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Influence of superplasticizer, temperature, resting time and injection pressure on hydraulic lime grout injectability. Correlation analysis between fresh grout parameters and grout injectability

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ABSTRACT

The grout injection technique is commonly used for the consolidation of old stone masonries. In particular, the multi-leaf masonries which generally exhibit low compactness in the inner core and very few links between the internal and external leaves. Grouts are concentrated suspensions that can be seen as mixtures of binder with water, and special admixtures. To ensure an adequate flow of the grout and a correct filling of the internal voids inside the masonry, it is essential to assure good fresh grout properties. Thus, the evaluation of the performance of the grout injectability is firstly started by checking the intrinsic properties of the grout (namely rheological parameters) and then by controlling the injectability, through injection tests in porous media that simulate old masonries.

The main goal of this paper is to provide indications and valuable data about the combined effect of superplasticizer dosage, environmental temperature, resting times (i.e. the time after the grout mixing had ended) and injection pressure on grout injectability, aiming at a successful injection process. The lack of information about the influence of the referred parameters on the injectability of hydraulic lime grouts enhances the importance of a detailed research on the subject.

1. Introduction

Old buildings, either common of culturally relevant, represent the large majority of the construction types in most urban centres all over Europe. Due to a lack of maintenance, the masonries of old buildings are frequently in a poor state of conservation [10,21,44]. This masonry typology presents very different characteristics; some are made of a single leaf, while others have multi-leaf. In the case of a multi-leaf wall, the existence of voids and cracks and the absence of cohesion and connection between leaves lead to masonry walls with non-monolithic behaviour, contributing to a brittle behaviour when undergoing vertical and horizontal loads. In order to stabilise such walls and to prevent structural failure, grout injection is widely used as a consolidation [29,48]. The main goals of grout consolidation are to increase the compacity, which also increases the adhesion between stones, mortars or other materials inside the masonry and, at the same time to create new bonds between the internal and external leafs of the wall. In this way, the monolithic behaviour and the resistance to permanent loads is enhanced without altering the morphology and load-bearing system of the wall [13,30]. According to Uranjek and Bosiljkov [43] the behaviour of the wall after grout injection is significantly influenced by the efficacy of grout injection. For a successful injection it is necessary to ensure an adequate grout flow inside the masonry (porous media). This means that it is essential to ensure good fresh properties, such as good rheological behaviour, water retention and stability to allow a good injectability and also to regulate the consolidation quality. Thus, the grout design must take into account all these factors. One of the key points in grout design is the use of dispersant admixtures. The SP is a well-known dispersant admixture whose function is based on repulsive forces [2]. Through SP action, an improvement of fresh grout parameters is expected by increasing the fluidity, water retention and stability [5]. However, it is well known that fresh grout behaviour of cementitious pastes with SP depends on type and dosage [7]. So this issue will be further detailed, as well as the influence of SP action on hydraulic-lime grout injectability.

According to other studies [17,7] hydraulic lime-based grouts show a shear-thinning and time dependent behaviour-thixotropic materials. So, the grout viscosity depends not only on the applied shear stress, but also on the time for which the suspension has been submitted to a shearing stress. If the injection is stopped during an intervention, the grout is at rest and the particles will

Abbreviations: PM, porous medium; SP, superplasticizer

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start to flocculate into agglomerates (structural build-up), leading to a loss of workability [49]. Besides the resting time, the workability loss also depends on grout temperature. Indeed, different environmental conditions lead to different grout microstructure and consequently different injection performances. Thus, it can be stated that temperature and resting time could be crucial parameters in the quality of a grouting intervention. Regarding hydraulic lime grouts limited data are available about the combined effect of temperature, resting time and grout composition on fresh grout performance. For this reason this article analyses the influence of temperature, resting time and grout composition on the rheological properties, such as yield stress and Bingham plastic viscosity. In addition, the flocculation area that is directly related to the bonds between the binder particles (agglomerates) was also evaluated.

