Construction and Building Materials 94 (2015) 817–825

Contents lists available at ScienceDirect

Construction and Building Materials

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

Microstructural examination and potential application of rendering mortars made of tire rubber and expanded polystyrene wastes

Marcos Lanzón [a,*], Veerle Cnudde [b], Tim De Kock [b], Jan Dewanckele [c]

[a] Departamento de Arquitectura y Tecnología de la Edificación, ARQ&IDE, Universidad Politécnica de Cartagena, Paseo Alfonso XIII 50, 30203 Cartagena, Spain
[b] Department of Geology and Soil Science, PProGRess/UGCT, Ghent University, Krijgslaan 281/S8, B-9000 Ghent, Belgium
[c] Inside Matters, Sylvain Van der Guchtlaan 24, 9300 Aalst, Belgium

HIGHLIGHTS

- µCT provides additional information on the tire rubber–cement bonding.
- Expanded polystyrene shows better adhesion to cement than tire rubber.
- Calcium stearate is detected on tire rubber grains exposed to cement.
- The mortars meet essential EN 998 requirements (e.g. CS IV and W2).
- Finishing and undercoat renders can be industrially produced using the wastes.

ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form 10 July 2015
Accepted 14 July 2015

Keywords:
Rendering mortars
Microstructure
X-ray tomography
Visualization
Capillary water absorption
Mechanical properties
Calcium stearate

ABSTRACT

This paper studies the microstructure and potential application of rendering mortars containing tire rubber and expanded polystyrene wastes. The mortars were scanned at the Centre for X-ray Tomography (UGCT – Ghent University) and the µCT images were studied using 3D analysis software package Octopus. The samples' porosity increased due to the incorporation of the wastes and particularly, expanded polystyrene. Optical microscopy (thin sections) and SEM examination showed that tire rubber particles were not entirely bonded to cement, while expanded polystyrene showed better adhesion to the matrix. In addition, EDS Ca-mapping analysis confirmed expanded polystyrene was almost totally enclosed by a cementitious phase rich in calcium. The practical application of the mortars was tested taking into account the basic requirements applicable to rendering mortars (EN 998-1 standard). Despite the above microstructural limitations, it was found that using low doses of sodium oleate (0.25% w/w) the mortars accomplished the highest performance in terms of capillary water absorption and mechanical strength.

1. Introduction

The re-use of tire rubber and expanded polystyrene wastes may bring new solutions in the field of building materials and particularly, in renders and plasters. The role of tire rubber aggregates in the mechanical performance of cement materials has been studied by different authors. Pelisser et al. found that the compressive strength of concrete made with 10% w/w of recycled tire was reduced by only 14% comparing with conventional concrete [1]. Similar studies confirmed that the controlled addition of rubber wastes produces minor changes in the mechanical properties of cement materials [2,3]. A major advantage of incorporating tire rubber wastes to cement materials is that they become more ductile and flexible [4,5]. As regards the compatibility between tire rubber and cement, Segre et al. found that alkaline-treated tire rubber aggregates had better bonding to cement [6]. This lack of bonding to cement can be partially explained by the presence of anti-adherent additives, such as zinc stearate in tire rubber formulations [7]. Nevertheless, tire rubber grains can be externally modified to improve their compatibility with cement and asphalt mixtures [8,9]. Similarly, expanded polystyrene is recyclable into building materials to be used in non-structural applications [10]. Bouvard et al. used X-ray tomography to study thermal and mechanical characteristics of concrete made with expanded polystyrene. Using appropriate operations, such as threshold,

* Corresponding author.
E-mail address: marcos.lanzon@upct.es (M. Lanzón).

http://dx.doi.org/10.1016/j.conbuildmat.2015.07.086
0950-0618/

Table 1
Physicochemical characteristics of tire rubber and expanded polystyrene grains.

	Tire rubber grains	EPS grains
Type	Elastomer	Foam
Major constituents	Styrene-butadiene (synthetic), natural rubber and carbon black	Styrene
Other components	Additives	–
Air content	None	Up to 98%
Density (EN 1097-3), kg/m^3	391	20
Color	Black	White
Particle geometry	Irregular	Spherical
Size range, mm	0.125–2.0	0.5–3.5
Most abundant size, mm	0.5	2.0
Moisture, %	⩽0.05	⩽0.05
Water absorption	Negligible	Negligible

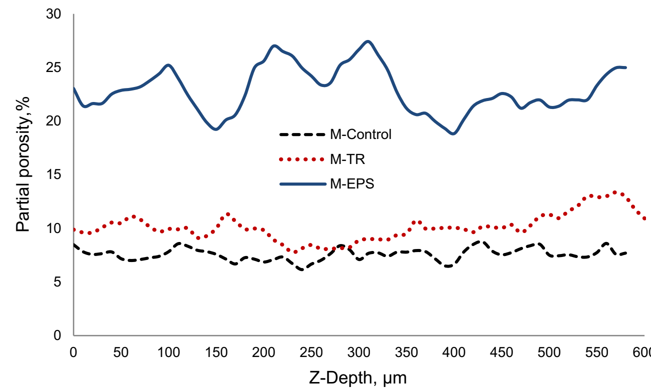

Fig. 1. Partial porosity variation in the studied formulations.

segmentation, and labelling of objects they reconstructed images showing EPS spheres and pores [11]. Ferrándiz et al. have recently studied the durability, thermal conductivity, microstructure and mechanical characteristics of expanded polystyrene mortars [12,13]. They found that expanded polystyrene was highly effective to reduce the thermal conductivity of mortars. However, the soft nature of the waste was a major drawback to study microstructural features by mercury intrusion porosimetry.

