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CONSIDERATIONS FOR IN-SITU APPLICATION OF SUSTAINABLE RESTORATIVE MATERIALS IN THE PASARGADAE WORLD HERITAGE SITE

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Abstract

In this study, considerations for design, characterization, and in-situ application of sustainable materials for restorative use in the Pasargadae world heritage site are discussed. The study as a preparatory stage of an eminent restoration project deals with several preliminary requisites leading to mortar design for in-situ application. In this research, one of the most important considered requisites is compatibility. This property does not exclude any of its physical, chemical, mechanical, or aesthetical manifestations. Reversibility, where is practicable, is another essential property expected from such a restoration material to be taken in account. Moreover, sustainability of the conservation project is highly dependent on the environmental considerations in the design of the restorative materials. Economic considerations will also play a critical role in the frame of conservation plan as their enhancement can broaden the domain of conservation potentials. The designated waste-based strategy in design of restorative materials and their response to certain requisites of the conservation plan are discussed. Furthermore, the particular considerations for restorations in Pasargadae incorporated some exclusive strategies as a restorative tailored design task.

Keywords

Restorative material; compatibility; sustainability; reversibility; cultural heritage.

1 Introduction

Pasargadae world heritage site is located in the heart of Fars province of Iran and its unique stone architecture gets back to 559–530 BC [1]. The construction system in the Pasargadae – like the Persepolis- had been stone architecture without application of joint mortars. However, during the time with stone degradations, the stone joint gaps need to be filled with proper, compatible, and sustainable repointing material to decrease the weathering penetration effects in the depth of historic materials. The new restorative materials and their similarity with traditional mortars should be always evaluated, as this similarity is considered to be significant for the soundness of the compatibility requirement [2]. One of the most reliable materials as designated restorative grout has been always lime. The historical importance of lime as a basic material in constructions since ancient times has been frequently claimed [3,4]. On the other hand the incompatibility of some newer materials such as ordinary Portland cement (OPC) binders for restoration of historical masonry is now proven [5-9]. These, have rendered lime-based materials conventional and usually reliable restorative material [10]. However, lime mortars due to their high porous structure, slow setting and hardening through slow carbonation, and not high internal cohesion have been often mixed with various additives to enhance and meliorate such properties [11]. In many cases of historic mortars fatty acids in the form fatty organics have been used as additives inside the mortars to contain the moisture problem as fountainhead of many degradation problems for mortars [8] and inclusion of different types of oils in lime mortars in recent researches have almost always manifested progressive hydrophobic enhancements [12-13]. Manufacturing of mortars with waste-based additives can bring superior sustainability to the systems as a consequence of cutback of dependency on natural recourses [13,14]. This environmental advantage can enhance the index of the restorative material in the frame of conservation plan in order to facilitate and broaden the domain of restorative potentials. Broadening the potential domain of conservation is demanding, especially in the cases of developing countries with numerous tangible cultural heritage in need of conservation.

This study deals with the preliminary stage of tailored design of restorative mortars for pointing application in the Pasargadae world heritage site. A list of perquisites and considerations for material design in this particular site-application is listed. Compatibility considerations are discussed in categories of technical, conceptual (philological), and aesthetical. The considerations were directed at providing discernment into the contribution of the waste additives to enhancement of restorative mortars in a tailored design.

Figure 1. A view of the Pasargadae world heritage site

2 Main considerations

In the recent decades, many elements of the historic built environment are dealing with various types of decays and damages; hence exploring their conservation and preservation by compatible materials is demanding [15]. For a successful restorative intervention, compatibility of the designated materials for repair with the historic substrate masonry is a demanding prerequisite. Furthermore, sustainability and being economically friendly are other important issues for considerations [16]. However, the discussed low affinity of OPC mortars/binders and modern polymer-based materials with historical substrates and energy consumptions and emissions regarding OPC manufacturing are intensive due to the significant heat required for their production. Production of only one ton of OPC requires about 5 million kilojoules of energy, equivalent to almost 180 kilograms of coal, and emits nearly a ton of carbon dioxide [17]. The most destructive environmental problem regarding these materials is related to their contribution in increment of the mean air temperature [18], which is emanating from CO_2 formation in the atmosphere.

