Materials & Design 83 (2015) 185–192

Contents lists available at ScienceDirect

Materials & Design

journal homepage: www.elsevier.com/locate/matdes

Preparation and study of light transmitting properties of sulfoaluminate cement-based materials

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ARTICLE INFO

Article history:
Received 9 January 2015
Revised 10 April 2015
Accepted 3 June 2015
Available online 19 June 2015

Keywords:
Sulfoaluminate cementitious materials
PMMA fiber
CCD
Optical power
Mechanical properties
Microstructure

ABSTRACT

Polymethylmethacrylate (PMMA) optical fibers with two types of diameters were uniformly arranged in sulfoaluminate mortar by different methods. Light transmitting sulfoaluminate cement-based materials (LTSCM) were prepared. Optical and mechanical properties of LTSCM were studied. The compressive strength decreased linearly with increasing volume fraction of optical fiber in LTSCM. Compressive strength of specimen after 80 °C water bath was larger than that of specimen under standard curing conditions. According to CCD technology, brightness of optical fiber in different positions of LTSCM can be exhibited clearly. Light transmitting performance of LTSCM was tested by optical power method. Transmittance of specimen decreased with increasing spacing between the detector and specimen. Optical power increased with increasing number of fiber and with increasing diameter of fiber. Transmittance of fiber was weakened due to water bath at high temperature. Voids existed between the fiber and matrix.

1. Introduction

Light transmitting cement-based material (LTCM) is a new type of light transmitting material [1,2]. Its light transmitting properties depend on a large number of optical fibers, which transmit light through the cement-based product. It can greatly enhance the lighting effect of buildings, reduce the energy consumption of architectural lighting, and promote building energy saving. Nowadays, LTCM is usually used as building envelope, such as exterior walls of museum and opera house. In the World Expo Shanghai 2010, light transmitting cement-based materials were used as exterior walls of Italian Pavilion. In addition, LTCM also has artistic value, and can be used as decorations in exhibition hall and museum [1].

A few studies concerning components, preparation and properties of LTCM have been reported. (1) From the standpoint of material components, the matrix materials of LTCM are primarily Portland cement or mortar [3–8]; the types of optical fiber are mainly glassy fiber [3–6] and organic fiber [7,9,10]. (2) From the standpoint of preparation, literature [6] reported that parallel optical fibers were arranged in matrix; literatures [7,9,10] reported the application of optical fabric technology in preparation of LTCM. However, the studies described above have not solved the problem – the irregular arrangement of fibers in matrix. Literatures [11–13] introduced that molds were used to prepare LTCM, while the embedment of optical fiber was difficult, and the workload was heavy. (3) The properties of LTCM, including physical, mechanical, and light transmitting properties were studied. In the previous work of the authors [3–5], LTCM was composed of Portland cement mortar and glassy fibers. Parallel fibers were arranged in mortar uniformly. Compressive strength was tested, light transmitting properties were measured by spectrophotometer, and the microstructure of LTCM was observed by SEM. The results showed that completed LTCM had high light transmittance. In the range of 520–630 nm wavelength, the light transmittance of LTCM reached, or even exceeded that of 70g A4 printing paper. With increasing volume fraction of optical fiber, its light transmittance gradually increased, while its compressive strength decreased. The compressive strength at 28 days was less than 25 MPa.

Previous studies demonstrated that main performance of LTCM depends on the characteristics of matrix materials, type of optical fiber, and its arrangement. In existing papers, matrix materials are all made from Portland cement. Sulfoaluminate cement has many advantages, such as high early strength, high ultimate strength, and low alkalinity, compared with Portland cement. In addition, the representation form of light transmittance in previous work

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http://dx.doi.org/10.1016/j.matdes.2015.06.021
0264-1275/

was relatively simple, and different test methods need to be developed. Thus, the main object of this paper is to study the preparation of LTSCM, including the components of raw materials, arrangement method of optical fiber, molding process and curing. Moreover, the physical, mechanical and optical properties of LTSCM are discussed, and its microstructure is analyzed. This study aims to promote research and engineering application of this type of material. The matrix is composed of sulfoaluminate cement, two methods are designed to produce the spatial form of optical fibers. Strength performance of LTCM is studied, and two test methods, which provide the references for design and preparation of the materials, are used to evaluate its transmitting properties.

2. Materials and methods

2.1. Raw materials

Cement: The high early strength sulfoaluminate cement used in this work was from BJX CO., LTD, Tangshan, China. Its physical properties and chemical composition were given in Tables 1 and 2, respectively.

