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**RILEM TC 167-COM: 'Characterisation of Old Mortars with Respect to their Repair'**

# Introduction to requirements for and functions and properties of repair mortars

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## 1. INTRODUCTION

The objective of this document is to define the requirements that mortars, meant to repair or replace historic mortars, should fulfil. An important starting point for the final design of the repair mortar mix or recipe is the characterization of the old mortar and its historic context.

But, why is it so important to analyse old mortars before proposing a composition for new (repair) mortar? Is it not enough to refer to technical requirements directed by the materials themselves? Is it important to refer to the environment in which it belongs? We believe more general "philosophies" and concepts on how to intervene in historic buildings should be taken into account.

In the field of the conservation of the architectural heritage, characterisation of mortars may serve different purposes *e.g.*: documentation, damage analysis and the design of any intervention.

Documentation is the first step before any intervention on an existing structure, historic or recent. Its aim is to collect as much information as possible in order to produce evidence on the following:

- to support evidence for the cause of the damage (damage analysis)
- to justify any proposed intervention

Part of the problem with historic buildings lies in the fact that, in their majority, they are not as well documented as more recent ones. Therefore the documentation phase also serves in producing technological, artistic or historic information, that may be of use in the design of any intervention, and for future consultants or researchers, because inevitably some of the material used for analysis will no longer be available to them.

The documentation phase contributes to determining the heritage values of the construction, but of course, the extent of the documentation phase depends on the importance of the building and socio-financial aspects. Understanding the damage to historic mortars is often best served by understanding the damage mechanism that caused its deterioration. In cases where for example historical pointing is damaged, the characterisation of the materials (bedding mortar, pointing mortar, masonry units) will contribute to the understanding of the mechanisms responsible for the damage. In fact it contributes to the understanding of the lack of compatibility or the limit of that compatibility. For a more

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general discussion on damage mechanisms please refer to Chapter 3 in [1].

The next step is to use this information to develop any intervention strategy and for that we will have to evaluate different alternative ways of intervention and define the intervention that will best suite the preservation of the heritage with its embedded values *i.e.*: "the most compatible intervention".

Working within the conservation of monuments and historic buildings, which includes the planned replacement of historic mortar, it is almost impossible to neglect authenticity questions. Therefore it was felt important to first describe a complete framework ranging from the (abstract) philosophy to the (practical) mix design as a background for the description of functional and technical requirements for repair mortars.

A proposed (limited to repair mortars) framework of requirements from "General Approach" to "Mortar Design" is shown in Fig. 1.

The presentation of the levels of requirements is schematic and does not imply a linear one-way relationship between them. The following paragraphs follow the order given in Fig. 1.

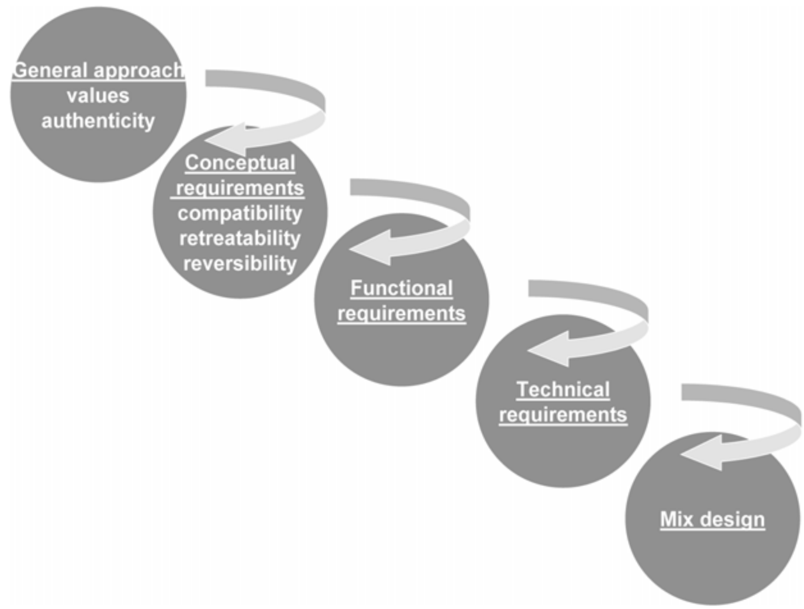


Fig. 1 - Proposed framework of requirements.

## 2. REQUIREMENTS

### 2.1 Philosophy: values /authenticity

Any intervention in a historic building should be guided by various principles. The question why a monument is considered so important is usually related to its 'authenticity'. There is a general feeling that the "authenticity" of the architectural heritage should be understood and preserved as much as possible. The understanding of this "authenticity" is still much debated even after the Nara document [2] on authenticity developed by ICOMOS in 1994.

