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CIVIL INFRASTRUCTURE

Characterisation of Innovative Mortar Formulations for the Restoration of Roman Mosaics

This contribution is focused on the study of the workability and mechanical properties of innovative mortars previously developed for preservation of ancient mosaics. The new formulations are based on the study of the Vitruvian recipe for Roman mortars, respecting the compatibility criteria with the original material. Different additives in different concentrations have been added to the previous formulations with the aim of studying their role in improving the durability, physicochemical, and rheological properties of the consolidating formulations. Preliminary slump tests were carried out to evaluate the effect of the additives on the workability of designed lime-based mortars. The achieved results highlighted the benefits of the use of plant-derived gel and inorganic nanoparticles in mortar mixtures, when added in suitable concentration. Considering these results, the best mortars formulations have been selected to examine in depth their mechanical properties.

Keywords:
Mosaic, consolidation, mortars, workability, durability.

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INTRODUCTION

Composition of roman mosaic stratifications were reported already in ancient literature. Vitruvius [1] indicates a system made of 5 different strata: (i) tesserae; (ii) supranucleus, a strata of putty lime; (iii) nucleus, a thin layer made of fine pozzolana, sand, air lime mortar and water; (iv) rudus, composed by fine and great pozzolana, putty lime and water; (v) statumen, a strata of rough big stone and bricks. In Figure 1 the scheme of the typical mosaic floor stratification is reported. This system has been discovered in several archeological sites, including Aquileia [2, 3], which has been well documented and recognised.

Due to the inherent heterogeneity of the materials used to construct each stratum, restorers encounter several challenges when conserving mosaics [4]. The interaction of each layer with the environment causes several degradations, including fractures and swelling of mortar. This results in the loss of tesserae and, therefore, the loss of mosaic decoration integrity. A range of traditional interventions are available to address damage in mosaics systems, including the consolidation of different strata, namely (i) application of consolidants in grouting process; (ii) filling of cracks with injection mortars; (iii) repointing of lost tesserae with pastes [5-6]; and if needed (iv) detachment of mosaics from the original site and their collocation on new supports [7].

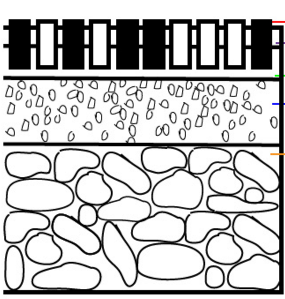

Fig. 1. Structure of mosaic with indication of all the superficial strata.

Operations as described in i-iii involve the use of either hydraulic or non-hydraulic lime mortars mixed with acrylic emulsions [8]. It is good practice, that the compounds employed for preservation are selected to be compatible with and sympathetic to conservation requirements, i.e. be physically, chemically and mechanically compatible with the host material [9]. So, the mortar mix design used for restoration is the reproduction of ancient compositions with modern materials, selected among which have chemical compositions similar to the original ones [10].

Fluidity is one of the most important parameters to take into account when dealing with the development of mortar pastes. The water/binder ratio is the key factor to consider in order to change the viscosity and workability properties of the formulation [11]. As early as ancient literature, the addition of natural organic compounds such as figs or fats to mortar mixtures was a practice in use [12] in order to change mechanical and physical characteristics.

Nowadays, the trend towards producing greener and more sustainable compounds is bringing about a renewal of the use of plant products as additives for admixtures of building materials. For example, the practice of adding Opuntia mucilage to construction mixtures is traditional and currently in use among the Mexican population [13, 14] to improve durability and mechanical properties [15several Thermogravimetric Analysis (TGA], inhibit quick drying and prevent cracking on renders [16]. Generally nanotechnology is used to increase or vary properties of materials [17].
In the last decades, several researchers tested the use of nanoparticles in order to change the mechanical properties of cements and mortar mixtures. The addition of inorganic nanoparticles nanoparticles increases the compressive strength of cement paste and mortar thanks to pozzolanic reactions [18]. More recently, self-healing materials have been developed in many fields of material science, including restoration of built heritage, as an alternative to the traditional damage prevention methods [19], [20].

In this research the mechanical behavior of innovative mortar formulations has been investigated. Taking in consideration Vitruvian recipes for the production of both nucleus and rudus, hydraulic mortars produced in order to have compatible hydraulic compounds for both the strata have been mixed with natural gel and inorganic nanoparticles. The effect on workability of the mixtures containing different proportions of additives have been evaluated through slump test and the results were used to select the best set of concentration and composition of additives to be studied from a mechanical point of view.

MATERIALS AND METHODS

Table 1 summarises the composition of the investigated mortars. Mix design for producing the studied mortars is drawn following Vitruvius' description, with binder to aggregate volume ratio kept constant at 1:3. Mortar A was based on "Nucleus" recipe, with 100%v of cocciopesto as aggregate. Mortars B and C were based on "Rudus" composition, containing respectively 25%v and 50%v of sand to cocciopesto ratio.