Aggregate: The sand used in this study was ISO standard sand based on Standard ISO 679:1989 (ISO Standard Sand CO., LTD., Xiamen, China). The particle size distribution of sand was continuous grading of 0.06–0.6 mm.

Optical fiber: The optical fibers used in this study were PMMA fibers (JT, Nanjing, China) with diameters of 1.0 mm and 0.5 mm, respectively. The tensile strength of the fiber with diameter of 1.0 mm was 65.73 MPa, and its elongation capacity was 10%. The tensile strength of 0.5 mm fiber was 78.47 MPa, and its elongation capacity was 20%. The coating of the fiber was fluororesin. The loss rate of fiber at 650 nm wavelength was less than 350 dB/km. Its bending diameter was eight times greater than the diameter of the optical fiber. The operating temperature was from −20 to 70 °C.

Table 1
Physical properties of cement.

Density (g/cm^3)	Blaine surface (g/cm^3)	Water requirement for standard consistency (%)	Compressive strength (MPa)		Flexural strength (MPa)	
			1d	3d	1d	3d
2.87	427	24.4	49.0	52.9	8.8	9.4

Coupling agent: A-151 silane coupling agent, and its component is vinyltriethoxysilane.

Water reducer: F0X-8H polycarboxylic acid powder with water reducing rate of 30%.

Antifoaming agent: P764 antifoaming agent powder. The admixtures were from China Building Materials Academy.

2.2. Testing methods

2.2.1. Test method for strength and micro-properties

Compressive and flexural strength tests for hardened pure cement mortar and LTSCM were carried out in accordance with China national standard GB175-2007 (title: Common Portland Cement). The consistency of high flowing cement mortar was carried out in accordance with China national standard GB/T2419-2005 (title: Test method for fluidity of cement mortar). In compressive strength test, the orientation of optical fibers parallels to the length of specimen, and is perpendicular to compression. In flexural strength test, the optical fibers parallel to the load.

The pore structure of specimen was tested by full-automatic mercury penetration porosimetry (Quantachrome PoreMaster 60GT). Sample under standard curing conditions for 28 days was shaped into 2.5–5.0 mm particles by using a sharp knife. The particles were classified into two sets. Sample A was a particle without fiber; Sample B was a particle that had one fiber. The microstructures of Sample A and B under standard-curing conditions for 28 days were observed by SEM (QUANTA-FEC250 scanning electron microscope).

2.2.2. Preparation of LTSCM

2.2.2.1. Preparation of sulfoaluminate cement mortar. Based on lots of trials, the mix proportion of sulfoaluminate cement mortars with high consistency, high strength, and high compactness was determined. The water–cement ratio was 0.35. The dosage of water reducer and antifoaming agent was 0.7% and 0.2% of cement content by mass, respectively. And the mass ratio of sand to cement was 0.8. The consistency of mortar was 150 mm, and its compressive strengths at 3 days and 28 days were 54.2 MPa and 69.8 MPa, respectively.

2.2.2.2. Embedment of optical fibers and casting. Optical fibers were immersed in silane coupling agent solution with volume concentration (volume ratio of solid to water) of 20%. After 2 min, they were air-dried. Then, two methods can be used to fasten optical

Table 2
Chemical composition of cement.

Loss (%)	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	SO_3 (%)	R_2O (%)	Na_2O (%)	K_2O (%)
6.82	37.18	16.40	25.83	1.09	1.82	9.22	0.59	0.16	0.31

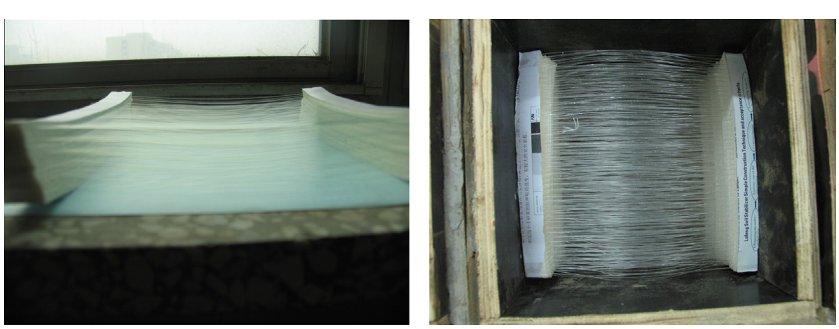

Fig. 1. Fastening method and casting mold (Method 1).