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Valorization of spent cooking oils in hydrophobic waste-based lime mortars for restorative rendering applications

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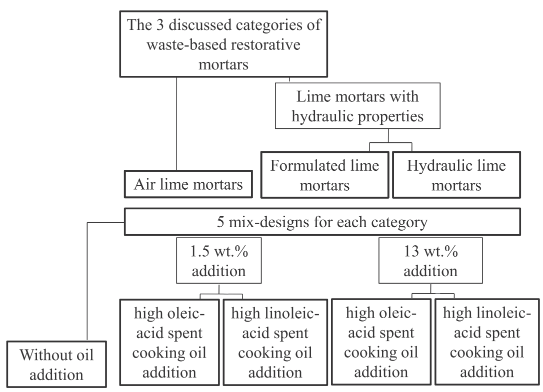
HIGHLIGHTS

- Use of waste-based fatty organic additives improves restoration sustainability.
- Inclusion of spent cooking oils in mortars brought significant hydrophobic values.
- High-oleic acid oil addition decreased the formation of macropores.
- Oiled mortars exhibited substantially increased frost resistance.

GRAPHICAL ABSTRACT



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ABSTRACT

The suitability of new lime mortars for restorative rendering applications was investigated. Air-, formulated- and hydraulic-lime mortars were synthesized with inclusion of two different types of spent sunflower cooking oils and, when necessary, brick waste powder as pozzolanic addition. The results of spent cooking oils addition in the mortars exhibited promising hydrophobic effects, such as sorptivity reduction up to 60 times and improvement of superficial durability. Addition of high-oleic acid cooking oil in 13 wt% in the formulated and hydraulic lime mortars significantly increased their hydrophobicity without worsening their mechanical strengths. All the investigated mortars exhibited appropriate indexes as restorative materials.

1. Introduction

Lime has historically been an important material in construction since ancient times. The history of application of limes manifests their highest use before 18th century, when they were gradually replaced by hydraulic limes, and later in 20th century by ordinary Portland cement (OPC) binders [1–3]. It is proven that application of the OPC cannot be an option for repair and rehabilitation of old buildings, due to incompatibility problems frequently associated with the pathology origin in the restoration of historical buildings. The low affinity of OPC binders/mortars with historical substrates has been frequently discussed [4–8]. On the other hand, chemical, physical and mechanical compatibility of lime mortars

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for restoration of historical masonries has been confirmed, due to their permeability and not very high compressive strength [9].

Lime mortars, due to their slow carbonation, low internal cohesion and high porosity, have often been mixed with many different additives to modify their properties. Studies of ancient formulations demonstrate that various organic additives have been used in the mortars in the past centuries [10]. These mixtures have been prepared in order to enhance one or some of their properties, such as setting time, adhesion, impermeability, hardness and porosity. Application of some fatty organic additives in the mixes, which lead to enhancements in the hydric properties of the lime mortars, had been a historical solution [7]. Addition of different types of oils in lime mortars has been done by many scholars and the developments of hydrophobic properties were almost always observed [11–19]. As recent instances, Nunes [16,18] reported that hydraulic lime mortars added with metakaolin and enriched with linseed oil, manifested a remarkable capillarity reduction and consequently higher resistance to NaCl cycles. In some studies, the additives source was from the food industry and possibly from the agro-food wastes. This could bring superior sustainability to the system by reducing the dependency on natural resources [20–22]. In most of the previous studies, the effects of unsaturation levels of the oils used as mortar additives have not been studied. However, unsaturation extent of these additives can be a key factor in microstructural alterations and hydrophobicity of the final product.

Hydraulic properties of the air lime mortars could be achieved as a result of pozzolanic materials additions in lime mortars, since many ancient civilizations have contributed to the development of limes with hydraulic properties, namely by being in contact with water [23]. "Cocciopesto" or crushed brick mortar is a material that goes back to the later Roman epoch and was used as plaster on surfaces prone to humid conditions [24]. These mortars as outdoor rendering materials manifest an aesthetic appearance for historical masonries with promising durability and performance. The enhancement of lime mortars with hydraulic properties by adding pozzolanic materials, in terms of mechanical resistance and durability, especially in humid conditions with limited exposure to air, is indicated in the literature [4,25].The studies by Donatello [26], Cachim [27] and Nunes [18] have demonstrated that a mixture of lime binders and pozzolans or amorphous siliceous materials enhances the characteristics of the mix.

