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Physico-mechanical and thermal properties of composite mortars containing lightweight aggregates of expanded polyvinyl chloride

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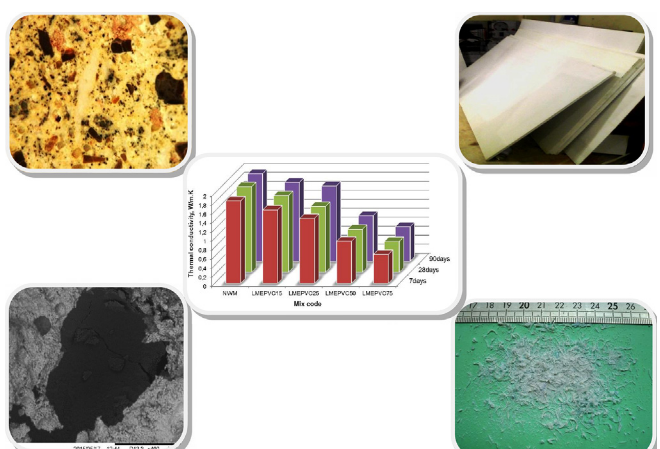
HIGHLIGHTS

- The incorporation of EPVC waste affects the properties of lightweight mortars.
- The addition of EPVC reduces the weight of the LMEPVC mortars and increases its ductility.
- The values of the UPV, E_d and λ for the composite mortars decrease with the increase of the volume of EPVC.
- LMEPVCs prove to be promising as building materials, due to their interesting properties and cost-effectiveness.

GRAPHICAL ABSTRACT



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ABSTRACT

Expanded polyvinyl chloride (PVC) or "FOREX" is widely used in advertising and signage boards, shop fittings and shop window decorations. This article attempts to study the physico-mechanical and thermal properties of lightweight composite mortars based on expanded polyvinyl chloride (LMEPVC), in which the natural sand are replaced by lightweight aggregates from expanded PVC sheets, with different volume proportions (0, 15, 25, 50 and 75%^{V}). The consistency, density, porosity accessible to water, mechanical strengths (compressive and flexural tests), ultrasonic pulse velocity (UPV), dynamic modulus of elasticity (E_d), and thermal conductivity are measured on various LMEPVC samples. Scanning electron microscopy (SEM) for microstructural analysis is performed to elucidate the mechanism of strength development. The results obtained showed that reduce the specific weight of the LMEPVC composites and improve their thermal insulation, particularly the composite LMEPVC75 (λ = 0.760 W/m.K). On the other hand, the dynamic modulus of elasticity (E_d) of that same composite was found to decrease by about 66% as compared to that of the reference mortar.

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1. Introduction

Waste, whether domestic, agricultural or industrial, represents one of the biggest problems of the 21st century. Indeed, the increasing world population and its concentration in the cities, as well as the development of industrial equipments and consumer goods are actually generating astronomical quantities of residues. In addition, traditional building materials of natural origin are eventually exposed to scarcity and even depletion. It is therefore important to think about developing new composite materials based on artificial or recycled light aggregates from industrial and agricultural waste.

Various types of recyclable materials, of industrial origin, are currently used in civil engineering applications; some of these materials are polymeric waste particles (rubber, chlorinated polyvinyl chloride (CPVC), polyethylene terephthalate (PET), polyurethane fibers, high density polyethylene (HDPE), rigid polyurethane foam, expanded polystyrene (EPS)), ceramics, wood, glass, cork, steel fibers [1–19] and agricultural byproducts such as flax, olive, rice shell, jute, and palm fibers [20–25]. Each type of waste has a particular effect on the properties of cementitious materials in the fresh state as well as in the hardened state. Lightweight aggregates (LWA) from waste materials are increasingly used due to their beneficial properties. The replacement of natural aggregates with light waste particles generally leads to lower densities of concrete or mortar [17,25–30]. Choi et al. [26] carried out a study on the incorporation of PET bottle waste as aggregates in mortars and concrete. They found out that the density of concretes containing 75% PET-siliceous sand composite aggregates was 16% lower than that of control concrete. So, according to Hannawi et al. [27] and Dulsang et al. [29], the decrease in the weight of the structure contributes to reducing buildings' risk for structural damage from an earthquake.

