Journal of Cultural Heritage 16 (2015) 185–191

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Original article

Conservation of building materials of historic monuments using a hybrid formulation

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ARTICLE INFO

Article history:
Received 10 December 2013
Accepted 6 May 2014
Available online 7 June 2014

Keywords:
Hybrid formulation
Volcanic tuff
Loseros
TEOS
Conservation

ABSTRACT

Green volcanic tuff has been used in the construction of very important historic buildings in the city of Guanajuato, Mexico, a UNESCO World Cultural Heritage city since 1988. The chemical and mineralogical composition as well as the physical properties observed in the stone (Loseros tuff) presently used to restore such buildings suggests the need for preventive treatment to delay the decay process. A hybrid formulation based on tetraethyl orthosilicate (TEOS), colloidal silica, and hydroxyl-terminated polydimethylsiloxane (PDMS-OH) has been used to treat the volcanic tuff. Several studies were performed in order to evaluate the properties of the stone after treatment; such as determination of the percentage of formulation deposited, as well as variations in porosity, hardness, and salt crystallization resistance.

1. Research aim

The objective of this work is the study of a hybrid formulation based on TEOS/colloidal silica/PDMS-OH in the treatment (consolidation and hydrofugation) of stone used to restore several historic monuments in the city of Guanajuato, Mexico. Most of the colonial buildings were built with natural stones called Loseros Tuff, a greenish to reddish vulcanite.

This material, once extracted from natural deposits, presents different lithofacies with heterogeneous properties and weathering effects. Loseros have similar properties to degraded stones located in some historic buildings; for example, the Brinell hardness (HB) of the Loseros is only 3 to 6 percent higher than the hardness observed in degraded stone (i.e., monuments' stone). Therefore, a treatment to improve the mechanical properties based on the hybrid formulation is suggested. On the other hand, physical properties such as water absorption and mineralogical composition of the Loseros stone suggest that a combination of a consolidant hydrophobic treatment could delay the natural decay of the rock.

2. Introduction

During the colonial and post-colonial period (16thto 19th centuries), Guanajuato city was one of the most important cities in New Spain due to its gold and silver production. Hence, the neoclassical architecture style adopted in the construction of its most representative buildings which used two different volcanic tuffs, one of them was the green volcanic tuff known as Loseros. Fig. 1 shows the location of the main deposits currently. Rock is extracted from *Cerro El Tepozan* (Tepozan Hill) to build and restore monuments and buildings in the city. However, the current quarry no longer corresponds to the stone originally used.

This stone was extracted from six different quarries in the past. Today, the only active quarry left is the so-called *"Loseros"* (Fig. 1, marked as A). There is a lack of understanding regarding the characteristics and properties of the quarries. Meanwhile, the origin and age of the deposit are still under debate. Some authors such as Guiza et al. have suggested that the stone is rhyolitic volcanic ash [1], whilst Schulze has suggested that Loseros is a tuffaceous deposit resulting from the aqueous-igneous [2]. Other authors consider the deposit a green tuffaceous sandstone formed in lacustrine conditions [3].

Fig. 2 is a representation of the Loseros deposit. Fig. 2a illustrates the wide variety of colors (reddish brown, pink, green and even white) of the stone. Recently, a physical and petrographic study of Loseros reported the identification of three different lithofacies

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http://dx.doi.org/10.1016/j.culher.2014.05.004
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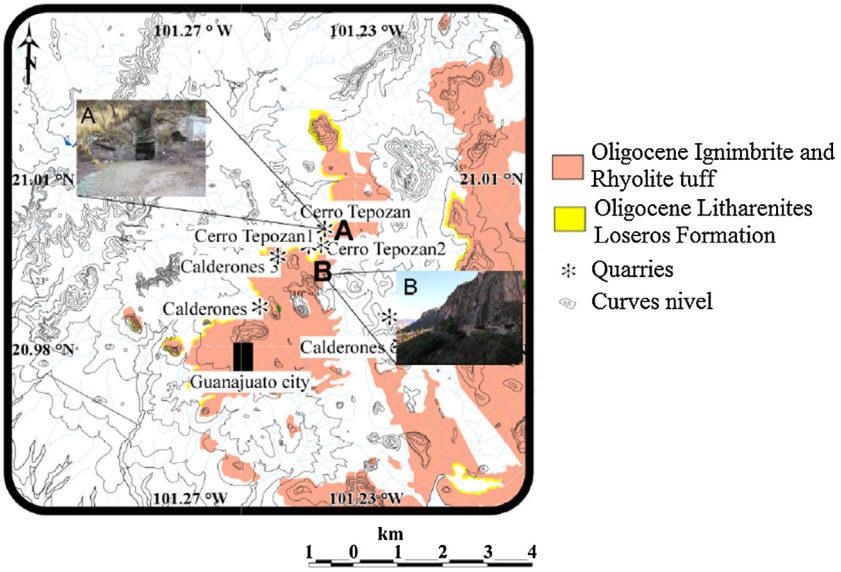