The term refers to the understanding of values that are embedded within the heritage arena, the reasons for which we may consider a building or an object to be part of our heritage and not an ordinary artefact.

In the Nara document, the term "authenticity" was defined as a layered (or multifaceted) concept of values, meaning that it can be subdivided in different aspects:

*form and design, materials and substance, use and function, traditions and techniques, workmanship, location and setting, and spirit and feeling, and other internal and external factors.*

Each of the aspects can be looked after, according to various traditional dimensions, which apart from "social" those are the traditional "western" ways of looking at values of the architectural heritage:

**artistic, historic, social and scientific** (Fig. 2).

The following scheme represents those aspects and dimensions that could be considered in the form of a table.

| ASPECTS/DIMENSIONS | Artistic | Historic | Social | Scientific |
|---|---|---|---|---|
| Form and design | | | | |
| Materials and substance | | | | |
| Use and function | | | | |
| Tradition, techniques and workmanship | | | | |
| Location and setting | | | | |

Fig. 2 - Scheme based on the Nara Document.

It can be used as a checklist that helps the user to identify the various ways to look at heritage values.

In this way of identifying ancient and repair mortar, one should consider those aspects listed above, recognising the inter-disciplinary methodology of heritage conservation, for further development and detailing about the way those aspects and dimensions can be understood [3].

### 2.2 Conceptual requirements

Interventions in historic buildings have been guided for a long time by the concept of reversibility [4] and although the first aim is to have a reversible intervention, this is often not possible. Therefore a more realistic approach is required which is why the concept of compatibility is introduced here together with retreatability/repairability. Simply stated, "compatibility" means that introduced treatment materials will not have negative consequences and "retreatability" means that the conservation treatment / repair material in the present would not preclude or impede further treatment in the future

If any intervention in a historical building has to be carried out using repair mortars, one of the most important concepts on which the design of the repair mortar should be based, is the compatibility between new repair material and the old structure.

Conservation actions should therefore, (keeping in mind the previously mentioned principles), find further guidance in the use of the concept of "retreatability / repairability" that includes the compatibility concept. A group of experts at the Dahlem conferences in Berlin 1997 were the first to propose those concepts to overcome the lack of really "reversible" conservation treatments [5].

Furthermore, interpreting the meaning of compatibility and retreatability it could be argued that a compatible and/or retreatable repair mortar is a mortar that behaves in a similar way as the old mortars, to different types of action (*e.g.* static, hydrothermal) and that does not create or aggravate new types of damage.

This interpretation leads to the fact that the characteristics of repair mortars and the surrounding masonry have to be defined as they determine the proper boundary conditions of more functional and technical requirements.

*Long term resistance/durability/longevity* is also a concept of great importance from an economic point of view. Repair mortars have to have an adequate resistance to weathering or to aggressive environments. They have to meet today's constraints of construction, which may prove difficult to achieve since traditional materials used as binders provide relatively weak mortars with a slow hardening rate.

*Sustainability*: Although sustainability was unknown as a term in ancient society, the study of old mortars has shown that local materials were used in construction that required less energy to produce or deliver. More sophisticated materials with higher energy needs were only used if and where really necessary [6]. Besides, masons of the past tried to improve the capacity of their materials by adding fibres or other additives or by the combination of materials. The suggestion nowadays, to use as much as possible local materials or low energy material is in fact a concept that had already been applied in the past.

*Harmonization:* This concept refers to aesthetic compatibility of the new repair mortar with the old substrate of the structure (see Fig. 3: example of unsuccessful aesthetic harmonisation). As clarified above this is not only related to the materials used but also to the techniques, the craftsmanship and the historical context. Evaluation of this criterion is often in the hands of the leading architect but is often debated by a wider audience (local community and society).

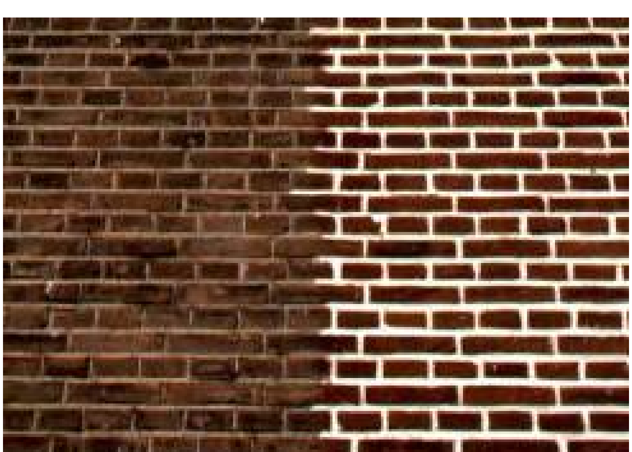

Fig. 3 - Unsuccessful aesthetic harmonisation.