The compressive strength of concrete and cement mortar is a fundamental property that has been studied in detail in many research works related to the valorization of waste as lightweight aggregates (LWA). In most of these studies, it was found that the incorporation of lightweight aggregates (LWA) reduces the compressive strength of the resulting cementitious material [12,14,31–33]. Like the compressive strength, the incorporation of any type of lightweight aggregate reduces the flexural tensile strength of concrete or mortar [31,34]. Hannawi et al. [27] reported that the compressive strength of composite mortars, prepared by replacing 3%, 10%, 20% and 50% of sand by PET and polycarbonate (PC) aggregates, at 28 days, decreased when the amount of plastic aggregates in the mortar increased. They also found out that the compressive strength decreased by 69% for mixtures with 50% PET aggregates and by 64% for mixtures with 50% polycarbonate aggregates. During the determination of the compressive strength, samples containing lightweight aggregates can withstand a load for a few minutes after failure without disintegrating completely [27,28,35,36]. Additionally, authors in a number of researches [25,33] indicated that the porosity of light composites is higher than that of a mortar containing natural aggregates. However, few studies are found on the evaluation of the ultrasonic pulse velocity (UPV) in concrete or mortar containing recycled lightweight aggregates [2,37,38].

On the other hand, many researchers are fairly unanimous on the fact that the introduction of light aggregates into a cement mixture results in a significant improvement of the thermal insulation properties of blocks of cement or mortar containing lightweight aggregates from industrial waste as a partial substitute for natural aggregates, due to their low thermal conductivity [14,30]. Gouasmi et al. [30] worked on the valorization of PET plastic bottle waste and silica sand. They found out that the thermal conductivity of mortars containing 75% of composite aggregates based on PET-siliceous sand was 21% lower than that of control mortar. In addition, various research studies [11,39,40] indicate that lightweight aggregate-based mortars have a small modulus of elasticity. This feature is considered as potentially beneficial for certain applications such as in sidewalks, roads, safety barriers; they can also be used as seismic shock wave absorbers.

FOREX® is the best known trade mark for expanded PVC. Expanded PVC sheets are ideal for indoor and outdoor use in the areas of advertising, construction and industry. Expanded PVC panels are rot-proof, lightweight and rigid [41]. The expanded polyvinyl chloride is poorly permeable to water and has high chemical resistance and low thermal conductivity (0.081 W/m.K) [41].These expanded PVC sheets have a density 2–3 times lower than that of solid PVC sheets.

Regarding the waste recovery/recycling, expanded PVC (EPVC) sheets represent a non-negligible percentage of the total volume of waste discarded annually. Composite materials are nowadays an interesting subject of both theoretical and experimental research, as there is renewed interest worldwide in the use of Polymer-Mortar Composites or lightweight aggregate-based mortars in the building industry as a finishing or restoration material, or in other specific applications. Our work, which falls within this context, proposes the development of lightweight composite mortars, known as LMEPVC; they are based on expanded PVC (EPVC). A physico-mechanical characterization of the LMEPVC mortars was carried out in the fresh state and then in the hardened state in order to determine their long-term mechanical strengths, first without any additions, and then with the addition of light aggregates from expanded PVC, and their densities in the hardened state as well. Next, an attempt was made to explain the deformations starting from an analysis of the microstructure, using SEM images. The results of the ultrasonic pulse velocity (UPV), the dynamic modulus of elasticity E_d, along with the thermal characterizations, such as the measurement of the thermal conductivity λ at different curing ages, were then presented.

2. Test materials and methods

2.1. Materials

2.1.1. Cement

This is the Portland Composite Cement CPJ-CEM II/A-L 42.5, originating from the LCO plant of Lafarge group, located in the north-west of Algeria. This cement has a fineness of 4180 cm^2/g, a density equal to 3.12 and a compressive strength of 45.2 MPa, at 28 days.

The chemical and mineralogical characteristics of this cement are given in Tables 1 and 2.

2.1.2. Sand

The sand used in this work is a mixture of 60% quarry sand and 40% sea sand, with fraction 0/2mm. This sand came from the SECH Spa quarries of HASNAOUI Group of companies, located in Sidi Ali Benyoub (Wilaya of Sidi Bel Abbès). The granulometric curve of this sand is shown in Fig. 1. Its main physical characteristics are summarized in Table 3.

2.1.3. Waste from expanded PVC sheets (EPVC)

The EPVC waste is a composite containing 21% of calcite. It is used as aggregate in the form of fine particles of finely ground

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