Apart from all the environment mentioned issues, in order to respect the essence of the original masonries, application of historic mixes as restorative grouts, renders, or mortars is highly recommended as both historic solutions and modern research discuss their high potentials of compatibility in restoration [19]. However, some traditional/ historical materialistic solutions are not significantly eco-friendly products, basically due to their production process or their compounds [20]. Hence, introduction of more environmentally friendly restorative materials is necessary especially due to recent acceleration in global warming.

Although the performance of many modern historic mortars is acceptably high, their expenses are quite high and their each single additive targets a certain property enhancement. Therefore these additives are usually combined in utilization and increase the workload and consequently the final price**.** The economic considerations play an important role in the conservation plans. Introduction of economically friendly materials spread the possibilities to treat historic built environment as best practice within the conservation plan and maintenance routines. Development of the sustainable and low cost repair mortars for rehabilitation of built environment is the concern of many scholars in fields of civil, materials, and cultural heritage.

In the historic site of Pasargadae there are various types of damages and deteriorations in need of repair with sustainable material. There are many gaps in need of pointing with restorative and compatible grouts (Figure 2). Such grouts/mortars rather than compatibility are recommended to have high indexes of performance, availability, durability and sustainability.

Figure 2. Example of degraded masonries in need of pointing with compatible mortars (Pasargadae, Iran)

Repointing was historically a common restorative practice, when new gaps were forming due to material degradations or when the external part of the mortar joints was periodically renewed. However, in the Pasargadae, pointing mortar does not have historical evidence as the construction system was not based on wet assemblies (without mortar joints). This new need is due to stone degradations over the years and the risk of weathering penetrations that can highly accelerate deteriorations. Despite the apparent easiness of repointing, the new materials used for these applications should be carefully designated, as their compatibility with the existing historic masonry is demanding to prevent negative consequences on the original materials. For example, the application of too stiff and compact cement-based mortars frequently ends to material detachment (significantly when sulphates release in the masonry after rising damp), or might end to corrosion and powdering of the surrounding masonries [21]. Hence, it is usually recommended that restorative materials manifest high similarities to the existing historic ones, in terms of microstructure and physical properties, mechanical properties and thermal properties. Even if it is usually suggested that restorative mortars be designed by incorporating simulations of the historic ones, still using traditional raw technologies does not guarantee the compatibility of restorative interventions, therefore the necessity of investigating new but historic-based restoration materials comes out.

Starting from the short discussion above, this paper discusses the considerations for new historic waste-based mortars that were formulated and manufactured for restorative applications in the Pasargadae. The microstructural and physical properties of these materials are under determination, in order to assess their compatibility with existing old/ historical masonries. Particularly, proper properties such as pore size distribution, water absorption and water vapour permeability, are significant to guarantee that exchanges of liquid water and water vapour can take place between the historic materials and the ambient. After application of the restorative grouts and mortars, if such exchanges were reduced, degradation has high potentials to take place.

2.1 Pointing the joints as the prior application

The stone-based construction of the Pasargadae was based of three categories of limestone classified according to their essence and colours (white, dark-gray, and green-gray). The two formers have a compact microstructure and the latter with higher porosity, respectively [22]. The stones demonstrate diverse macroscopic features, such as textures and decay patterns. A recent study on these stones manifests the main reasons of decay in the two latter categories as dissolution of calcite crystals and the lumping of clay minerals. However, in the case of the former category, the main decay factor was introduced as dissolution induced by microorganism activity [22]. The construction system of stone architecture in the Pasargadae –as well as Persepolis – had been dry without mortar joints as the stones were placing beside each other flawlessly. The mentioned before, degradations have ended to formation of gaps between the placed stones that potentially accelerate the materials deterioration through weathering penetrations. Hence, they should be pointed with compatible re-pointing mortars.

