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Technical note

A novel lightweight cementitious composite with enhanced thermal insulation and mechanical properties by extrusion technique

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ABSTRACT

Extrusion technique was used for producing arched lightweight cementitious composites panels (LCCPs) to protect thermal leakage of pipe with high temperature. The results indicated that with 40. 0 wt% addition of expanded perlite (EP) with mean size of 40 μm, thermal conductivity of the LCCPs can be greatly reduced by 78.4% without scarifying too much of mechanical strength, which ensured that two arched LCCPs can be riveted together as a cover to protect circular pipelines from thermal leakage. More attractively, compared with casting method, the novel LCCPs by extrusion showed a higher automatic and massive production, lower cost and better sustainability, which can be served as a good candidate of thermal insulating materials for piping system.

1. Introduction

Cement-based materials with good thermal insulation properties by incorporating lightweight aggregates [1], such as glass beads, expanded perlite (EP) [2–4] and diatomite, have been widely developed for energy-efficient buildings. Most of the products are regular-shaped (such as rectangular or cubic) boards or panels due to the limitation of traditional casting method, and they are usually used for thermal insulation in ceiling and envelop of infrastructure. However, it has not widely been used for thermal insulation of piping heating system (PHS) due to the circular shape of pipelines, which is not only difficult for demolding of cement-based materials but also increases the design/materials cost for casting molds. Currently, glass fiber-based [5] and rock wools-based materials [6] are the two major thermal insulating materials for PHS since both can be easily enwrapped to cover the pipelines, but it suffers from several limitations, such as a high cost, labor-consuming and long construction period, and rock wool-based materials are easily inhaled into respiratory and might cause cancer for laborers. Therefore, it is necessary to develop a novel material with shape diversity, good thermal insulation, high-temperature resistance, massive production and low cost for PHS insulation.

Extrusion is an advanced material processing technique that can be used to develop high performance fiber-reinforced cement-based composites [7,8]. Compared with casting technique, it has many superior advantages, including mass production with low cost, environmental friendly, lower energy consumption and better quality control of final products. Zhou et al. [9] developed a novel light-weight wood-magnesium oxychloride cement composite modified by sawdust and perlite with enhanced flexural strength and better high temperature-resistance performance by extrusion technique, which can be used as full-scale door frame and door panel. More importantly, it enables flexibility in fast fabrication of building products with complicated shapes by using different shape of dies, which greatly reduces the production cost and increases the shape diversity of products. As a result, the extrusion has a great potential to fabricate arch-shaped cementitious composites. In this study, by incorporating EP as lightweight materials and optimizing the mix proportions, a kind of novel lightweight cementitious composites panels (LCCPs) with satisfied mechanical strength is expected to be developed to prevent the thermal leakage of PHS with high temperature of 180 °C.

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Table 1
Chemical composition of cement, FA and EP.

Series	CaO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	SO_4	K_2O
Cement	71.94	20.30	3.78	3.07	–	4.76	1.68
FA	8.18	50.44	33.30	3.46	–	1.15	1.58
EP	1.07	77.40	11.91	0.84	3.70	–	4.80

Table 2
Mix proportions of the LCCPs.

No. Series	Binder		EP	Sand	PCE	W/C	HPMC	PVA fiber (vol.%)
	OPC	FA						
1. EP0	0.7	0.3	–	0.1	0.01	0.20	0.005	1.0
2. EP30	0.7	0.3	0.3	0.1	0.02	0.22	0.005	1.0
3. EP40	0.7	0.3	0.4	0.1	0.03	0.23	0.006	1.0
4. EP50	0.7	0.3	0.5	0.1	0.05	0.24	0.006	1.0

Note: EP, sand and HPMC are by the weight of binder.

