**TC.08**

**Performance and Repair Requirements for Flooring Mortars**

**Members of RILEM TC 203-RHM**

**Members:** Koen van Balen, BE; Beril Bicer-Simsir, USA; Luigia Binda, IT; Christine Bläuer, CH; Jan Elsen, BE; Caspar Groot (chairman), NL; Eric Hansen, USA; Rob van Hees, NL; Fernando Henriques, PT; John Hughes (secretary), UK; Eleni-Eva Toumbakari, GR; Thorborg von Konow, FI; Jan Erik Lindqvist, SE; Paul Maurenbrecher, CA; Bernhard Middendorf, DE; Ioanna Papayianni¹, GR; Stefan Simon, DE; Maria Stefanidou, GR; Maria Subercaseaux, CA; Cristina Tedeschi, IT; Margaret Thomson, USA; Jan Valek, CZ; Maria Rosa Valluzi, IT; Yves Vanhellemont, BE; Rosario Veiga, PT

¹ corresponding author: Ioanna Papayianni
Dept. of Civil Engineering, Aristotle University of Thessaloniki, Greece, papayian@civil.auth.gr

**Abstract**

Mortars have been widely used even in prehistoric periods in making pavements in open areas or floors inside dwellings. They are found as surface layers well-compacted and polished, as sub-bases on which stone or ceramic units has been applied (as well as the mortar between the units), and as multilayer substrates for floor mosaics. Repairing flooring mortars constitutes a great part of restoration projects of archaeological sites. In particular, the repair of mosaics attracts great interest since they could be considered as non-detachable work of art. This paper considers aspects of the performance requirements for repair mortars for mosaic substrates and joints in historic pavements and stairs.

1 **Introduction**

Flooring mortars may comprise the multilayer substrates of floor mosaics, sub-bases on which units such as stone or ceramic pavers have been applied (as well as filling the joints between the units), or even a finished or polished floor surface. Figures 1-6 show different floors found in archaeological sites and historic structures. Most of mortars are lime-based apart from those flooring mortars found in constructions dated from the period after industrial revolution which were often based on stronger hydraulic binders such as hydraulic lime, natural cement or...
Portland cement. Flooring mortars which are applied on the ground are characterized by their high degree of compaction and high content of aggregates. This paper highlights aspects of the performance requirements for repair mortars for mosaic substrates and joints in historic pavements and stairs. This will form part of the chapter on flooring mortars in the forthcoming RILEM TC 203-RHM guide on repair mortars for historic masonry [1].

Fig. 1 Byzantine floor mosaic in the archaeological site of Filippoi, Greece (6th cent AD)

Fig. 2 Hellenistic substrate of a floor mosaic in Pella, Greece (4th cent BC)

Fig. 3 Hellenistic floor mosaic in Pella, Greece (4th cent BC)
The deterioration problems of floor mosaics and their repair have drawn the attention of many researchers [2-6]. This includes the conservation of tesserae.

Fig. 4 Floor mosaic of the Palace in Aiges, Greece (4th cent BC)

Fig. 5 Pavement in Urdiales fortress, Spain

Fig. 6 Floor paving subject to severe exposure. Note salt saturation from de-icing salts at the bottom of the columns (side entrance Parliament buildings, Ottawa, Canada)
and consolidation of tesselatum [2] or damage of the thick stratified mortar substrate such as:

- Cracks due to ground movements.
- Loss of mortar layers or lacunae formation.
- Detachment of substrate mortar layers due to depression or bulging of the ground.
- Cavities due to intrusion of vegetation.
- Completion of missing parts of the mosaic substrate.

Most binders in flooring mortars are lime or lime and pozzolan, which are soft materials in comparison to cement based mortars.

In the floors of historic structures exposed to outdoors conditions (Figs. 5, 6), a common problem is the deterioration of the mortar in the joints between paving stones, due to air pollutants, frost action, de-icing salts, and marine environments where sea spray accelerates salt weathering mechanisms [7].

2 Functional requirements

Floor mortars should fulfil the following functional requirements:

- Compatibility so the authentic parts of the ancient mosaics or other floors are protected.
- Aesthetic harmonization with the old floor.
- Adequate mechanical strength and resistance to abrasion to serve as pavements.
- Resistance to leaching, freezing and de-icing salt attack.
- Low cracking tendency.
- Easy to remove and replace.

When repointing historic floors in cold climates, very often the compatibility issues are practised by pursuing the best match with the existing stone and a high resistance to salt and frost damage.

3 Pre-design issues

The input of a broad range of disciplines is strongly recommended (e.g. archaeologists, surveyors, geotechnical engineers, architects and material specialists). For example, several pre-mixed mortars are available for repair without sufficient documentation of their performance in practice. A material specialist could alternatively design a mortar mix for the particular project.