## 2.3 Functional requirements

The design of a compatible repair mortar is also dependant on the functional role it performs within the structure, which should be considered as a whole.

Functional requirements derive from:

1) the role or the function of the mortars in the masonry element;

2) the role of the masonry element in the building.

Considering masonry in a facade, the requirements can be both technical and aesthetical.

The most important functional requirements are considered to be:

- to ensure the load bearing capacity of the wall and, when applicable, good earthquake behaviour.
- to prevent water penetration through a wall; the sequence of pore size distributions of superimposed mortar layers and those of the other neighbouring materials will influence the ease with which water and water vapour will migrate through the masonry system.
- to resist different kinds of environmental influences and processes acting on a wall and protect the user of the building against negative effects; in this respect the estimation of environmental conditions (macroclimate and microclimate) to which the new repair mortar will be exposed is essential for the selection of repair materials and their proportion within the mortar composition.
- the diagnosis of the degradation mechanism should be determined to avoid any eventual detrimental effects (see Chapter 3 – Damage analysis, in [1]).
- to contribute to the aesthetic appearance of a façade.
- to contribute to the durable performance of the wall; this depends, amongst others, on the conditions under which the new repair mortars are applied

## 2.4 Technical requirements

From a practical point of view the above-mentioned series of requirements (Values / Authenticity, Concepts and Functional requirements) must be refined and translated into technical requirements that help to define the design of mortars. These requirements deal with the material characteristics/properties and performance of new repair mortar. This seems to be overlapping with the last bullet point of the functional requirements.

Technical requirements are defined starting from a systematic analysis (chemical, mineralogical and physical analysis, and also includes damage analysis) the details of which are given in Chapters 2 and 3 in [1]. Once the technical analysis has been carried out, the problem is how to use the numerous data/pieces of information in designing the repair mortar, taking into account the conceptual and functional requirements. Besides, technical requirements for a repair mortar should be based on the knowledge (science and technology) about the behaviour of modern mortars (*e.g.* lime-based mortars including lime-pozzolan, hydraulic lime, lime-crushed brick). For example, what is the rate of strength development of different types of lime-based mortars [7] or their long-term deformations [8, 9], or their porosity evolution with time [10].

A number of papers have been written [7, 11-16] which are orientated to technical requirements of repair mortars especially to pointing mortars.

For the application of repair mortars the technical compatibility between old and repair material is a basic belief with regard to an acceptable application.

The most decisive technical characteristics for compatibility between new and old mortar are:

1. Surface features (colour, texture, surface finish);
2. Composition (type of binder, type of aggregates, grain size distribution);
3. Strength (compressive, tensile and bond);
4. Elasticity (modulus of elasticity, deformability);
5. Porosity properties (total porosity, app. specific gravity, pore size distribution, water absorption by capillarity and vapour transport);
6. Coefficient of thermal dilation;
7. (Other)

*1. Surface features / Harmonization (colour, texture, roughness, technique of finishing)*

Determination of these characteristics could be made by observing mortars by the naked eye, or by microscopic analysis (see Chapter 2 – Visual analysis, in [1] for further details).

*2. Composition (type of binders, type of aggregates, grain size distribution).*

Chemical and Mineralogical analysis of old mortars, determination of their aggregate type and grain size distribution have been described more fully in Chapter 2 in [1] (see mineralogical and chemical characterisation). The possibility of using local raw materials (binder or aggregates) should also be examined. For example, a local natural pozzolanic material could be suitable after grinding or local sand could be used after washing (if there is a risk that it might contain salts).

*3. Strength (compressive, tensile and bond strength)*

The strength of old mortar should be estimated by direct crushing tests (if it is at all possible) or indirect methods as described in Chapter 2 – Mechanical characteristics, in [1]. It is obvious that the determined strength is the residual strength depending on the state of conservation of the mortar at the moment of the testing. This means that the results should be interpreted taking into account the damage due to degradation and also possible effects due to sampling. Therefore an estimation should be made about the strength requirement of the new mortar, but also taking into the account the requirements that are imposed by the environmental conditions (see Chapter 3 – Damage analysis, in [1]). The strength requirement is an important consideration for compatibility as the compressive strength is closely related to tensile strength and elasticity whose properties affect the deformability of masonry, however it may not always be a priority in all cases *e.g.* pointing.

