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Water-retention properties of porous ceramics prepared from mixtures of allophane and vermiculite for materials to counteract heat island effects

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Abstract

Porous ceramics for anti-heat island effect were prepared from mixtures of allophane and vermiculite (VA samples). Allophane and vermiculite which had been ground for 0.5–2 h was mixed in various mass ratios, formed into pellets by uniaxial pressing at 40 MPa, and heated at 600–800 °C to form porous ceramics. The large thermal expansion of the vermiculite upon explosive dehydration of interlayer water causes cracking of the pellets with higher vermiculite contents. However, this can be controlled by grinding the vermiculite prior to heating. Grinding the vermiculite for ≥2 h suppresses its expansion, enabling pellet samples with high vermiculite contents to be prepared without cracking. The bulk densities of samples prepared at 800 °C from vermiculite ground for 2 h decrease from 1.72 to 0.94 with increasing allophane content. The pore size distribution in these samples shows a distinct peak at about 1 μm irrespective of the mixing ratio. The number of smaller pores (<50 nm) increases with increasing allophane content while the number of larger pores (20–40 μm) increases with increasing vermiculite content. The compressive strengths of the samples range from 1 to 3 MPa except for samples containing a high proportion of vermiculite ground for 1 h. The water absorption (W_a) of the samples increases from 37 to 63% with increasing allophane content. This absorption rate is fast enough to absorb >90% of the W_a within 1 min for samples of 10 mm Ø × 5 mm^3 size. By contrast, the release of the absorbed water is very slow, with 50% of the W_a retained for ≥30 h in the VA samples at a relative humidity of 55% at 20 °C; this is slower than in pure allophane and much slower than in a reference sample of foamed glass (about 4 h). All these properties make the VA samples useful as water-retaining materials to combat ‘‘heat island’’ effects.

Keywords: Water-holding property; Allophane; Vermiculite; Porous property; Anti-heat island material

1. Introduction

In the large cities of industrial countries, most of the ground surface is covered by artificial pavement materials and many large buildings. The materials generally used are of low thermal conductivity and absorb solar energy rather effectively due to their dark color. Furthermore, exhaust heat from automobiles and air conditioners is increasing with increased population, economic activity and the adoption of modern lifestyles. The reduction of cooling by vapor evaporation from the ground surfaces and increases in the generated heat is causing large cities to become hotter. Cities heated by sunlight retain their high temperature up to midnight, especially in the summer season. The number of nights on which the minimum temperature is greater than 25 °C (called tropical nights) is increasing; for example, the average number of tropical nights in Tokyo has increased from a few to more than 40 over the past 100 years, reflecting an average temperature increase of about 4 °C [1]. This phenomenon has recently been termed a ‘‘heat island’’. Such changes in the ground surfaces of big cities also causes another climate change effect in winter, namely the lowering of the relative humidity to an over-dried state similar

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to a desert environment, leading to the spread of diseases such as influenza.

Many materials with water-retention properties have been developed for use in various types of functional pavement systems. In these pavements, a particular cooling effect arises from vapor evaporation occurs from the surface of pavements containing water-retention materials and/or water-retaining porous ceramics. Candidate water-retaining materials include slag [2], bentonite [3] and diatomite [4]. Water-retaining porous ceramics have also been prepared using various wastes, e.g., blast furnace slag [5] and Kira (the waste generated from the benefication process of silica sand and plastic clay [6]). However, it is difficult to maintain this effect for any length of time without supplying water because the water-retaining materials developed so far have a rather poor ability to release the retained water continuously since little consideration has been given to the importance of this slow release property. Water-retaining materials for use in pavements should therefore have a fast rate of water-absorption, high water absorption capacity and a slow release rate of the adsorbed water.

Soil used for agriculture may contain the clay minerals vermiculite and allophane which are well-known for their water-retention properties. If they are used as powders, their outer surfaces do not present many adsorption sites. For this reason, vermiculite is heat-treated to create spaces between the layers of the particles and allophane is used in a granular form to utilize the spaces between the agglomerated nano-particles. We, therefore, considered that more spaces might be made available for water adsorption if these powders were mixed and lightly sintered to form necks between the contacting grains. The mixing of platy particles should not only enhance slow water release by a shielding effect [7] but also increase the mechanical strength [8].