It is also advisable to choose an independent laboratory to undertake the monitoring and quality control during the restoration work.
3.1 Preparatory work: Repairing substrates for mosaics (Mediterranean conditions)

The following preparatory work is suggested:

- Document the authentic floor parts and record them on the ground plan. Make a representation of the ancient architectural design.
- Decide upon the conservation and protection of the authentic parts during the restoration work.
- Make a topographic plan of the field.
- Make a survey of the old floor, and map the damage and its severity. Collect information about previous earth movements, ground water level, ancient rivers, stratigraphy of the ground etc. as well as climatic conditions, soil characterization and other items.
- Study the ancient drainage system and save the existing parts.
- Describe the stratigraphy of the old floor mortar (Figs. 7, 8).
- Analyze systematically mortar samples from the old floor to find their characteristics and properties (Fig. 8).
- Do research to find local sources for raw materials.
- During excavations the sub-ground of the floor will be “disturbed”, therefore measures should be taken for reconsolidation of the ground sub-base such as removal of plants and treatment of the soil for elimination of vegetation.

It must be pointed out that the compaction or modification of the soil base, on which the repair floor mortar will be spread, is of great importance for the service life. In addition, special care must be taken for the leveling of the finishing mortar layer in order to allow good water drainage.

Fig. 7 Roman floor mosaic and stratigraphy of the substrate, ancient city of Dion, Greece (2nd cent AD) [8]
3.2 Repointing historic pavements and stairs (cold weather conditions)

- For horizontal surfaces, drainage away from the adjacent walls should be ensured by having a minimum slope of 2%.
- It is important to understand how the components of the pavement (units and joint mortars) behave and interact.
- The severity of climatic conditions should be taken into account for the selection of a suitable mortar. Use of movement joints or sand joints is a possibility where needed. Expect cyclical maintenance every two or three years (Fig. 9).
4 Materials and performance requirements (Mediterranean conditions)

4.1 Repairing mosaic substrates

For repair mortars for floors, apply the general criteria of suitability mentioned in the RILEM TC 203-RHM document [1]. In the particular case of repair mortars for mosaic substrates, the aggregate’s mineralogy and gradation should follow that of each layer of the existing floor. The binding system should be based on lime or lime-pozzolan as occurs in the old mortars. Admixtures free of sulphates may be used to improve workability. Mortar mixes for flooring must have low workability (about 11±1 cm expansion measured by the flow test). In addition, it is essential to compact the mortar very well with a hand or mechanical tamper. Cold joints must be avoided and in large outdoor floors include shrinkage joints.

Colour, texture or design motifs of the finishing layers should aesthetically harmonize with the existing old floor. The appearance of soluble salts on the floor surface can be eliminated by controlling the salt and alkali content of all mortar ingredients.

Complete drainage is important for increasing the mortar’s service life. Stagnating water on top of floors results in surface damage and scaling. It is important that water not to be retained within the mortar floor slab. In floors, water can infiltrate from the surface into ground and rise from the soil into the mortar. The use of a crushed stone layer at the bottom of mortar slab in contact with soil is an old and effective way to avoid damage from ground water.

Lime leaching from floor mortars could be eliminated by selecting binders in which lime will be sufficiently bound, such as lime + reactive pozzolan.

The design of the mortar mix for flooring includes strength requirements. The strength level should match as much as possible the strength of the old floor slab in addition to other performance requirements. Mortar strength has to be defined previously at the laboratory with sufficient tests in order to be reliable. Apart from compressive strength, bending strength may also be estimated by testing.

Lime-based mortars have a lower modulus of elasticity in comparison to cement-based mortars. This difference has to be considered in the selection of the binders. For comparing mortars, the modulus of elasticity may be evaluated by sonic equipment (dynamic modulus) or by stress-strain tests (static modulus of elasticity).

- Resistance to freeze-thaw cycles

These issues are discussed in more detail in the RILEM TC 203-RHM document [1]. The efficiency of air-entraining agents to improve resistance to frost is less in the case of flooring mortars which are fully compacted. Covering the mosaics in archaeological sites during winter with nylon sheet and sand seems to be effective in practice.
4.2 Repointing historic pavements and stairs (cold weather conditions)

Aggregates should fulfil the general suitability criteria about harmful impurities. Their colour should preferably match the existing mortar or the stone units. The size of aggregates should be selected according to the width of the joint.

Based on existing experience in North America, hydraulic lime and natural cement are not yet so reliable for these repair works, while mixes of lime and cement are more effective (with integral air entraining agent). Air entraining admixtures have been only used in restoration projects to improve resistance to frost attack. Pigments resistant to UV radiation are added after testing for optimum dosage.

The most crucial requirements for mortars used in repairing joints of pavements and stairs are those related to frost and salt damage (Fig. 10). To avoid such damage, the moisture content of the mortar must be kept low by taking care to have a proper slope on horizontal surfaces to avoid water stagnation. To eliminate efflorescence and salt crystallization within mortars, the salt content of all ingredients of the mortars and surrounding materials should be kept at low as possible.

