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Study of the pore structure of the lightweight concrete block with lapilli as an aggregate to predict the liquid permeability by dielectric spectroscopy

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HIGHLIGHTS

- Characterization of the pore structure of LCBL by MIP and dielectric spectroscopy.
- High values of hydraulic conductivity compared to conventional concrete were found.
- Prediction of porosity of LCBL by modified Bergman dielectric response equation.
- New criterion for the choice of the lower frequency limit in conductivity spectra.
- Prediction of the liquid permeability by a modified Katz–Thompson equation.

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ABSTRACT

Lightweight concrete with basaltic lapilli as an aggregate is commonly employed in the Canary Islands to manufacture prefabricated blocks. The high porosity of this aggregate provides blocks with low density and good acoustic and thermal insulating properties. However, these properties are the source of moisture condensation inside the block, compromising the building comfort. For these reasons, the pore network by means of dielectric spectroscopy, mercury intrusion porosimetry and hydraulic conductivity is analyzed. The electrical conductivity of the concrete block is measured and used to describe the porosity and pore connectivity factor using a modified form of Bergman equation that considers two conducting phases. Besides, hydraulic conductivity is also measured by a falling head permeability cell, finding a correlation between the liquid permeability and its predicted value by the Katz–Thompson equation. From these studies the measured parameters (porosity, tortuosity, hydraulic and electrical conductivity) are related to the pore network parameters (connectivity and permeability).

1. Introduction

Basaltic lapilli is widely used as an aggregate to make concrete blocks in the Canary Islands. Because of its abundance in the Canarian territory, it has become the main aggregate for the regional building industry. Called “picón” in the Canarian archipelago, it consists of small pyroclastic fragments (Fig. 1a) ejected during volcanic activity, ranging in size from 2 to 64 mm and of basaltic composition.

Morphologically it exhibits high vesicularity, making this aggregate to have low density (average bulk density of 1400 kg m^{-3}), high porosity (0.30–0.50 void fraction), and high values of water absorption (about 12%) [1]. These properties classify picón as a natural lightweight aggregate [2]. Lightweight aggregates such as natural or artificial are available in many parts of the world and can be used in producing concrete in a wide range of unit weights and suitable strength values for different fields of applications such as internal and external walls, inner leaves of external cavity walls, fill panels and isolation of roof decks and floors [3].

Lapilli is mainly used as an aggregate in the production of lightweight concrete (LWC), especially a kind of concrete block called “Canarian block” (Fig. 1b), which is made of lightweight concrete with basaltic lapilli as aggregate [1]. Lightweight concrete (LWC) refers to any concrete produced with a density below 2000 kg m^{-3}. LWC for structural use is defined as concrete with a bulk density range of 1600–2000 kg m^{-3}, while LWC used for insulation purposes has a bulk density below 1400 kg m^{-3}. The main advantages of LWC over normal concrete are: (a) it allows a reduced weight structure, (b) it provides high thermal insulation for buildings, and (c) it improves the inherent fire resistance of buildings [4]. The production of LWC has increased and now includes all types,

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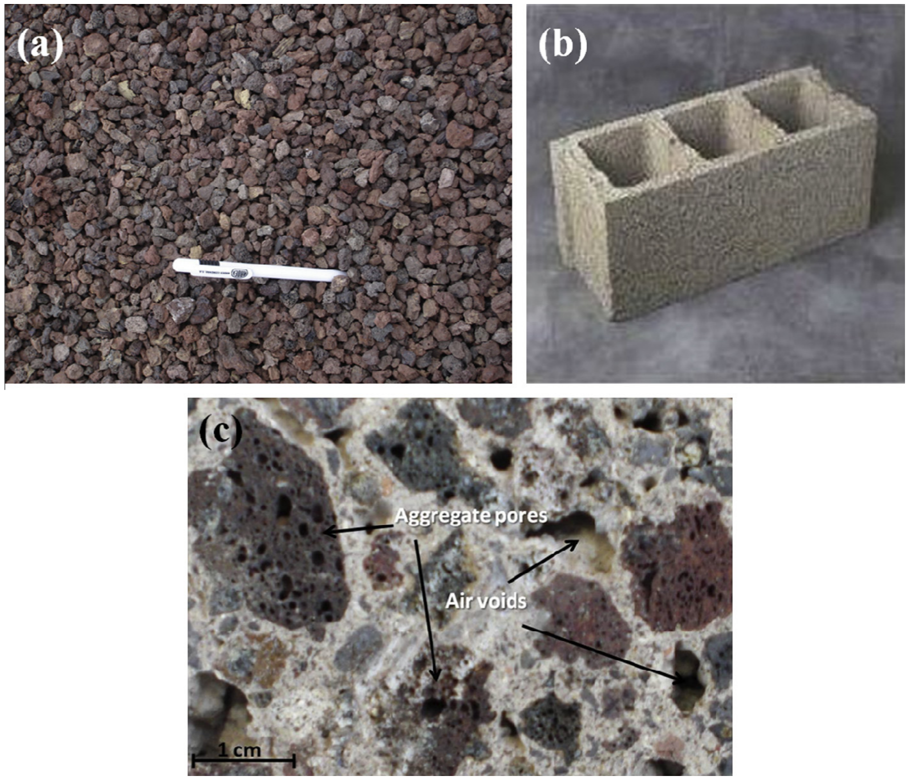

