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Characterization and engineering application of a novel ceramic composite insulation material

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A B S T R A C T

Thermal insulation materials have attracted increasing attention in recent years for energy conservation in thermal power plant. A novel ceramic composite insulation material (hereafter refer to CCIM) composed of alumina fibers and hollow silica powders with excellent pliability and thermal insulation properties has been designed and fabricated. The effects of alumina fiber and hollow silica microspheres on the performance of composite were characterized through microstructure observation using scanning electron microscopy (SEM) and thermal conductivity evaluation. In the novel CCIM, ceramic fibers and particles of different sizes were uniformly mixed to form multi-scale sizes of pores which can decrease the heat conduction and convective heat transfer at high temperature significantly. The comparison between the traditional mineral wool and the fabricated CCIMs focused on microstructure and thermal insulation property was also performed in this work. The novel CCIM shows much lower thermal conductivity than the standard value of thermal conductivity of traditional inorganic insulation materials when the mean temperature is between 126 °C and 538 °C. The novel CCIMs were applied in a supercritical Power Plant. The surface temperature and surface heat flux measured during service in the supercritical Power Plant further demonstrated that the novel ceramic composite has better insulation properties than traditional inorganic insulation materials.

1. Introduction

Insulation products are worldwide applied for a number of fields such as building construction and heating, industrial processes as well as high performance products or systems [1]. Generally, an insulating layer reduces heat transfer between two workpieces held at different temperature and thus helps to reduce energy losses and CO_2 emissions [2] [3]. Apart from the energy saving and the related reduction in CO_2 emissions, insulation also offers additional advantages: in an insulated building or industrial piping system one encounters a more uniform temperature distribution which results in a more agreeable living experience or improved plant operation respectively [4] [5].

Inorganic insulation material is a kind of insulation material for using on surfaces with temperatures between room temperature and high temperature. Vacuum insulation panels [6] [7] and aerogels [8] [9] with very low thermal conductivity are the state-of-art inorganic insulation material, but they are very expensive and lack of engineering application in industry [1]. Mineral fiber, calcium silicate block, expanded perlite block are the traditional inorganic insulation materials [10] which are much cheaper than vacuum insulation panels and aerogels and widely applied in frame houses and other structures with cavities. But there are a number of disadvantages for these traditional inorganic insulation materials which make them can't meet the necessary for the application in a harsh environment with safety, high efficiency and long service life. Besides inorganic insulation materials, some environmental friendly insulation materials using plant fiber as starting materials [11] [12] are also researched in some laboratories. But these kinds of materials can't be used in high temperature evironment. Therefore, the preparation of a new grade thermal insulation materials with lower thermal conductivity and better overall performance based on traditional procession technology with low cost is necessary. Traditional inorganic insulation materials can be divided into flexible insulation material (soft material) and inflexible insulation

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materials (rigid material) according to whether they are easy to be bent. The mineral wool belongs to flexible insulation material with an open-cell structure and is manufactured from mineral substance such as rock, slag, or glass, processed from a molten state into fibrous form with binder. The calcium silicate block and the expanded perlite block belong to inflexible insulation material with a closed-cell structure which can reduce the convective heat transfer at high temperatures. Flexible insulation materials are mainly fabricated by different kinds of fibers which can easy to pack on the pipeline, thus benefit for construction. However, the loose structure of soft materials such as alumina fiber can result in obvious increasing of thermal conductivity along with the increasing of the service temperature and loss of the initially low thermal conductivity as time goes on, thus limited the service lifetime. While the rigid thermal insulation materials are mainly fabricated by hollow particles which are more stable at high temperature, but are difficult for construction due to its rigid nature. The disadvantages of soft and rigid thermal insulation materials make them not suitable for a better energy conservation and emissions reduction effect in industry, such as sustainable development of ultra-supercritical power plant. New grade thermal insulation materials with improved performance and low cost are highly demand. If the new grade thermal insulation materials using both fibers and hollow particles as the main starting materials which can combine the advantages of flexible and inflexible insulation materials, while mitigate the disadvantage of both materials, namely, developing a kind of rigid insulation material which has a flexural property will be very interesting and attractive for engineering application. Hollow particles were also used to fabricate syntactic foam which is a kind of composites fabricated by dispersing hollow particles in a matrix. The addition of hollow particles can decrease the density of the materials. Fibers are also added in the matrix for reinforce the syntactic foam. One important application of syntactic foam is for vehicle structures, which is mainly concern about low density combined with high strength and stiffness [13] [14]. For thermal insulation materials composite by fibers and hollow particles is mainly concern about thermal insulation performance at service temperature and construction convenience. In this work, a novel ceramic composite insulation material (CCIM) which is was produced by a conventional wet mixing process of hollow glass beads, alumina fiber and sepiolite fiber, together with nano-silica was fabricated and characterized. The verification of engineering application of this new material in a power plant was also performed. It was found that the composite of fibers and hollow particles can ensure the material good flexibility. The material shows a typical porosity microstructure with multi sized pores. This material shows very low thermal conductivity and very good thermal insulation performance.

