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Physico-chemical stone-mortar compatibility of commercial stone-repair mortars of historic buildings from Paris

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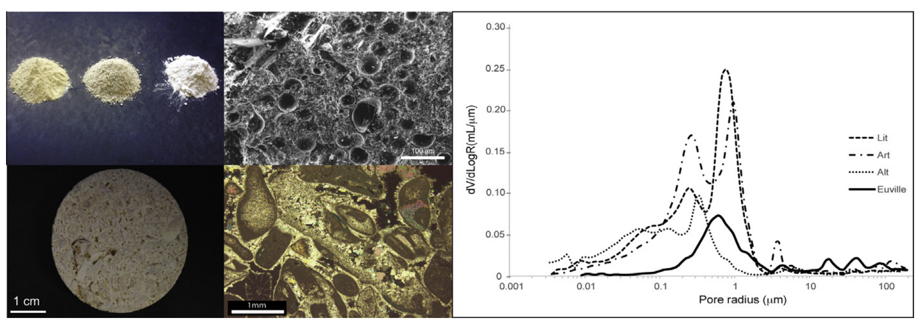
HIGHLIGHTS

- Commercial stone-repair mortars for surface damaged limestone.
- Raw anhydrous mortars, stone/mortar samples, buildings/laboratory characterization.
- Physico-chemical stone-mortar compatibility assessment.
- Chlorides, sulfates and nitrates from past restorations and environmental pollution.
- Better chemical and mechanical compatibility of mortars with no phyllosilicates.

GRAPHICAL ABSTRACT



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ABSTRACT

The physico-chemical compatibility of the most frequently used commercial stone-repair mortars applied to repair surface damage of a common limestone (Euville stone) employed in the basements of historic buildings from Paris was assessed. The characterization of anhydrous raw mortar materials, of stone and mortar samples collected from these buildings and laboratory specimens was carried out.

The presence of chlorides and sulfates (gypsum and mixtures of calcium and sodium sulfates) with minor amounts of nitrates in mortar samples collected from the buildings suggest an origin of salts caused by contamination/pollution coming from past restoration products and environmental pollution. The mortar containing quartz, marble aggregates, portlandite and hydraulic components (C_3S, C_2S and C_2AS) with addition of aluminosilicate micro-spherical particles with cementitious properties, and no phyllosilicates, shows a better chemical compatibility with the stone. The mechanical properties of this mortar are also closer to those of the limestone. However, some differences in the hydric properties due to their different pore systems and aesthetic features should be improved in further restoration works.

1. Introduction

From many architectural purposes, mortars can be used as plasters or renders covering the whole surface of walls or building facades, as bedding, jointing or pointing between stone ashlars or bricks, or even they can be used for rebuilding a decayed structure in restoration works. Some kinds of repair mortars can be applied for surface repairs of architectural surfaces. Various terms are used for these specific mortars, *stone repair mortar*, *reconstitution mortar* or '*plastic*' *repair mortar*, which have the same or very similar meaning to *surface repairs*, *plastic repairs*, *surface fills*, *loss*

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compensation mortars or *artificial stone mixtures* [1]. During restoration of heritage buildings, mortars are frequently used for the repointing of joints or for the 'plastic' repair of stone, which are designed to fill in missing parts of stone. These mortars are moldable mortars that can be applied in situ, and sets into place by its own adhesion to the substrate [2]. From all the possible terms that can be assigned to this kind of mortars, we have chosen '*stone-repair mortar*', since it is the clearest name for the purpose of our research, which involve mortars that have been used for repairing or reconstruction of surface damaged stone from restoration works that were carried out in historic buildings. A missing part of an original material is modelled by a new material, which is pliable when applied, and therefore can be adapted into various shapes and finished with required surface textures [1].

Repair mortars used for stone restoration are assumed to be highly compatible with historic materials in terms of physical, chemical and mechanical properties in order to assure the durability of masonry on the long term. A systematic approach for the characterization of historic mortars and materials to be repaired has been defined by RILEM TC 167 COM which offers a valuable tool to identify mortar components, nature of binder, aggregate, additives, and their relative proportions [3,4]. Ashurst in 1990 [5] described some decision factors on surface repairs, whereas Hughes and Valek in 2003 [6] reviewed the compatibility concept. These mortars must meet a series of requirements from a Cultural Heritage preservation point of view to avoid accelerated deterioration of original material. Material compatibility between repair mortars and the original material suggests that no damage should be caused to the repaired material. For example, the incompatibility among building materials due to the combination of sulfate-bearing mortars and magnesium-rich stone and mortars applied in XVIII restoration works lead to extensive weathering on a historic Monastery (XII century) by magnesium sulfate crystallization processes [7].