Mortars designation	B v/v	A v/v		W w%	N w%	S w%
		S	C			
A	1	-	3	0.04	-	-
AN_1	1	-	3	0.04	1	-
AN_2.5	1	-	3	0.04	2.5	
AS_1	1	-	3	0.04	-	1
B	1	3		0.025	-	-
		1	4			
BN_1	1	1	4	0.025	1	-
BN_2.5	1	1	4	0.025	2.5	
BS_1	1	1	4	0.025	-	1
BS_2.5	1	1	4	0.025	-	2.5
C	1	3		0.025	-	-
		1	2			
CN_1	1	1	2	0.025	1	-
CN_2.5	1	1	2	0.025	2.5	
CS_1	1		2	0.025	-	1
CS_2.5	1	1	2	0.025	-	2.5
		1				

Table 1. Composition of investigated mortars. Designation conforms to the following: Binder (B), Aggregate (A); Fine Cocciopesto (C); Fine Quartz Sand (S). Content of Water (W%); natural gel (N%) and inorganic nanoparticles (S%).

For mortars B and C are reported the ratio of sand and cocciopesto used for the composition of the aggregate, expressed in the ratio of volume of sand on total volume of cocciopesto. Two types of aggregates were used, fine cocciopesto (granulometry < 0,4 mm) and fine quartz sand (grain size of 0,1-0,3 mm). Water addition was scaled proportionally to parity of different aggregates for the preparation of mixes A and C. Binder and aggregates used for mortar production are purchased by C.T.S.

Mortars containing the addition of either natural gel or inorganic nanoparticles to A, B, and C at two concentrations (i.e. 1% and 2.5% by weight of mortar) were also studied. The nature of the inorganic nanoparticles and the plant-derived gel (properties and pre-treatment) cannot be disclosed as subject to evaluation for patent protection. The concentrations of additives and water are expressed in % on total weight.

Mini slump tests were performed on all mortar mixtures in order to evaluate the change in viscosity induced by the different compositions. The size of the cone normally used for testing concrete was proportionally scaled to analyse small quantity of mortars in laboratory, while respecting the normalised procedure [21].

RESULTS

Results of the first mini slump test indicated how additives affected viscosity and fluidity.

In Table 2 and Table 3 mini slump test results respectively of mortars A, B, C and of additivated mortars (AN, BN, CN, AS, BS, CS) are reported.

Mortars designations	r^2 (cm)
A	4,2
B	5,1
C	4,3

Table 2. Results of slump test of mortar mixtures (M) A, B, C; values of the diameter of slump of the mortars.

Mortars designations	r^2 (cm)	
	1 %	2,5%
AN	5,2	5,4
BN	5	5,2
CN	4,9	5,1
AS	4,1	4
BS	4,1	4,1
CS	4,2	4,1

Table 3. Evaluation of the diameter of slump of mortar mixtures with additives natural gel (AN, BN, CN) and inorganic nanoparticles (AS, BS, CS) in different concentrations 1%, 2,5%.

Mixture A and C showed similar results with a slump diameter of ~4,2 cm. It was found that the two mortars had similar workability being stiff enough to maintain the shape of the cone. Differently, mortar B resulted to be more fluid and is characterized by a greater diameter of 5,1 cm.

Greater addition of natural gel (confidential) had increased the slump of mortars A and more significantly of mortar C. Mortar B exhibited similar slump parameters regardless of the amount of natural gel added.

In all mortars, the addition of inorganic nanoparticles (confidential) seemed to have a negligible influence on the workability, i.e. slump diameter equal to 4,1 ± 0,1 cm.

DISCUSSION

Fluidity and viscosity are the main important characteristics to take in consideration for the design of mortars. Slump test is a first step to evaluate these characteristics. Mortar A and C show an equal slump parameter. Increment of fluidity was achieved for paste B, with respect to mortar C and A. To parity different ratios of sand and cocciopesto, the same amount of water is added for mix B and C, demonstrating the need to scale water content to parity with a reduction in sand ratio.

For mixtures A and C, the increase of slump test diameter is proportional to the increase of natural gel, demonstrating that paste fluidity increases with gel addition (confidential). Results suggested that the addition of plant-derived gel might result in a lower amount of water, further research will be carried out to assess the retention of water by the use of gel. The slump tests for mortar mixtures B were the same regardless of the addition of 1% gel concentration (5 cm ± 0,2) and results increase of ± 0,2 with the addition of 2.5 % of gel. No relevant changes in viscosity have been seen in mortars containing inorganic nanoparticles (confidential) additions. All mortar mixtures with this additive showed similar slump test values of 4,2 cm ± 1 and conserved the cone shape of the slump test, as shown also for mixtures A and C.

Based on the results presented in this work, the best mortar-additive formulations are selected to be studied by the application of mechanical test and multiple characterization techniques, for the definition of their physical and chemical characteristics. Furthermore, in the future the rheological properties of mortars containing natural gel as a fluidifier will be intensively investigated as well as the effect of inorganic nanoparticles addition. Tailored self-healing materials will be also added with the purpose to improve durability of the injection mortar once used for conservation process of mosaic system.

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Conflicts of interest
The authors declare no conflict of interest.

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