Fig. 1. (a) Basaltic lapilli, (b) lightweight concrete block with lapilli aggregate (LCBL), and (c) surface of a LCBL saw-cut wall, showing aggregate pores and air voids.

from low density concrete without fines for the production of blocks, with densities of 300–1200 kg m^{-3}, to structural concrete with densities up to 1000–2000 kg m^{-3} and compressive strengths from 1 to 100 MPa. The production of these concretes is closely related to the availability of lightweight aggregate.

As for any composite material, the physical and chemical properties of the constituents and the interaction between them determine its behavior. Aggregates usually are a 60–80% of the total volume of the LWC. Given the high volume fraction occupied, aggregates exert great influence on the characteristic properties, and can be expected to have a major influence on the other properties. In contrast, the use of lightweight aggregates in concrete production is generally a simple way to reduce its specific gravity [2]. In recent years there has been an increasing interest in the use of new local materials and byproducts as aggregates, such as polystyrene beads and coal in the manufacture of lightweight concrete blocks [3].

The lightweight concrete block with lapilli as an aggregate (abbreviated for this study as LCBL) used in Canary Islands has been tested and approved by building regulations of Spain and the EU. According to these studies, LCBL has the following properties [4]: (a) the constituents are mainly cement, sand, water and lapilli, with 65% of the block material being lapilli; (b) it has low density, about 1300–1900 kg m^{-3}, (c) it exhibits low mechanical resistances depending on the block weight and dimensions, ranging from 14.7 to 24.5 MPa [1]; (d) it has very high values of water suction, and (e) it has good thermal and acoustic insulation properties [6]. However, the main disadvantage is the porous structure of the aggregate (Fig. 1c) that implies high absorption capacity of mixing and environmental water. This water absorption capacity is favored by high relative humidity environments, resulting in the appearance of fungus, stains or cracks, the main pathologies suffered by buildings in Canary Islands. In recent years, several studies have been conducted to analyze this phenomenon and to minimize its harmful effects, but to date no satisfactory solution has been reached [7–9].

Publications about the use of lapilli as an aggregate in concrete are scarce [10], although there are many references of the characterization of properties of lightweight concrete with low density aggregates [2,5,6,11–15]. For this reason, it is necessary to obtain new experimental data to accurately quantify the moisture transfer between hygroscopic building materials and air if the humidity conditions vary in a cyclical form. Furthermore, these experimental data are also important and a prerequisite for the numerical models that will be used in developing new building products based on LWC.

A widely used method for the characterization of porous materials is the mercury intrusion porosimetry (MIP), which allows to determine the porosity, pore size distribution, critical pore diameter and tortuosity of the pore network [16,17]. Additionally, for many researchers the dielectric spectroscopy constitutes a fundamental technique in order to characterize the microstructure of the aforementioned materials. The application of this non-destructive method for porous materials allows the prediction of parameters such as porosity and pore connectivity by analyzing the dispersion curves of the conductivity and/or dielectric permittivity as a function of frequency [18,19]. Porous materials and specifically concrete blocks can be studied roughly as two-phase media. One phase is considered the solid phase, being constituted by the cement matrix and the aggregates; the other phase comprises all the open pores and voids in the media. These pores are filled with a mix of dry and moist air. If we consider the electrical parameters of this simplified model, we observe that the medium is considered an electrical insulator, with a very low electrical conductivity. However, if we fill the open pores with a conductive fluid, such as a NaCl solution, the porous phase becomes conductive, and so the conductivity and permittivity increases in respect of the solid phase. In these conditions, the medium is constituted by an