Nowadays, most professionals turn to commercial pre-mixed mortars. There are many available commercial mortars ready to use in restoration works, from local and international companies. The advantage is that these are prefabricated, and the manufacturer can guarantee that the content's mix is standardized, creating the same workability and properties for each batch, with consistent composition and working properties. This is much appreciated by restoration architects and contractors [8,9]. However, this advantage can be a disadvantage as well. The specially designed mortar for one specific stone can work just for stones with the same or similar physico-chemical characteristics. Furthermore, in cases where the stone is very heterogeneous, and properties can differ greatly from one stone sample to another, the standardized process will be less successful when aiming to achieve a compatible mortar [10]. Besides, these mixes present an uncertainty about the ingredients they contain. In restoration studies using commercial mortars, aggregates are frequently added to solve the problem of stone heterogeneity [11]. In the case of ready-mixed mortars, powders can simply be added with the required amount of clean water. However, is important to know the physical properties of the commercial product in order to assure the compatibility with the stone.

The selection of a binder is a starting point of the mix design as it predetermines the physical and mechanical properties of the mortar mix, as well as the capacity of the mix to be adapted to the appropriate form and appearance [1]. Natural Hydraulic Lime mortars (NHL) are produced from a naturally occurring 'impure' limestone/chalk. Typically, the impurities are those from clay minerals and other sources of alumina and silica. NHL mortars have been manufactured since the XVIII century by burning these limestones below the clinkering point. These NHL are able to set and harden even under water, as the mechanical strength development is mainly driven by hydration. Carbonation of the slaked lime contributes to the hardening process as well.

Hydraulic Limes mortars (HL) are produced by artificially blending calcium hydroxide, calcium silicates and calcium aluminates. This is commonly achieved by blending mixtures of clays and pure limestone, or calcium hydroxide with suitable pozzolanic materials. Pozzolans or pozzolanic materials (fly ash, burnt clays, etc.) are reactive materials that in the presence of soluble calcium hydroxide form hydrated compounds which act as binders. These are often added to increase strength gain in hydrated, hydraulic and natural hydraulic lime based mortars.

Greeks and Romans first used hydraulic lime mortars with natural pozzolans in ancient times [12] and Phoenicians employed these binders in Jerusalem (10th century BCE) [13]. NHL was used mostly during the nineteenth century. They are nowadays used in restoration of historical buildings because their chemical and physical properties are similar to those of materials used by the original builders, and because they ensure the development of superior mechanical properties, without having the general drawbacks of Portland cement. NHL was the precursor of Portland cement. The main difference in the production of NHL and cement is the burning temperature. Callebaut et al. in 2001 [14] focused on the characterization of nineteenth century hydraulic restoration mortars used in the Saint Michael's Church in Leuven (Belgium), for restoring weathered mortar joints. Based on the presence of a calcium aluminosilicate (gehlenite (C_2AS)), the dominance of di-calcium silicate (larnite (C_2S)), the large amounts of portlandite (calcium hydroxide, CH), together with chemical analyses and historical sources, these hydraulic mortars were characterized as NHL mortars.

The ready-mixed mortars are available as powder materials composed of binders, aggregates and additives already packed together in appropriate ratios. The mortars preparation only consists of simple mixing operations with the correct amount of water (which is usually indicated in the technical data sheets). NHLs are frequently employed as binders in the commercial mixes because of their quick setting capability and remarkable mechanical strengths [13,15,16]. The characterization of commercial ready-mixed mortars, allows verifying their real composition and performance characteristics [17]. However, these composition and properties often differ from those declared in the technical specifications supplied by the manufacturers, finding disagreements with the composition declared by the supplier [18]. There is still a lack for testing the physical properties and durability of mortars according to European standard tests, especially in terms of compatibility with stone, and the long-term behaviour of the repaired mortar/stone interface [11].

The aim of this research is to determine the physico-chemical compatibility of the three most frequently used commercial stone-repair mortars applied to repair the surface damage of Euville stone, a common limestone used in the basements of historic buildings in Paris city.

2. Materials and methods

2.1. Characteristics of selected materials

Three commercial stone-repair mortars (Fig. 1a) were selected in this research on the basis of their application on some damaged surface areas of the same type of stone, repaired due to salt crystallization processes, in different historic buildings of Paris. These buildings were repaired in the same period of time corresponding to the restoration campaign 2008–2010. The selected stone is the so-called Euville limestone (Fig. 1b) that was used in the outdoor basements of the Grand Palais, Palais de la Découverte and Préfecture de Police historic buildings.