![Fig. 10 Salt damage on mortar, stones and concrete base of stairs. Partial dismantling (Canada)](image)

5 Construction

Issues concerning the set-up and running of a worksite, site supervision, manipulation of the materials and sufficient mixing of ingredients are mentioned in more detail in the RILEM TC 203RHM document [1].
5.1 Repairing substrates of mosaics (Mediterranean conditions)

- Preparation of the ground sub-base

The floor mortar is in contact with the ground, and therefore directly affected by ground movement. Any differential deformation between surface layer and the ground sub-base could lead to cracking. In the case of large surfaces, permeable geomembranes are often used between the ground and the new floor mortar slab. Very often the old way of spreading a layer of crushed stone on the ground is also followed.

- Mortar mixing

Mixers of greater capacity and stronger than conventional ones are needed because of the high content in coarse aggregate. The bulk density of the mixture could be used as a measure of its homogeneity. Decide about proper moulds for taking fresh mortar samples for quality tests (mechanical strength and other properties).

The water demand for a desirable workability level has to be defined by trial mixes, and adjusted to weather conditions and the moisture content of the ingredients. The work plan has to be well scheduled since successive mortar layers will be applied and cold joints are unavoidable when the surface dries too quickly. In addition, because of the low water content in the mortar there is risk of rapid stiffening of the mix at high temperatures (e.g. >27°C). Measures have to be taken to protect the fresh mortar mix and the surface of the mortar layer.

In mortar mixtures with large size aggregate, the Vicat cone test method is not suitable to assess consistency. A simple cone slump test is preferred [1]. Special care must be taken with pigments to ensure a uniform distribution in the mix.

- Mortar application

It is important to keep the ground sub-base damp (but not wet) to avoid premature drying of the mortar mix. Decide upon the floor area to repair according to the status of the worksite (capacity of the mixer, personnel etc) and keep strictly to a work plan.

After placing the mortar, adequate compaction has to be provided (the method and degree of compaction to be decided beforehand using trial mixes). Work interruption is not acceptable or has to be programmed. The level of compaction can be checked periodically on site by taking cores.

In large floor areas, the cutting of joints must be decided beforehand as well as the method for finishing the surface. The joint spacing should be decided according to the mechanical strength of the mortar.

Temperature and wind conditions during application should be documented.
Mortar curing and protection

Mortar slabs for flooring are very susceptible to shrinkage during the first 24-48 hours (depending on the mortar binder), as well as long-term drying shrinkage. The former can be reduced if proper curing is provided. The curing period should be extended in hot-dry weather. Experience from field-work showed that two weeks damp curing (provided by wet burlap covered with nylon sheets) is effective in the case of mortar binders with low hydraulicity (such as lime-pozzolans). Even with lime mortar, protection from drying is necessary.

The resistance to frost of moist lime-based mortars is low. The addition of air-entraining agents to flooring mortars which are spread and compacted is not very effective. Early frost damage is avoided by selecting the proper season for application. Even hardened floor mortars are covered with nylon sheets and a layer of sand during winter to avoid frost damage. This is considered part of the maintenance work.

Quality control

Quality control tests include:
- Tests for suitability of the raw materials (binders, aggregates, additives). Aggregate gradation should meet the coarser gradation of the recommended ones in standards for concrete aggregate.
- Tests for fresh mortar.
- Tests for workability or consistency of the mortar.
- Air content of the mortar.
- Density of the fresh mortar (with and without compaction).
- Mortar samples must be moulded, cured and tested under a defined regime for testing compressive and bending strength. For mortar with large size aggregate, larger moulds may be needed depending on aggregate size (e.g. cubes 15x15x15cm and prisms 10x10x40cm).
- A curing regime must be defined depending on the type of mortar binder. For lime-pozzolan mortars longer curing periods are suggested.

5.2 Repointing historic pavements and stairs (cold weather conditions)

Adequate workability is very important for achieving good workmanship. Apart from testing the properties of a mortar for its suitability, trial applications on site are recommended.

Quality control tests should include control of mortar consistency, air content, setting time, bond of mortar to masonry units, checking for voids behind repointing, as well as mechanical characteristics by making test samples for each mortar batch. Simple tests such as Vicat cone test may be used to check the consistency of the mortar batches [9].
Fresh mortar joints should be protected from rain, wind and sun by keeping them damp for three to seven days to avoid shrinkage cracks or obscuring the natural colour of the mortar (Fig. 11). Mortar should also be protected against early freezing in cold weather.

A maintenance strategy after completion of repair work is of great importance. A technical description of the whole intervention should be delivered to the owner of the pavement/stairs with recommendations for regular visual inspections using a checklist.

![Curing with wet burlap and plastic for a minimum of three days](image)

**Fig. 11** Curing with wet burlap and plastic for a minimum of three days

### 6 References