In this study, ground brick waste as a ceramic residue is used as a pozzolanic additive in lime mortars. This ceramic waste material is usually rich of quartz and fired clays, and consists of dehydrated alumino-silicates [28]. According to the newest version of EN 459-1 [29] standard of building lime, some limes with hydraulic properties formerly classified with other names are now classified as formulated limes (FL) or hydraulic limes (HL) as a function of the pozzolanic content. According to this, the synthesized mortars prepared in the present study are defined in two groups: air lime mortars (AL) with or without spent cooking oils as additives, and lime mortars with hydraulic properties with or without spent cooking oils as additives. The latter group includes formulated lime mortars (FL) containing brick waste powder (3.1 wt%) and hydraulic lime mortars (HL) containing brick waste powder (6.2 wt%). Two different percentages (1.5 and 13%) of two types of spent cooking oils (high-oleic acid oil and high-linoleic acid oil) were used as additives for the synthesis of the three mentioned categories of lime mortars. Diverse quantities and characteristics (unsaturation levels) of the above mentioned variety of oils were used to study their effects on physical and microstructural alterations of the mortars, respectively.

Rendering applications are required for many old deteriorated exterior surfaces. To prevent damages to original masonries, the compatibility of the substrate with the new materials designed for this issue is essential [30]. In this paper, the feasibility and compatibility of using hydrophobic waste-based lime mortars for rendering application in historic/old buildings are investigated and discussed. Mortars are characterized in terms of properties that are important for the application of restorative outdoor rendering, such as workability at the fresh states, calcium carbonate formation rates, pore size distribution, water absorption through capillarity, water vapor permeability, mechanical strengths and durability life cycles. The characterizations aimed at providing an insight into the contribution of the waste additives to the hydrophobicity, performance and durability of lime-based mortars, when compared to the conventional restorative rendering materials.

2. Experimental part

2.1. Materials

The lime putty used for the present research is a commercial product (Candor®, supplied by Calceviva, Fasano, Brindisi, Italy), available in the Italian market and classified as CL 90S according to EN 459-1 [29]. The high calcium lime (CaO > 98% – 12 month aged and with 48.8% of water content) and pure siliceous sand with normalized granulometry according to EN 196-1 [31] (particle size between 0.08 and 2 mm), were used to form the reference mortar specimens. The mineralogical composition of drained lime putty was performed by XRD Philips Diffractometer PW 1840, 40 kV/20 mA- Cu Kα radiation, and it detected Portlandite as the major crystalline phase (Fig. 1). The designated pozzolanic material was provided from discarded commercial bricks (kindly supplied by Wienerberger S.p.A., Feltre, Italy) which, due to some physical defects, could not meet the suitability standards for the market. The supplied bricks were ground by laboratory hammer and ball mills, in order to obtain a fine powder. An average particle size of ≈10 μm was determined by laser granulometry (Malvern Instrument). Chemical composition of brick waste powder determined

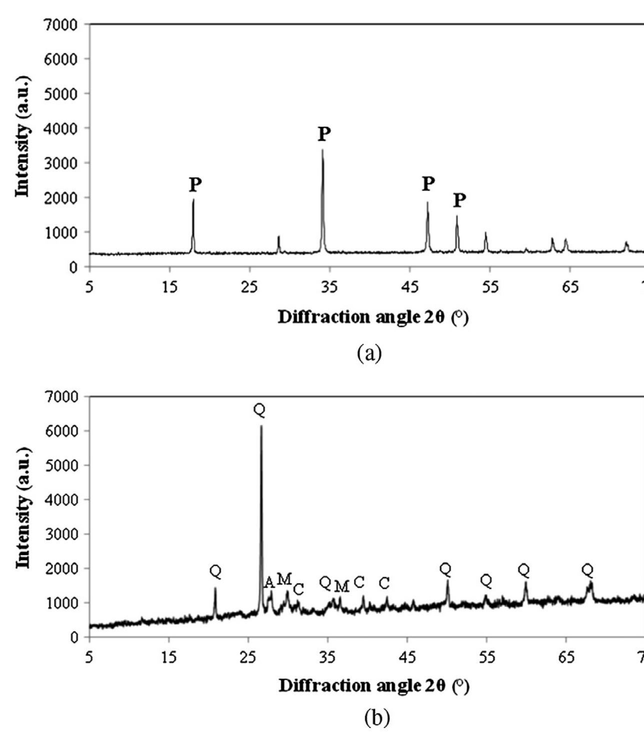

Fig. 1. X-ray diffraction analysis of the lime putty (a) and the brick waste powder (b); P: Portlandite; Q: Quartz; A: Albite; M: Maghemite; C: Calcite.