This paper describes the preparation of porous ceramics by heating mixtures of vermiculite and allophane at relatively low temperatures. The effect of changing the mixing ratios, grinding times of the vermiculite and the heating temperature was investigated. The water absorption rate, amount of water absorbed and its release rate was determined for these materials and compared with a foamed glass sample.

2. Experimental

2.1. Preparation of the samples

The starting materials were vermiculite from Phalaborwa, South Africa (0 grade, Vermitech Co.) and allophane from Kanuma pumice (Lead Co.). The vermiculite (4 g) was ground in a planetary ball mill (Itoh Co.) at 300 rpm using Si_3N_4 balls (Ø10 mm) for 0.5, 1 and 2 h. The allophane was obtained by sieving (#200) the Kanuma pumice. The two clays were mixed in various ratios using an agate mortar and pestle, then uniaxially pressed at 40 MPa to form 10 mm Ø × 5 mm pellets. The pellets (designated VA samples) were heated at 600–800 °C at a heating rate of 10 °C/min. Foamed glass prepared by heating waste glass powder at about 900 °C with a small amount of SiC as a foaming agent was used as a reference material when cut to similar size and shape as the VA samples.

2.2. Characterization of samples

The expansion of the VA samples upon heating was determined from the diameter and thickness of the pellets, measured using a micrometer. The bulk densities of these samples were calculated by the conventional method. The microstructures of the VA samples were observed by SEM (JSM-5310, JEOL) at an accelerating voltage of 15 kV. The compressive strengths of the VA samples were measured using a universal testing machine (Autograph DCS-R-10TS, Shimadzu) with a 500 kg load cell and a head speed of 0.5 mm/min. The pore size distributions of the VA samples were determined by Hg porosimetry (Pascal 140 and 240, CE Instrument).

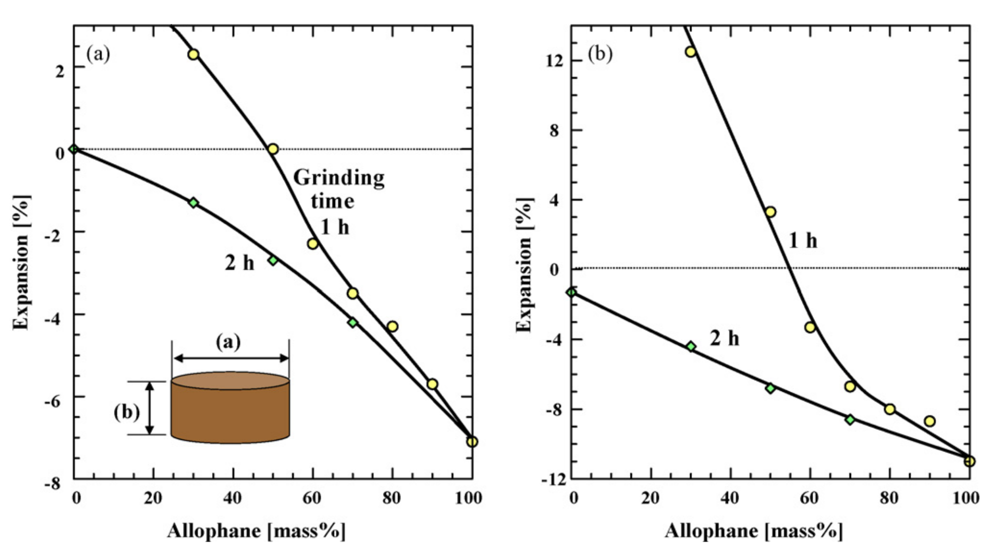

Fig. 1. Expansion of the VA samples prepared at 800 °C from 1 and 2 h ground vermiculites as a function of the allophane content.