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Original article

An experimental study on earth plasters for earthen building protection: The effects of different admixtures and surface treatments

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ABSTRACT

In rainy climates, the external surfaces of earthen buildings suffer water erosion. In this paper, the properties of earth plasters have been investigated considering the specific relationship with the underlying substrate. Ten typologies of earth plasters containing different admixtures and surface treatments, a cob wall and a rammed earth wall were produced in laboratory. The aim is to evaluate the effectiveness of the coatings in protecting the earthen walls against weathering. An in situ procedure consisting of a shrinkage test followed by an adhesion strength test was performed in order to identify the earth/sand ratio optimal for the plaster manufacturing. Then, a series of tests was carried out both on the plasters and the two walls: compression, water vapor permeability, surface color, wettability, water absorption and erosion. The results demonstrate that all the plasters are physically and mechanically compatible with the earthen substrates and that the most important differences are in the specific relationship with water. The earth plaster treated with the silane–siloxane product was found to be the best one: it is fully compatible, water-repellent and highly resistant to water erosion. Hence, there is a potential for the use of earth plasters for the protection of earthen buildings against weathering.

1. Introduction

Raw earth buildings represent an important, although difficult to quantify, part of the world-building heritage. They can be found in very different climates, in the arid zones as well as in the tropical and temperate latitudes. At present, about 15% of UNESCO Heritage Sites is represented by earthen architectures [1]. In the Marche region (Italy), a total of 245 earthen buildings are still present according to a recent official cataloguing [2]. They need to be preserved from ruin and deterioration, as they represent a cultural and architectural heritage.

The main drawback of raw earth is its affinity for water. In rainy climates, the degradation of historic earthen buildings is mainly due to water in combination with other factors, such as abandonment state, lack of roof maintenance and inadequate protective elements. It is important to identify plasters able to protect the external surfaces of such buildings against weathering. The plaster should have specific characteristics, such as good workability, physical and mechanical compatibility with the substrate, hydrophobicity and high resistance to water erosion.

The earth plasters seem to be the most suitable [3,4]. The earth for plastering is taken from the natural soil under the arable layer and consists of grains of variable size. In particular, the clayey component acts as a binder for the sand grain skeleton (or gravel), and the particles of silt with intermediate diameter complete the grain size distribution curve. The clay binder provides the dry strength and causes the drying shrinkage of the soil material. To regulate the shrinkage and prevent the cracking of the plaster, the soil can be admixed with other materials, such as straw, coarse sand or other mineral aggregates [5].

These renders have several advantages. Unlike cement-based coatings, they are compatible with the earthen walls in terms of material, esthetic appearance, water vapor permeability and mechanical behavior [3]. The continuity of the water vapor permeability throughout the wall is an important feature: when moisture inside an earthen wall is not free to evaporate outside because trapped by a waterproof coating, deleterious phenomena, such

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	Soil used in this study	Earthen build. n° 1	Earthen build. n° 2	Earthen build. n° 3
Gravel (> 4.750 mm) %	0	0	0	0
Sand (4.750 mm - 0.075 mm) %	13	17	17	16
Silt (0.075 mm - 0.002 mm) %	47	51	47	51
Clay (< 0.002 mm) %	39	32	36	33
Water natural content %	22	-	-	-
Liquid limit %	44	39	39	37
Plastic limit %	25	19	19	20
Plasticity index %	18	20	20	17
USCS Classification %	CL	CL	CL	CL