According to some authors [18,30,44], the grout injectability is a key parameter for a successful intervention, since the injection of the interior of masonry is a challenging matter due to different reasons, such as: non homogeneity, presence of cracks, voids and discontinuities of different size and high water absorption of bricks, mortars and stones. Thus, in the last stage of this work, some injection tests were performed to study the injectability of the studied grouts. The injection setup is similar to that used by other authors in their grout injection tests [12,18,44,46]. Reduced models were used in order to simulate certain channels/ paths that may exist in the inner core of a multi-leaf stone masonry. Nevertheless, comparing to literature the outputs achieved are different. In this article, the injectability of the grout was analysed based on two equations. One proposed by [18] that takes into account the time and injection height. Another from a more recent work [25] that expresses the percentage of voids that is filled after grout injection. Different grout injectability results were obtained for the various compositions studied and different conditions tested (environmental temperature, resting time and injection pressure). Moreover, these results were compared and correlated with the properties of the fresh grouts. This goal is particularly relevant due to the absence of information about the real influence of fresh grout properties on the performance of grout injection.

Thus, in summary, this paper is composed mainly of three phases:

(1) A study of the influence of SP dosage in some fresh grout properties, namely: fluidity, water retention and stability.
(2) Evaluation of the combined effect of temperature and resting time on the grout rheological properties (yield stress and plastic viscosity) and thixotropy (flocculation area), studied through rheometric measurements in order to allow a better understanding of the flow behaviour of HL-based grouts under different environmental temperatures and resting times.
(3) Injection tests performed on reduced models to analyse and correlate the grout injectabilities with the values of fresh grout properties previously studied in the previous phases.

According to Miltiadou and Tassios [30–32] the grout design methodology should be based on the study of grout injectability characteristics: penetrability, fluidity and stability. This research gives continuity to the papers [25,6,8] where the influence of mixing procedure, grout composition and the granularity of porous media on the grout injectability were studied. In the present article the influence of superplasticizer dosage, temperature, resting time and injection pressure on the grout injectability was studied through the analysis of the injectability characteristics mentioned above.

2. Experimental details

2.1. Materials

The experimental programme was carried out using grouts made with HL produced in Portugal by Secil-Martinganca according to the European Standard EN459-1:2010 and labelled as HL5. The physical and chemical properties of the hydraulic lime are listed in Tables 1 and 2.

The grain size distribution of HL5 is represented in Fig. 1.

The SP used is based on polycarboxylate (Glenium Sky 617), produced by BASF, whose characteristics are presented in Table 3. This SP belongs to the third generation whose repulsion is a combination of coupled steric and electrostatic effects, known as electrosteric [36,38]. Due to the dispersion action, the particles remain far enough so that they cannot come together, i.e. prevent the flocculation of binder particles [49].

2.2. Mixing procedures

The hydraulic lime mixes were prepared at a room temperature of 20 ± 2 °C and a relative humidity of $55 \pm 5\%$. For the preparation of grouts water at the temperatures of 5, 20, 30 and 40 °C was used and the dry hydraulic lime was hand-mixed to ensure a homogeneous distribution before the beginning of the mechanic mixing. The mixing procedure adopted was based on previous works of the authors [6]. It is divided in three phases. In the first phase, 100% of the binder is added to 70% of total mix water and mixed during 10 min. The remaining water (with diluted SP) is added within 30 s (without stopping the mixer, speed = 2400 rpm) – second phase. According to several authors [1,14,23], the delay of 10 min on the SP addition improves the effectiveness of the dispersing particles. In the last phase, after all materials had been added, the mixing was maintained for 3 min at 2400 rpm. Regarding the mechanical mixing, as concluded by Toumbakari et al. [42], a high turbulence is required in order to obtain an adequate deflocculation of hydraulic lime. In fact, low mixing turbulence leads to a mixture with large flocculates since the low mixing speed is not capable of deflocculating all the formed flocs comparatively with grouts obtained with high (2400 rpm) mixing speeds.

2.3. Grout design

Regarding to the grout composition, certain parameters play an important role on the fresh grout behaviour, such as binder type, water/binder ratio (w/b) and SP dosage [19,7,8]. For that reason, it is extremely important to study the different parameters that are involved in grout composition and their influence on fresh state behaviour. In the present paper, a w/b content (0.5) was chosen (and maintained in all grout compositions) in view of the results reported in the literature [32,44] and previous research of the

Table 1
Hydraulic lime characteristics.

Compression strength at 7 days (MPa)	> 2.0	
Fineness	90 μm	15.0%
	200 μm	2.0%
Setting time	Start	> 1 h
	End	< 15 h
Expansibility	< 2.0 mm	
Free lime	3.89%	
Ignition loss	19.84%	
Density	2.85 g/cm^3	
Fineness (Blaine)	9400 cm^2/g	