Fig. 1. The main deposits for green volcanic tuff in Cerro Tepozan (A) Loseros and (B) Bufa locality.

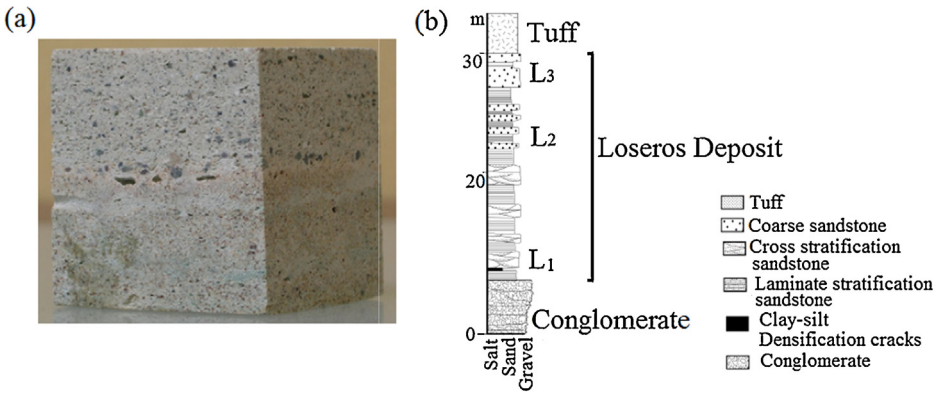

Fig. 2. a: Loseros stone; b: stratigraphic reconstructions of the Loseros [4].

after stratigraphic reconstruction (Fig. 2b). Namely, L_1 consists of beds of coarse and fine sand with units featuring cross-lamination and cross stratification sandstone; while L_2 and L_3 present layering consisting of beds of fine and coarse green sand with horizontal lamination. The difference between these lithofacieslies is the amount of laminated stratification sandstone. The lower level (about 30 m) presents properties only related to tuff material [4].

This stone's grain size varies from gravel (granule) up to fine or coarse sandgrain. Some Loseros properties could suggest that this rock can be considered as a sedimentary rock due to pseudo-stratification and cross-lamination. However, Edwards [5] and other authors [1–3] have indicated that the chemical composition of Loseros is more similar to tuff, which will be discussed in this contribution.

Table 1 includes the physical properties and the clast size observed for the lithofacies present in Loseros. According to the pyroclastic classification by Schmidt [6], Loseros presents a mixture of coarse and fine tuffaceous materials with a little epiclastic consolidated stone.

Table 1
Properties of Losero litofacies [4].

	Color	Clast size (mm)	Classification according to Schmidt [6]
L_1	Green to red	50–5	Lapilli-tuff
L_2	Green to white or cream	20–5	Croase (ash) tuff
L_3	Green to light yellow	5–1/16	Tuffaceous sandstone

Many buildings, gardens, houses and historic buildings were constructed with Loseros. Fig. 3 shows two Guanajuato city monuments (Belen Church and the Main Theater) where Loseros stone was used; scaling and crumbing deterioration are appreciated. Extreme moisture variations in the medium are the main cause of these weathering processes [7]. López-Doncel et al. report that the causes of deterioration for this stone cannot be attributed to a single factor; the main contributor to the decay process of Loseros could be the porosity and heterogeneous pore radii distribution [8], as well as repeated shrinking and swelling of clay minerals, caused by wet/dry cycling.

In terms of composition and lithofacies, the material presently extracted from Loseros for restoration of historic buildings in the Guanajuato city has different mechanical and chemical properties [4].

Silicon-based compounds have been an alternative in the consolidation and hydrophobic treatment of stone; the first is used to improve mechanical properties in degraded stone and the second one as a water repellent [9]. The formulations using alkoxysilanes as TEOS-based consolidants, along with consolidants based on TEOS/colloidal or silica nanoparticles [10–12] have been widely studied. Consolidants containing polyhedral oligomeric