2. Experiment

2.1. The material fabrication process

The raw materials employed in the novel CCIMs were as follows: alumina fiber; hollow glass beads with a size of 3–50 μm; nano-silica powder; sepiolite fiber and other addition agent. The raw materials were mixed homogeneously by wet process using water and alkylphenol ethoxylates-10 (OP-10) as dispersing agent. The method of rapid mixing (300 revolutions per minute) was adopted to ensure the materials dispersed homogeneously. Then the prepared slurry was formed in a mold and dried at temperature below 100 °C until all free water were evaporated. Fig. 1a shows the external shape of the fabricated CCIM. This material shows very low compressibility, which similar to the traditional rigid (inflexible) inorganic insulating materials, such as calcium sillicate. But after a large angle bending of the CCIM, there has no any cracking and deformation on the direction of the thickness occurred, as shown in Fig. 1b, which shows better flexibility compared to the traditional flexibility thermal insulation materials, such as mineral wool. The reason why the CCIM can be bent easily but no crack and deformation on the direction of the thickness is due to the composite between fibers and particles, which will be discussed later.

2.2. Characterization

Microstructure of the materials was analyzed by scanning electron microscopy (SEM). Thermal conductivity was texted by the Hot Plate Thermal Conductivity according to the Steady-State Method [15]. For verification of engineering application, the CCIM was applied in a supercritical Power Plant. After long-term stable operation, the surface temperature of the insulation layer was measured to investigate the thermal insulation effect. The comparison between the traditional aluminum silicate wool and the CCIM focused on microstructure and thermal insulation property was also performed.

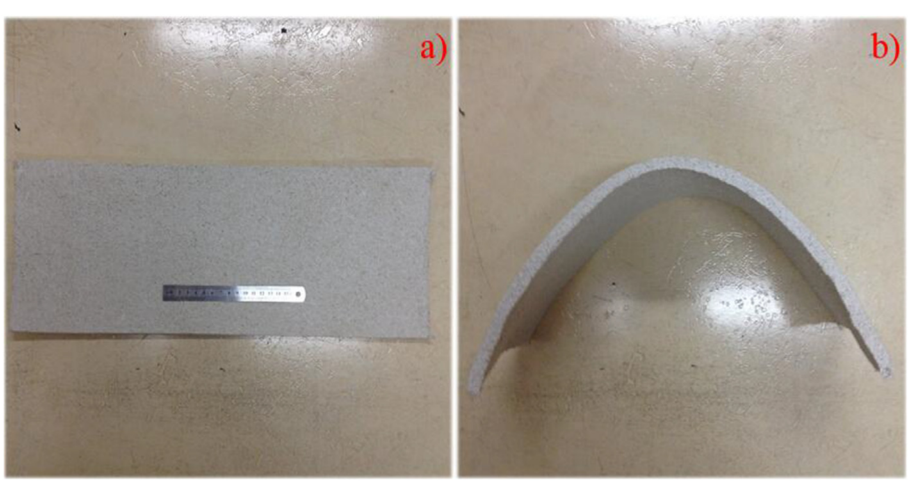

Fig. 1. Photograph of the material. a, before bending. b, after bending.