Mortar as a repair material in the majority of cases is likely to be bonded to other (old) mortar or to masonry units. Therefore the nature of those materials will influence the type of repair mortar to be used to guarantee a good bond.

*4. Elasticity (modulus of elasticity, deformability).*

These properties can be estimated on the basis of the compressive strength. In some cases (such as mud mortars or lime-mud mortars with natural fibres), deformability or energy absorption capacity depends also on fibre content.

*5. Porosity properties (total porosity, app. specific gravity, pore size distribution, hygric properties)*

The response of the mortar to the environmental action (hydrothermal changes) is governed by its porosity and composition (see also point 2). Long-term deformations are also influenced by porosity and pore size distribution.

The methodologies that could be used as more reliable for the determination of the porosity properties of lime-based mortars are described in Chapter 2 – Porosity in [1]. Ideally the porosity and the pore size distribution of the old and new mortar will match as close as possible and help to provide a good contact. This guarantees compatible hygric properties and the elimination of boundary interface effects. (However, compatibility may also be achieved in different ways such as sacrificial mortars). Many processes influence the development of the pore morphology. In order to design a mortar mixture with predefined porosity, factors such as the binding system, the gradation of aggregates, the water content of the fresh mortar, the addition of admixtures must all be taken into account. It is important to realise that the pore morphology of mortars will change with time due to hydration and carbonation [10, 18], and this should also be taken into account.

Hygric properties may influence the drying behaviour of the whole masonry and therefore may be decisive for durability of the whole [17].

*6. Coefficient of thermal dilation*

This physical characteristic of mortar depends on its composition. For a series of lime-based mortars, the thermal dilation coefficient value can vary between 3-7 x $10^{-6}$ per °C. Compatibility in this respect means that new repair mortar should present a thermal dilation coefficient that is similar to that of the old mortar.

Recent research [19] on pointing mortar seems to confirm that the thermal dilation does not differ so much between different types of mortar (lime based and cement based) and that their thermal dilation is typically double that of ancient bricks. However this research also showed that in a confined state some mortars tend to follow the lower thermal dilation of the bricks while other mortars "keep" their own higher thermal dilation increasing the vulnerability of the masonry as a whole.

*7. Other requirements*

Besides the functional requirements mentioned above, other technical recommendations should be imposed which include the following:

• The content of soluble salts or impurities should be low in order to avoid efflorescence and crystallisation damage.

• The resistance to freeze-thaw cycles and to driving rain should be acceptable whilst also considering an economical evaluation of the maintenance frequency;

• Workability should be designed according to the specific application of the repair mortar. Plasters and renderings should have different workability properties than mortars used for bedding or reconstruction purposes.

• Curing conditions of repair mortars are very important for their longevity. Those conditions are related to the type of binder (air hardening or hydraulic) used [16]. Shrinkage and the long-term deformation are also strongly affected by the duration and the type of curing.

• Repair mortars should be worked properly and be very well compacted. Good workmanship improves the strength, the bonding with the substrate and the homogeneity of the mortar layer and consequently its durability.

• Reliable repair solutions require a good quality control system. This control includes evaluation of the constituents, the manufacturing process and the in-situ application. The behaviour of the repair mortars should be monitored on the site.

## 3. CONCLUSIONS

It is obvious that the aforementioned levels of requirements are corner stones in the development of the design of repair mortars. However more work has to be done to develop a manual of good practice for the repair of mortars based on a good understanding of the characteristics of old mortars and based on a good understanding of the external requirements to which they are subjected to.

The external requirements just presented, going from very abstract and general ones up to requirements that are the consequence of material properties of the neighbouring materials into the masonry, all affect the choice of possible repair mortars. Those requirements will also guide the analytical procedures to be carried out on mortars and masonry to find compatible repair mortars.

## 4. REFERENCES

[1] Final report of RILEM TC 167-COM ‘Characterisation of Old Mortars with Respect to their Repair’, Edited by C. Groot, G. Ashall and J. Hughes (RILEM Report 28, RILEM Publications s.a.r.l., France, 2005; ISBN: 2-912143-35-7) [in press].

[2] NARA Document on Authenticity, Nara Conference on Authenticity in Relation to the World Heritage Convention, held at Nara, Japan (1994).

