Abstract This paper summarizes the approach to test methods used for assessing repair mortars for historic masonry. It also discusses adaptations needed to the test methods when evaluating mortars with high lime content.

I Introduction

Repair mortars are designed following the performance requirements that are specific to the repair and the reason for the repair. Appropriate tests, prior to and during the repair, are useful to assess whether the mortar will be able to meet the performance requirements. This paper highlights aspects of the chapter on test methods to be included in the forthcoming RILEM TC 203-RHM guide on repair mortars for historic masonry. Test methods will concentrate on repair mortars having binders derived from limestone (e.g. lime, hydraulic lime, natural cement, Portland cement). Tests on mortar components and existing mortars are largely covered in an earlier report and paper [1, 2].

Most of the tests are based on existing European and North American standards, and RILEM recommendations. The more commonly used (standard) tests methods will be presented. Although similar names may be applied to test methods in different standards it is important not to consider the data as interchangeable. There are frequently too many differences in the equipment and
the manner in which the test is completed to make a direct comparison. It would be necessary to complete round robin testing to assess the variations.

In addition to assessing performance requirements, testing can be used to ensure quality control of the repair mortar in both the laboratory and on-site. Quality control issues might include aggregate particle size distribution, consistency in materials such as solid content of lime putty, and consistency of the mortar during application. Thought needs to be given to test methods that result in useful but relatively quickly determined results for site use. For low strength, typically high lime content mortars, construction and curing procedures on site are more critical, and therefore need more careful monitoring than higher cement content mortars commonly associated with modern masonry construction.

Most of the tests for mortar properties involve testing the mortar only, and making correlations to its properties in the wall need to be considered carefully. For example, mortar cubes/prisms for compressive strength do not relate directly to the strength of the mortar in a wall; therefore they are most useful for quality control. In addition, the properties of a mortar tested at ages ranging from 28 days to one year need to be determined in order to understand the longer-term performance expected for the repair. High-lime mortars can take a long time to gain full strength, and furthermore properties such as porosity, strength and adhesion may change over time, through dissolution and re-precipitation of the binder.

The nature of mortar constituents also has an impact on the test method that is used. Many of the currently available standard test procedures are based on mortars containing a relatively high proportion of Portland cement in their binders. Adaptations may therefore be required for pure lime, lime-pozzolan and hydraulic lime mortars. Mortars with a binder having a high component of lime require curing conditions at a lower relative humidity than mortars with a binder containing a higher component of hydraulic binder.

Guidance in the forthcoming guidelines is given for use of the tests which are commonly available. The test methods are categorised according to the state of the mortar, i.e. plastic (fresh) and hardened and not according to the type of repair mortar (eg pointing, bedding, renders). Performance requirements for each repair mortar application should be initially determined and be used for determining the most relevant test methods. This is addressed in the chapters on performance requirements.

2 Testing of plastic (fresh) mortar

A workable mortar is a mortar acceptable to a mason for a specific purpose (e.g. bricklaying or rendering) in combination with a specific type of substrate. Workability is not a well-characterised physical quantity and cannot be defined by any single test method. It does not even have the same meaning for masons of
different regional experience or different practice (e.g. pointing, bedding, render). Nevertheless some aspects of it can be measured and are the subject of standardised tests. These include consistency, water retention, density, air content, workable life (board life), and initial bond to the substrate. The interplay of the binder type, aggregate particle size distribution and shape as well as the amount of water and possible additives all contribute to the characteristics of the mortar in the plastic state. Most standard tests for fresh mortar can be used without any modifications for mortars with a high lime content. However, different types of mortar binder do not require the same target value in these tests. For example: mortars with pure lime binders generally require a lower flow value than mortars containing a cement binder. This means that the results of the standard test methods are mainly used for comparative purposes. It is essential that workability be based on the judgment of masons. Thereafter, consistent workability for a particular mortar mix can be achieved by using the same binder and aggregate materials and ratios, and monitoring the consistency. An example of a simple test for consistency that can be used in the laboratory and on site is the cone penetration test [3]. The test is suitable for mortars with aggregates up to 3 or 4 mm in diameter. On site, it can be used to assess the uniformity between different batches of mortar from the mixer.

