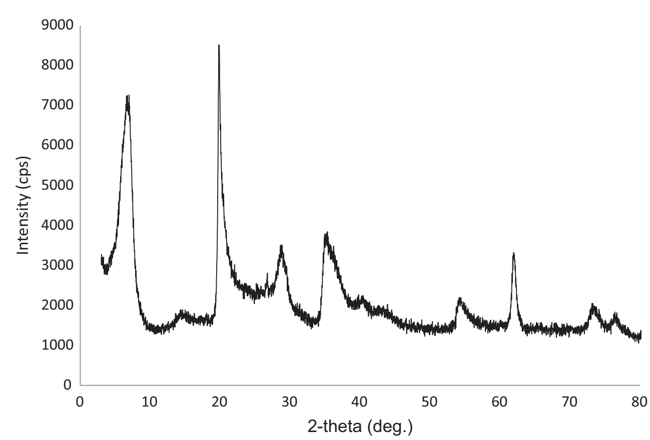

Fig. 1. XRD diffraction pattern of nanoclay used in this study.