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Review

Experimental characterization of commercial lime based grouts for stone masonry consolidation

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ABSTRACT

Conservation, repair and strengthening of historic masonry buildings should preserve their significance and ensure their structural stability. The condition of a given structure and the extent of damage determine the type of action needed. Grouting is a well-known remedial technique, which can be durable and mechanically efficient whilst preserving the historic value. Still, the selection of a grout for repair must be based on the physical and chemical properties of the existing materials. Parameters such as rheology, injectability and stability of the mix should be considered to ensure the effectiveness of grout injection. In addition, the bond strength of the grout to the existing material is the most relevant mechanical property. Several commercial lime based grouts are available but it is unclear what are the applicable standards and requirements. This paper evaluates the behavior of commercial grouts under laboratory conditions. First, the properties of the grouts as an independent product are assessed with the objective to perform a comparative analysis of their behavior subjected to different conditions (temperature and working time of grout after mixing). Then, the behavior of the grouts when used in combination with stones used in the construction of masonry buildings is addressed (granite, schist and limestone), again considering different conditions (dry, wet and saturated). It is shown that the performance of the commercial products is rather different and careful selection of injection materials in practical applications is recommended.

Contents

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1. Introduction

Grouting constitutes one of the most common techniques applied for the repair and strengthening of masonry structures, either in presence of voids or cracks. The technique requires that cracks and voids are interconnected to an extent that the grout can easily flow in the existing materials. This technique recovers the continuity of the existing material, providing a more homogeneous material, and increasing the cohesion and strength of the damaged structural elements, with minimal changes in their morphology and in the load-bearing system. Given that grouting is an irreversible intervention, the design of the grout as well as the method of its application to historic structures must satisfy a series of performance requirements, namely compatibility. The performance requirements involve aspects such as injectability, bond and durability, and they are set on the basis of an overall approach of the structure to be repaired, before and after intervention. The selection of grout requires information on the construction type and the dimensions of the structure, the nature of the existing materials, the nominal minimum width of voids to be filled and the distribution of voids, the possible presence of soluble salts and the desired behavior after repair.

Formulation of compatible materials for mortars or grouts to be used in conservation of ancient masonry structures is complex, due to specific requirements such as low modulus of elasticity and adequate strength, as well as the need of a physically and chemically compatible behavior with the existing materials. In the specific case of grouts for injection, the requirements are even more demanding. The complete and uniform filling of masonry voids with grout is essential in consolidation works [29] for a successful intervention. The success of this operation depends on parameters such as the distance between the injection holes, the injection pressure, the rheological properties of the grout, the water absorption capacity and the general condition of the masonry (number and width of cracks) [34].

Based on the required performance of the structure, the composition of the grout should improve the behavior of the injected system without affecting its durability. The use of lime-pozzolan-cement grouts seems to be one of the most attractive options [31]. Even if grout formulations remain, mostly, an empirical process, the effectiveness of ternary compositions has been proven in experimental studies in one and three leaf walls [31,32,26,21,37]. Alternatively, hydraulic grouts (natural hydraulic lime or cement grouts) have been proposed [23,9,5]. The injectability characteristics of grouts [24,25,6] as well as the effect of the addition of other materials (fly ashes, silica fume, plasticizers and superplasticizers, among others) on their behavior [10,4,22] have been recently studied.

Despite the fact that several formulations are proposed by different researchers, many commercial ready-mix grouts are available in the market and have been either frequently prescribed by designers or proposed by specialized companies in the area, mostly because of their easy preparation, quality control and guaranteed performance. The attractiveness of using commercial grouts mainly consists of the possibility to overcome the difficulty in formulating a suitable grout composition. Commercial grouts have been specifically formulated for this purpose, and guarantee a greater uniformity in properties and a better flow control. The preparation of these premixed grouts requires only water and no special equipment. The composition of commercial grout is varied and the description of their composition in technical data sheets is vague. Several applications of "in-situ" consolidation and laboratory tests of commercial grouts are available in the literature [7,33,19,30].

If commercial grouts are used, this means that it is impossible to define specific properties for a given application and the cost of these products is usually higher than prescribed formulations. Even if these materials are used frequently, e.g. consolidation of the towers of the Cathedral of Porto in [20], very few studies have been devoted to the characterization of their effectiveness and to a comparison between different products. Technical information is usually scarce and it remains unclear which standards should be used for quality control and which requirements are applicable. Thus, the objective of the experimental program presented here is to compare the properties of commercial grouts, providing a range of properties found and alerting for the adequate selection of injection materials. Durability tests for one of the commercial grouts are available in Luso [21] but these are outside the scope of this paper and are less relevant for practical applications.

2. Grout performance

It is consensual that grouts to be applied in masonry walls of ancient buildings should: (i) have good bond to masonry materials such as stone or brick; (ii) have low or no shrinkage, in order not to create additional stresses, to limit the loss of adhesion between grout and existing material, and to reduce moisture penetration through shrinkage cracks; (iii) have low segregation and exudation to maintain the volume and consistency, (iv) have high fluidity and injectability, in order to provide a proper flow and to fill both large and small openings and interconnected voids, even using low pressures; (v) resist to soluble salts, possibly present in the walls, and limit the salt contents that can be transmitted to the existing material. Other properties might need to be adjusted to a given case, such as: development of strength in early days; size of the aggregates in the composition; strength and elasticity modulus; thermal expansion coefficient, among others.

The compliance with the above requirements is greatly defined by the constituting materials of the grout, namely binder(s), aggregates, water and additives. In general, a binder with water is used, without sand but possibly with some fine aggregate (*filler*). The design of lime-based grouts for strengthening of historic masonry buildings seems to follow rather empirical procedures, with the related uncertainties, both in terms of cost and efficiency [24]. The ingredients and the final product must be compatible with the old materials in the masonry structure being repaired but there is no test available for this parameter. Still, the chemical and mineralogical properties of the components have to be identified and an effort needs to be made to prevent any negative interaction [28].

There are no specific standards to determinate the main properties of masonry injection grouts. Normalization concerns, mostly, cement grout, mortar or concrete and the existing standards are often used only as for guidance, having to be adapted. In this paper, the workability of grouts is determined by a series of rheological tests (fluidity, stability and bleeding) used by other researchers. The injection grout is also evaluated in terms of its injectability and penetrability. The properties of the hardened material are determined by mechanical tests, namely bond, deformability and flexural and compressive strength. Recent research [31,8] has shown that tension and shear bond along interfaces between external leafs and the infill, in three leaf walls, constitute the basic mechanism of integrity and resistance of multi-leaf walls. Therefore, in the present work special attention, is given to bond between injection grout and stone substrate.

3. Tests on commercial grout basic

In order to verify the requirements of building materials, the usual procedure is to assess their behavior under laboratory conditions. The first phase of the experimental program described herein