Workability is also related to the nature of the substrate: suction characteristics and geometrical aspects (e.g. size of masonry units, thickness of mortar layer). Usually a strongly absorbing substrate requires a mortar with a higher water retention or alternatively the substrate should be pre-wetted. Weather conditions during mortar application may also influence the requirements in a specific situation.

3 Testing of hardened mortar

Tests on hardened mortar, as with plastic mortar, are used to provide a framework for an estimation of the characteristics of the properties of the mortar once it is placed in the wall, or used for quality control of the mortar. The mortar may be prepared under laboratory conditions, or sampled and prepared at the site, but the final testing is commonly in the laboratory.

Regardless of mortar type the most typical tests include appearance (e.g. colour, efflorescence), physical properties (e.g. porosity, depth of carbonation), structural properties (e.g. flexural bond between mortar and masonry unit, compressive strength), deformation (e.g. elasticity, shrinkage), moisture properties (e.g. rate of water absorption, drying rate, vapour transmission), and durability (e.g. resistance to salts and freeze-thaw action). Test methods have been developed by different national standard bodies and most have been available for a long time. They are well characterized and generally well accepted.
Problematic, however, is the development of appropriate sample preparation and curing of pure lime and high lime (hydraulic lime) mortars. The mixing, moulding and curing procedures need to be different from those specified in most modern standards. High cement mortars achieve a significant proportion of their long-term characteristic properties after 28 days curing at 100% relative humidity. Under the same conditions lime in mortars does not carbonate.

4 Sample preparation and curing conditions for high lime mortars

Currently no common agreement among available test methods or research has emerged for the mixing, moulding, and curing procedures for high lime mortars. Mixing methods often are an adaptation of methods used for modern cement mortars. For pure lime mortars special pug-mill or mortar mill mixers are used on site to promote thorough mixing and effective kneading of the lime and aggregate. One adaptation for laboratory mixing is to extend the wetting and mixing time of the constituents [4]. Ensuring intimate contact of the binder to the aggregate is essential.

One of the largest challenges when preparing test samples of high lime mortars is that once moulded, they remain very fragile in the mould for days. Current standards specify leaving the mortar in the mould for at least 5 days [4, 5]. For pure lime mortars longer periods may be required. It has also been suggested to carry out demoulding in a series of steps in order to allow the diffusion of carbon dioxide gas inside the mortar specimen to allow hardening by the carbonation reaction to be started [6].

Curing procedures affect the mortar by altering the degree and the order of the hardening reactions which are principally hydration and carbonation; both occur in hydraulic lime and lime Pozzolan mortars. Pure lime mortars harden solely by carbonation which is best achieved by curing at a relative humidity in the range of 60 to 70% in contrast to the hydration reaction which requires 93 to 100%. A balance of moisture conditions needs to be achieved when the mortar binder contains both non-hydraulic and hydraulic components [7]. A longer initial damp curing time may therefore be needed before exposure to lower humidities. Full carbonation may take a year or more. Specimens stored outside to ensure adequate CO2 and wetted at weekly intervals have been found to carbonate more quickly [8]. When testing mortar samples it will be helpful to measure the degree of carbonation after the test.

Examples of curing periods given in standards and research papers are 28, 60, 90 and 120 days, and 1 year. Curing conditions vary too. For example the European mortar standard [5] requires 7 days at 95 ±5% humidity and 21 days at 65±5%. In contrast, the new ASTM standard [4] requires 120 days at 70±5% for pure lime mortars, 120 days at 90±5% humidity for hydraulic lime mortars and
lime/cement mortars with lime ≥45% by volume, and 28 days at 100% humidity for hydraulic cement mortars (including lime/cement mortars with less than 45% lime). For high lime mortars a 28 day curing period in the European standard is very short, while the ASTM standard has a much longer curing period but it only allows carbonation to occur with pure lime mortars.

There is a need for clear guidelines derived from research for appropriate preparation and curing procedures. These guidelines may vary depending on the purpose of the mortar test (e.g. quality control, mortar characterisation).

5 References

8. Kraus K (2010) Personal communication to the RILEM committee