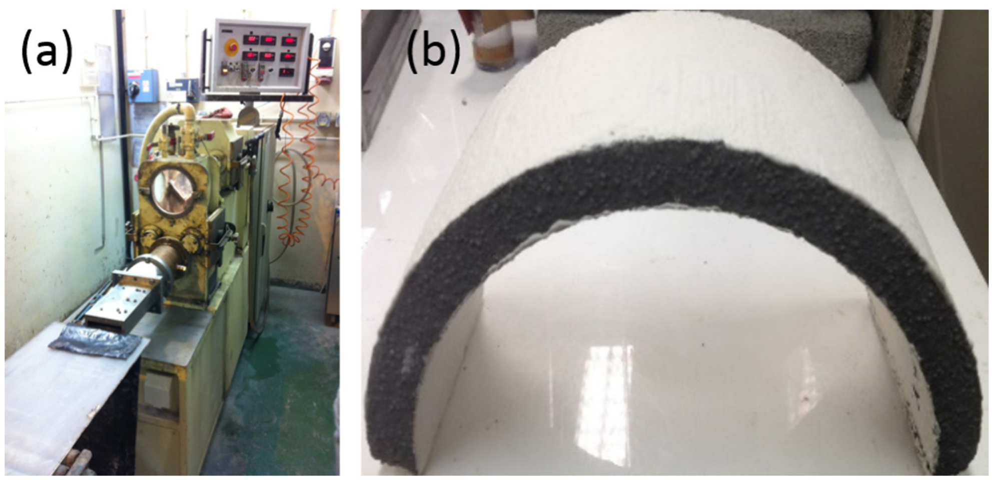

Fig. 1. (a) Extrusion equipment and (b) arched LCCPs by extrusion.

2. Experimental

2.1. Materials

Ordinary Portland cement (OPC) type 52.5 (Green island, HK), Class F fly ash (FA) and silica sand were used to fabricate the cementitious mortar. Different amount of EP with the mean size of 40 μm was used as the lightweight aggregates to fabricate the LCCPs. The chemical compositions of raw materials analyzed by X-ray fluorescence spectrometer (XRF, JSX-3201Z) are listed in Table 1. Hydroxypropyl methyl cellulose (HPMC, BASF) was added to improve the rheology and extrudability of the fresh cementitious mortar. Poly(vinyl alcohol) (PVA fiber, KURALON K-II REC 15) used in this study was 39 μm in diameter and 12 mm in length. The Polycarboxylate ether (PCE) superplasticizer (ADVA 189, Grace) with a concentration of 28–30 wt% was used to modify the workability of the mixture. Table 2 lists the mix proportions of the LCCPs by extrusion.

2.2. Sample preparation and extrusion process

In order to prepare the fresh mixture with good workability and extrudability, EP was firstly mixed with half of water and then mixed with other dry powders. After dry mixing for 2 min, the left half of water were gradually added for 4 min mixing at high speed. During the mixing, PVA fiber and HPMC were gradually added until the dough-like mixture was formed. The mixture was then fed into the hopper of the single-screw extruder (Fig. 1b) with arched die at the end, which was linked to the PHS, ensuing that the extruded LCCPs can directly deposit on the outer surface of the pipeline. All the arched specimens were demolded after 1 day curing in air and put in the curing room with the temperature of 25 °C and humidity of 95% for another 13 days. Finally, two arched LCCPs were riveted together to cover around the pipeline for thermal insulation, and the small gaps between the two LCCPs were filled with thermal insulating cementitious mortar to avoid the thermal leakage. Fig. 1 shows the extrusion facility and arched LCCPs after extrusion.

2.3. Measurements

Specimens with dimensions of 40 × 40 × 40 mm were used for compressive test and 150 × 30 × 10 mm for flexural test, at 14 days. The compressive test was conducted using a MTS system at a loading of 1 kN/s. The three-point bending test was conducted following the procedure prescribed by ASTM C78/C78 M-10 and measured with a span of 90 mm and a stroke control at a loading rate of 0.1 mm/min. A quick thermal conductivity meter (QTM 500, Kyoto Electronics Manufacturing, Japan) based on ASTM C 1113-90 Hot Wire Method was used. After the pipeline was filled with conducting oil (180 °C), the surface temperature variation of the arched LCCPs was record by 6 thermal couples. In order to make the results representative, three specimens of each mix proportions were tested for obtaining the mean value.

3. Results and discussion

Fig. 2 shows the compressive and flexural properties of the LCCPs with different amount of EP. As can be seen from Fig. 2a, with the increasing amount of EP, both of compressive and flexural strength gradually decrease, but a dramatic mechanical loss appears when the addition of EP reaches up to 50.0% because hydrated cementitious products are not enough to bind the large amount of EP together. Although the mechanical strength of LCCPs