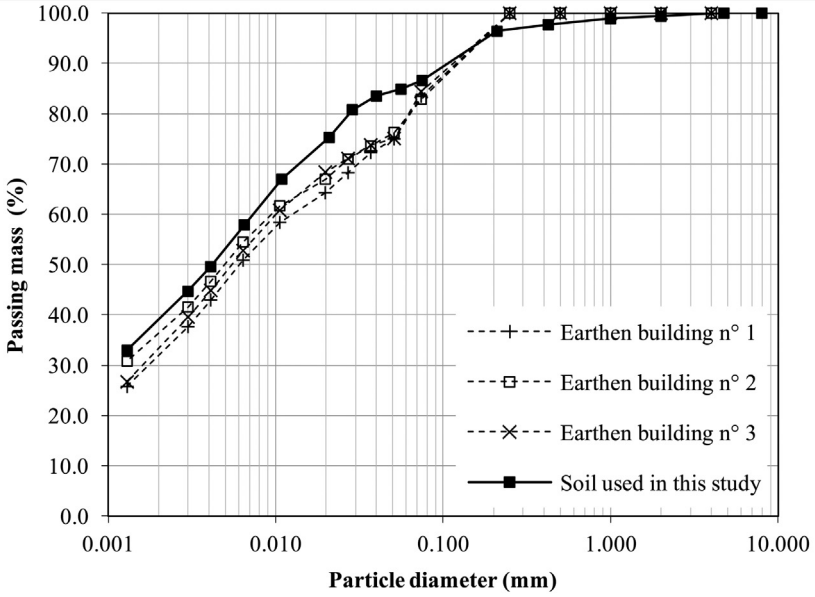

Fig. 1. Geotechnical characterization of the soil.

as blown render, damp internal walls and mould may occur. The mechanical compatibility is a key factor too: when there is too much difference between the Young's modulus of the wall and that of the coating, the stress changes due to overloads, moisture and temperature variations could generate a differential strain high enough to damage the bond of the plaster with the underlying substrate.

The earth plasters have a main weak point: they are poorly resistant against weathering because of their sensibility to water [4,6]. However, the addition of other materials (admixtures) in the plaster as well as the application of a protective treatment on its hardened surface could eliminate or reduce this lack.

In the international context, many authors studied the properties of raw earth as a building material, sometimes testing new solutions based on the combination of soil with low percentages of stabilizers (cement, lime, fiber, natural additives, etc.). Several aspects, such as sustainability, embodied energy and CO_2 emissions [7], building energy efficiency and thermo-hygrometric comfort [8–10], durability [11–13] and physical–mechanical behavior [13–17] were investigated. Some researchers deepened the effects of fiber contents on the mechanical properties [18–20] and on the shrinkage [19,20] of earthen materials. On the contrary, few studies have been carried out on the protection of earthen surfaces against atmospheric agents, both in the field of historic building preservation and in that of new constructions. Concerning the earth plasters, Hamard et al. [3] found that: both the nature of the substrate and the clay content of the plaster significantly influence the adhesive strength; an increase in clay percentage strengthens the plaster until the effect of shrinkage becomes predominant and weakens the plaster–wall interface; the presence of fibers prevents the plaster from cracking during the drying shrinkage.

Delinière et al. [21] studied the physical, mineralogical and mechanical properties of ready-mixed clay plasters, demonstrating that the linear shrinkage of fresh plasters as well as the flexural and compressive strengths of hardened plasters are correlated with the mass percentage of clay content whereas they are not linked with the nature of the clay minerals and with the initial water content; the adhesive strength depends significantly on the substrate preparation: an effective preparation should determine higher values with a lower dispersion for the adhesive strength.

According to Beas Guerrero de Luna [22], the mucilage admixture has no effect on the earth plaster; the acrylic additive improves the abrasion resistance, but significantly reduces the vapor transmission and increases the capillarity; the ethyl–silicate additive behaves like the acrylic, but makes the plaster more resistant to water.

Concerning the earth-gypsum plasters, Mattone [4] demonstrated that the use of treatments, such as aleurites oil and corn oil, unlike the potassium silicate, significantly enhances the behavior of the plaster in terms of water absorption and erosion resistance.

It is evident that some questions are still open: there are few studies in literature dealing with protective plasters for earthen walls; the latter rarely use a multidisciplinary approach for determining the performances of the plasters in relation with the underlying substrate; there is still a lack of effective solutions for