X-ray microtomography (µCT) is a relatively new non-destructive imaging technique that provides complete information on the internal volume of the sample [14]. Similarly to SEM, the sample requires minimal preparation and permits to extract valuable information on defects and pores inside the material. The fundamental properties and applications of µCT to materials characterization have been reported by Landis et al. [15]. In the context of geological materials, the use of X-ray computed tomography has been extensively described by Cnudde and Boone [16]. The main components of the scanner are: the source of radiation (X-ray tube), a rotational stage and a flat panel detector. While the sample rotates, the scanner acquires numerous 2D X-ray images (projections) that are recorded and reconstructed using a mathematical procedure. The resolution i.e., the smallest distance between objects that are recognized as individual entities, is expressed in voxels the 3D equivalent to a pixel. Phase analysis is one of the most interesting possibilities of µCT, since the phases are differentiated from each other by their X-ray absorption [15,16]. In cementitious materials, the dark spots/features are assigned to lower density phases, such as cracks or air voids naturally entrapped in the mortar [17]. The lighter areas, ranging in colour from white to dark grey, correspond to solid components of the mortar, such as cement or aggregates. An important strength of µCT is that the reconstructed images can be analysed with analysis software to retrieve 3D parameters, such as shape and volume. In this study Octopus Analysis was used for the 3D analysis. The combination of µCT and Octopus Analysis, formerly known as Morpho+, has proved to be useful to evaluate data on porosity and pore size distribution in geological materials [18–23]. Likewise, the reconstructed images can be imported into 3D rendering software, thus providing additional visualization about microstructural details of the samples [16,22,23].

Both the compatibility of hydrophobic wastes with cement and their influence on essential properties of mortars are not fully understood. Cement mortars are appropriate materials for recycling wastes, although the practicability of the resulting materials has been poorly studied. This paper examines microstructural features of mortars incorporating tire rubber and expanded polystyrene wastes. Special attention is focused on the extent of bonding between the wastes and cement using 3D visualization, microscopy and spectral analysis. The practical application of the mortar is demonstrated in the light of basic requirements covered by the EN 998-1 standard [24].

2. Materials and methods

2.1. Samples preparation

The samples were confectioned to reproduce as close as possible real rendering mortars formulations. Renders normally contain cement, aggregates, additives to improve certain characteristics and, optionally, pigments. Lightweight aggregates, such as expanded perlite are often incorporated in mortars to increase their workability and covering capacity. Having this practical information in mind, the mortars were composed of:

- Crushed marble (Macael) used as the principal aggregate (82.80% w/w).
- White cement (16.50% w/w); type EN 197-1 BL II 42.5R [25].
- Modified hydroxyethyl methyl-cellulose (0.10% w/w). Alkyl-celluloses are used in rendering mortars to adjust water retention, bonding to the substrate and workability.
- Tire rubber and expanded polystyrene wastes were added to the mortars at a dose of 0.6% w/w (equivalent to 2.54% v/v and 31.9% v/v, respectively). Additional information on the physicochemical characteristics of the wastes is shown in Table 1. The bulk density of the wastes was determined following the EN 1097-3 procedure [26].

The mortars containing tire rubber and expanded polystyrene wastes are termed M-TR and M-EPS, respectively. A reference mortar (M-Control) with the same composition except the wastes was used for comparative purposes. The components were mixed using a constant water percentage (21.1% w/w) in an automatic mixer-ToniMIX of variable speed (140/285 rpm) according to the EN 196-1 recommendations [27]. Then, the fresh paste was poured into $4 \times 4 \times 16$ cm metallic moulds and compacted. The specimens were cured for 48 h at 20 °C, 90% RH, stored at 20 ± 1 °C, 65 ± 5 % RH and tested after completing 28 days of curing.

2.2. µCT scanning and 3D analysis in Octopus Analysis

In µCT the achievable resolution is limited by the sample size and that makes it necessary to take small sub-samples. Cylindrical cores of 8 mm diameter were carefully drilled from the cured specimens and scanned using the in-house scanner developed in the Centre for X-ray Tomography of Ghent University (UGCT) [28].

Table 2
Closed, open and total porosity data obtained with Octopus Analysis.

Sample	Closed porosity (%)	Open porosity (%)	Total porosity (%)	ΔP (%)[a]
M-control	7.10	1.22	8.32	–
M-TR	7.68	2.64	10.32	2.00
M-EPS	7.27	15.64	22.90	14.58

[a] Porosity variation, ΔP, due to addition of TR or EPS to the mortar.