Measurement 63 (2015) 299–308

Contents lists available at ScienceDirect

Measurement

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

Monitoring macro voids in mortars by computerized tomography method

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ARTICLE INFO

Article history:
Received 23 June 2014
Received in revised form 17 September 2014
Accepted 27 November 2014
Available online 9 December 2014

Keywords:
Nondestructive testing
Porosity
Cement mortar
Strength
Void distribution
Computerized tomography

ABSTRACT

This study aims to investigate the use of ground pumice powder (PP) in cement production and to monitor void developments in mortars by X-ray Computerized Tomography (CT) which is a nondestructive test method. PP-blended cements were produced by replacing ordinary Portland cement with PP at 0% (control), 5%, 10% and 15% by weight. Paste and mortar specimens were manufactured by these blended cements. Some of the physical and mechanical tests are carried out on these mortar specimens. Experimental results showed that macro void developments in 100-day period for mortars with different PP replacement ratios exhibited different reduction in void ratios.

1. Introduction

Turkey is quite abundant in terms of natural pozzolans (NP) that can be utilized in cement production [1]. NP's are one of the raw materials of CEM II-type cement. Their usage in cement production ranges from 6% to 35% [2]. Usage of NP is controlled in cement production since they can increase water demand and decrease compressive strength of concrete mix [3]. On the other hand, utilization of NP improves numerous cement properties such as lower hydration temperature, resistance against chemical effects, freeze–thaw and strength at later ages. Besides, they can reduce the cost of cement production and lower CO_2 emission due to reduction of clinker ratio [4–6]. NP's grounded with clinker in cement production result in pozzolanic features as per their finenesses. Volcanic tuff (VT) is an NP, which is formed of the zeolitisation of the rocks of volcanic origin. In this process, pozzolanic activity of VT is altered by depending on chemical and mineralogical composition of VT [4]. Significant data have been obtained from several studies, having been conducted so as to observe the physical, mechanical and durability effects of the NP's in cement [7–9]. It was indicated therein that the ratio of the powdered NP to be substituted in the Portland cement was to be no more than 20% [9].

Porosity is the most important factor that governs durability of cement based composites [10]. Porosity is classified as gel voids, capillary voids and macro voids. Mehta and Monterio [11] quantify these voids as follows: gel voids are the ones with diameters of 15–20 Å (1 Å = 10^{-7} mm); capillary voids range from 0.01 mm to 1 mm; any voids with diameters greater than 50 nm are termed as macro voids. Capillary voids and macro voids,

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http://dx.doi.org/10.1016/j.measurement.2014.11.034
0263-2241/

known as air voids, are the most important factors affecting permeability since permeability controls durability of concrete [11]. In order to determine porosity of cement based composites, there are methods such as water absorption, Mercury Intrusion Porosimetry (MIP), gas adsorption, helium inflow, alternating current impedance spectroscopy (ACIS), solvent replacement, Nuclear Magnetic Resonance Imaging (MRI), image analysis and optical microscope method [12–14]. Although the MIP and water absorption methods are two of the most effective and commonly used methods to determine the total void ratio and capillarity [15–18] they are destructive methods. However, X-ray Computerized Tomography (CT) is more effective and a non-destructive method in determining porosity of cement based composites [19–23]. In CT method, part of X-rays beamed to a material from a certain distance is absorbed by the material and part of X-rays is also scattered. Some parts of X-rays pass through the material. These X-rays passed through the material are caught by detectors and then transmitted to a computer after being digitalized. The data in digital form are reconstructed to create an image via various algorithms. The solid, liquid and gas phases of the material can be displayed digitally making the analysis of the material easier. Amounts of X-rays absorbed by materials are also correlated with atomic density of substances. The higher the atomic density of a material, the higher the X-ray absorption percentage. It is also possible via CT to monitor void distribution development and void structure of the cementitious systems. Due to being extensively used in medical field, identification range of CT has been primarily made in medical field. Accordingly, -1000 is recognized by the international standards as the value of air and 0 as the value of water in CT; this scale has been defined as Hounsfield Unit (HU) to symbolize densities of substances. Although there are several other HU values obtained by studies related to concrete, HU values of numerous materials have not been defined yet [19,24–28].

In this study, the development of macro voids, the total macro void ratio, macro void distribution and macro void structure in mortar were investigated by CT in a non-destructive manner. Also, effects of pumice powder (PP) on consistency and setting time properties of cement pastes were studied. Likewise, effects of pumice powder (PP) on water absorption, unit weight and compressive strength values of cement mortars have been investigated.

2. Experimental program

2.1. Materials

The materials to produce mortars were standard CEN sand, pumice and Ordinary Portland Cement (OPC) (CEM I 42.5R) with specific gravity of 3.12 and specific surface area of 3780 cm^2/g. The chemical properties of these materials are given in Table 1. Ankara Limak Cement Factory donated the OPC; pumice was obtained from Kayseri Develi region. Pumice with a size of 4–8 mm was grinded in a laboratory ball mill with a screening range of 0–80 μm. Specific surface area, specific gravity and water absorption of the PP were found as 4190 cm^2/g, 2.50 g/cm^3 and 24.8%, respectively. While the biggest grain diameter was 80 microns, approximately 33% of the grains were below 10 microns.

Table 1
The chemical properties of OPC, pumice powder and CEN sand.

Oxides (%)	OPC	PP	CEN sand
CaO	62.39	4.61	0.21
SiO_2	19.49	56.06	93.59
Al_2O_3	5.28	16.40	2.01
Fe_2O_3	3.21	4.75	0.43
MgO	1.72	4.42	0.03
Na_2O	0.98	5.85	0.60
K_2O	0.75	5.35	1.02
SO_3	2.83	0.27	0.08
LOI	2.30	2.00	–

2.2. Preparation of cement paste and mortar specimens

Two types of preparations were used in this study; one of them was cement paste preparation according to EN 196-3 [29] and the other one was mortar preparation according to EN 196-1 [30]. Cement pastes were used for determining the amount of water to get consistency and setting time values via Vicat probes. Mortar samples were used for macro void development, the total macro void determination, water absorption and compressive strength tests. Blended cements were used in all tests; they were produced by PP replacement with 0% (control specimens), 5%, 10% and 15% ratios by weight. The paste mix proportions are given in Table 2.

As shown in Table 2, three different types of cements were obtained by PP replacement with differing ratios. The finesses of the cements manufactured increased depending on the PP replacement ratios while specific gravities of the cements decreased. The mortars with more PP replacement contained more particles but less cement as given in Table 2. As it is well known, the volume of cement particles grow 2.1 times at the end of hydration process leading to the generation of hydration products. On the other hand, PP reacts with $Ca(OH)_2$ and creates CSH; however, this reaction is slow [11]. Hence, macro void development of cements with PP replacement decreases in the early ages while this development increases in later ages.

The cement hydration needs water curing to generate more hydration products, standard curing temperature is 20 ± 2 °C. Increased curing water temperature accelerates the hydration in pozzolan added cements. In turn, porosity decreases rapidly [11].

When producing the mortars, 1350 g of standard CEN sand, 450 g of binder (OPC + PP) and 225 ml of water (3:1:0.5, respectively) were used in the mix, following EN 196–1 stipulations. The fresh mortars were filled in steel molds with 40 × 40 × 160 mm of dimensions and were compacted in 2 stages. Initially, 75% of the 40 mm height of the mold was filled with mortar and the compaction process was performed on a vibration table by applying 60 strokes per minute. At the 2nd stage the fresh mortar