2.2 Compatibility

2.2.1 Technical compatibility

Lime based mortars were selected to prepare the test samples. The physical, chemical, and mechanical compatibility of lime mortars for restoration of historical masonries has been confirmed by various researches, due to their high permeability and not very high stiffness [10]. According to the newest version of standard of building lime [23] EN 459-1, the mortars used for this consideration are classified as air lime mortars with or without sesame oils as additives. This decision is made due to the climatic status of the Pasargadae with low relative humidity. In this condition the formerly applied hydraulic, formulated, and natural hydraulic limes have been unsuccessful as for their hardening and setting they need humidity for their pozzolanic actions.

Lime mortars historically have been mixed with various fatty organics to enhance their hydric properties. A recent study demonstrated that unsaturation extent of these organic additives can be a key factor in microstructural alterations and hydrophobicity of the final material [24]. In this research, sesame oil, as a common product in Iran with two different unsaturation levels in used as an organic additive to enhance hydrophobicity of the restorative mortars.

2.2.2 Conceptual compatibility

One of the main principles of the historic Persian architecture have been always dependency on the materials from the surroundings of the site. For instance, stone construction of Pasargadae and Persepolis had been dependent on the mines of their actual province. This principle apart from bringing conceptual compatibility imports environmental and economic values to the final product. Hence, the mix designs were decided to be dependent on the site potentials, including stone powders and sand.

2.2.3 Aesthetical compatibility

In the considerations for tailored-design of restorative mortars for repointing aesthetical compatibility plays a key role. The term "aesthetical compatibility" here deals with appearance of these new mortars/grouts that firstly is similar to many historic mortars. Secondly, it deals with their color adjustability. As 75 w.t.% of these mortars are included by the inert, the non-reactive part plays the main role in the adjustability of the colors of these materials. As displayed in Table 1 the inert is composed by three different stone powders and one type of normalized sand from the close by river. These stone powders with different colors (white, dark-gray, and green-gray) were opted for with adjustable percentage to perform as natural-physical pigments that can set the desired color for various platforms to achieve the appropriate aesthetic compatibility.

Table 1: Designated materials to form the inert

Material	**Colour**	**w.t. %**
White stone powder	White	18.75
Dark stone powder	Black	37.5
Sandstone	Beige	25
Normalized sand	Beige	18.75

2.3 Durability

The durability of the mortars were placed under evaluation under two different conditions: 1) curing at lab temperature, 2) curing in the environment before the in-situ application. The latter one was carried out due to the complexity and numerous parameters of natural curing at ambient that affect the curing process of mortars. The mortars cured in both conditions will be characterized in terms of microstructural, physical, and mechanical properties to facilitate the perquisites preparation for in-situ application through they comparison.

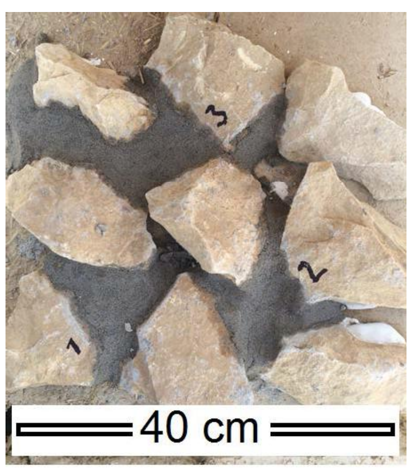

Figure 3. Curing of the mortars in natural condition and simulations

3 Conclusion

The considerations for tailored-design of restorative mortars in the Pasargadae world heritage deal with environmental, economic, compatibility, and technical issues. The waste-based policies are undertaken to cutback the dependency on natural resources. This apart from sustainability achievements, through economic advantages spreads the possibilities to treat historic built environment as best practice within the conservation plan and maintenance routines. Air-lime mortars were designated to make benefit of the low relative humidity of the environment for carbonation procedure and sesame oil was opted as additive to enhance hydrophobicity of the materials. Different percentages of various types/colors of the local stone powders where used as natural pigments to form the complex inert with aesthetic adjustability. The durability of the mortars/grouts were planned to be assessed in parallel conditions of laboratory and natural environment, as the latter one deals with more climatic parameters and leads to a more realistic tailored-design, respectively.

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