[3] Van Balen, K., Hayen, R., Naldini, S., Klugt, L. van der, Hees, R., van, Luxan, M.P., Dorrego, F. and Binda, L., Mortar characterisation, from values to compatibility, in Maintenance of Pointing in Historic Buildings: Decay and Replacement, Final Report, EC Environment Programme, contract ENV4-CT98-706, unpublished, (2001) 75-84.

[4] Venice Charter, International Charter for the Conservation and Restoration of Monuments and Sites (1964) (Web site: http://www.icomos.org/docs/venice charter.html).

[5] Teutonico, J.M., Charola, A.E., De Witte, E., Grasegger, G., Koestler, R.J., Laurenzi Tabasso, M., Sasse, H.R. and Snethlage, R., Group Report ‘How Can We Ensure the Responsible and Effective Use of Treatments (Cleaning, Consolidation, Protection)?’, Dahlem Workshop on Saving Our Architectural Heritage: Conservation of Historic Stone Structures, Baer, N.S. and Snethlage, R. (Eds) (Chichester, John Wiley & Sons, 1997) 293-313.

[6] Papayianni, I., ‘Durability Lessons from the Study of Old Mortars and Concretes’, ACI P.K. Mehta Symposium on Durability of Concrete, Nice, France, 1994.

[7] Schäfer, J. and Hilsdorf, H.K., ‘Ancient and new lime mortars-The correlation between their composition, structure and properties’, in Conservation of stone and other Materials RILEM/UNESCO Congr. Edit. J. Thiel (1993) 605-612.

[8] Binda, L., Anzani, A. and Gioda, G, ‘An analysis of the time dependent behaviour of masonry walls’, Proceedings 9th Int. Brick/Block Masonry Conf. 2 (DGFM) Berlin (1991) 1058-67.

[9] Binda, L., Tedeschi, C. and Baronio, G., ‘Mechanical behaviour at different ages of masonry prisms with thick mortar joints reproducing a Bizantine masonry’, 8th NAMC (North American Masonry Conf.) Austin, USA (1999) 382-392.

[10] Papayianni, I. and Stefanidou, M., ‘The evolution of porosity in lime-based mortars’, Proc. 8th Euroseminar on Microscopy Applied to Building Materials, Athens (2001) 451-97.

[11] Peroni, S. *et al.*, ‘Lime based mortars for the repair of ancient masonry and possible substitutes’, ICCROM Symp., Rome (1981) 63-99.

[12] Rossi-Doria, P.R., ‘Mortars for restoration: basic requirements and quality control’, *Mater. Struct.* **19** (114) (1986) 445-448.

[13] Faller, A. and Althaus, E., ‘Compatibility of modern mortars in historic masonry (Verträglichkeit moderner Mörtel in historischem Mauerwerk)’, in International Conference – Special Research Area 315, Investigations on Material And Construction of Historic Buildings, Working notebook (1991) 45-47 [in German].

[14] Knöfel, D. and Hüsmann, M., ‘Mortar for the joint restoration of historic buildings (Mortel zur Fugeninstandsetzung an historische Bauwerken)’, *Bautenschutz+Bausanierung* **16** (1993) 30-34 [in German].

[15] Ashurst, J., ‘Mortars for stone buildings’, in ‘Conservation of Building and Decorative Stone’, Editors John Ashurst, and Francis G. Dimes (London; Boston: Butterworths, 1990) 78-96.

[16] Henriques, F. and Charola, E., ‘Comparative Study of Standard test Procedures for Mortars’, Proceedings 8th Int. Cong. on Deterioration and Conservation of Stone, Berlin (1996).

[17] Van Hees, R.P.J., Pel, L., Wijffels, T. and Van der Klugt, L.J.A.R., ‘Non destructive monitoring in laboratory. Understanding damaging processes by use of NMR’, in L. Binda and R.C. de Vekey eds., Proceedings International RILEM Workshop ‘On site control and non destructive evaluation of masonry structures and materials’ 12-14 Nov. 2001, Mantova, Italy (RILEM Publications S.a.r.l., Bagneux, France, 2003) 137-145.

[18] Van Balen, K. and Van Gemert, D., ‘Interaction between drying and lime mortar carbonation’, in 3rd International Colloquium, Materials Science and Restoration (Expert Verlag, 1992) 1440-1452.

[19] Hayen, R. and Van Balen, K., ‘Thermal Expansion of Historic Masonry, Looking for Physical Compatibility’, in ‘Maintenance of Pointing in Historic Buildings: Decay and Replacement’, Final Report, EC Environment Programme. Editors R. Van Hees, S. Naldini, and L. Van der Klugt (2001) 169-74, contract ENV4-CT98-706.