Properties of Masonry Mortar

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Health and safety

All mortar mixtures, both wet and dry, are abrasive and alkaline. When working with wet mortar, waterproof or other suitable protective clothing should be worn. Guidance on the use of these materials can be found in MPA Mortar data sheet No. 20.

Introduction

This learning text covers the specification of mortar and its various properties both in the fresh and hardened states. A glossary of terms and a bibliography are included, along with self-assessment questions and answers.

A mortar joint acts as a sealant, a bearing pad, sticks the units together, yet keeps them apart and in this sense performs as a gap-filling adhesive. An ideal mortar:

- Adheres completely and durably to the brick, block or other masonry unit to provide stability
- Remains workable long enough to enable the operative to set the masonry unit right to line and level; this calls for good water retentivity
- Stiffens sufficiently quickly to permit the laying of the units to proceed smoothly and provides rapid strength development and adequate strength when hardened
- Is resistant to the action of environmental factors such as frost and/or abrasion and the destructive effects of chemical salts such as sulfate attack
- Resists the penetration of rain
- Accommodates movement of the structure
- Accommodates irregularities in size of masonry units
- Contributes to the overall aesthetic appearance
- Is cost effective.

The ability of a mortar to fulfill these various roles depends not just on the mortar manufacturer but also on the specifier who must select an appropriate mortar for the particular application. The craftsman on site also plays a key role. Overall. the factors to be taken into account include the environmental conditions, the composition of the masonry units involved as well as the workmanship and site practice of those engaged in the construction process.

Specifying mortar

Standards for the specification and testing of mortar are:

BS EN 998-2: *Specification for mortar for masonry - Part 2: Masonry mortar*

BS EN 1015: *Methods of test for mortar for masonry* (a multi part standard)
BS 4551: *Methods of test for mortar - Chemical analysis and physical testing.*
These standards describe mortar and require that it be specified under two categories - the plastic properties of fresh mortar and its hardened properties.

Fresh properties are those relevant in the un-set or wet condition, ie, before the mortar has begun to harden. Hardened properties are normally measured at 28 days of age. The specification of mortar is a compromise between all the requirements the mortar has to fulfill. Increasingly, UK mortar is being specified in terms of the performance concept as defined in BS EN 998-2.

The European design code for masonry structures (BS EN 1996) is frequently referred to as Eurocode 6.

Properties of fresh mortar

The role of fresh mortar during construction is a very important and complex one:

- Mortar must spread easily and remain workable long enough to enable the accurate laying of the masonry units to line and level
- It must retain water so that it does not dry out and stiffen too quickly, especially when using absorbent masonry units
- It must harden in a reasonable time to prevent it deforming or squeezing out under the weight of the units laid above.

Workability

Workability is the behaviour of a mortar in respect of all the properties required during application, subsequent working and finishing. The operative's opinion of workability is greatly influenced by the flow properties of the mortar - its cohesiveness and retention of moisture against the suction of the substrate.

A mortar with good workability will provide:

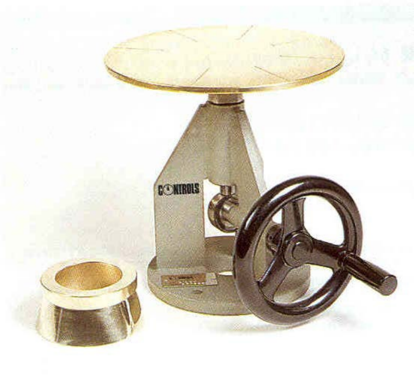
- Ease of use, ie, the way it adheres or slides on the trowel
- Ease of spread on the masonry unit
- Ease of extrusion between courses without excessive dropping or smearing
- Ease of positioning of the masonry unit without movement due to its own weight and the weight of additional courses.

If a mortar is 'harsh', that is of poor workability, the output of craftsmen will be reduced. Picking up and spreading will be slower and difficulty will be experienced in placing the cross or perpendicular joints and in obtaining a good finish. To assess the working properties of the mortar the consistence is first determined. Traditionally, this has been achieved within the UK by use of the 'dropping ball' test, prescribed in BS 4551. This involves dropping a 10mm diameter plastic ball a distance of 300mm onto the surface of a mortar and measuring its penetration. The British Standard, first published in the 1960s, refers to a so-called standard consistence of 10mm, originally defined by a number of bricklayers working with laboratory-controlled mortars at the Building Research Establishment.

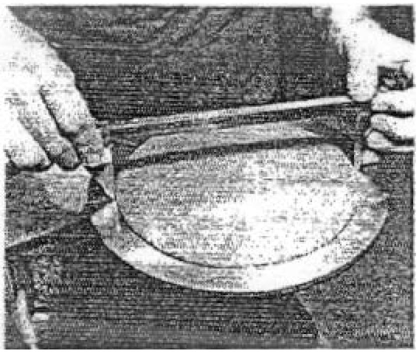
Figure 1: ***Dropping Ball Apparatus***

Once a laboratory mortar has been brought to a standard consistence of 10 mm, it is subjected to a flow test using the flow table as prescribed in BS EN 1015-3. (Further details of this test are given in the MPA

Figure 2: ***Flow Test***



Flow test equipment



Measuring the flow

Mortar learning text 8: Mortar testing). The flow test produces a result, which is the mortar specimen's width or spread expressed as a percentage of the original diameter. This value is a measure of the cohesion or plasticity of the mortar and enables its likely acceptability on site to be quantified in the laboratory.

There are two methods of measuring consistence defined in the mortar test method standards (the BS EN 1015 series). These adopt a slightly different approach with the consistence being determined using either a flow table or a penetrometer.

Water retentivity

This is the mortar property that resists water loss by absorption into the masonry units (suction) and/or to the air, in conditions of varying temperature, wind and humidity. Water retentivity is related to workability. A mortar with good water retentivity remains plastic long enough to allow the masonry units to be aligned and plumbed without breaking the intimate bond between the mortar and the units. Low-absorption units in contact with mortar with high water retentivity may 'float' and move out of alignment and plumb. Therefore, water retentivity should be neither too low nor too high. Adjustments can be made by varying the amount of entrained air and/or the amount/type of sand, admixtures, lime and cement. Loss of moisture due to poor water retentivity, in addition to loss of plasticity, may greatly reduce the effectiveness of the bond to the masonry units.

Air content

Mortar air content in its fresh state is also important. To achieve good durability there must be sufficient air content (entrained air) to enable freeze-thaw cycles to be resisted without disrupting the material's matrix. As the water in the mix freezes and changes to ice, it increases in volume, which generates disruptive forces. The incorporation of entrained air produces a vast number of evenly dispersed bubbles acting as expansion chambers, which allow the freezing water to expand without disrupting the mortar matrix. However, excessive air content results in a gradual reduction in strength, particularly in bond and flexure. Therefore a controlled air content is important. BS EN 998-2 does not impose a maximum limit for air content.

Air content may be measured by many different methods, the most common being based on the displacement of the air by pressure. The pressure method uses equipment that is based on Boyle's Law, similar to that used for the determination of the air content in concrete. Another method, is based on air displacement by an alcohol water mixture. The procedure for undertaking air tests is described in MPA Mortar learning text 8: Mortar Testing.

Stiffening and hardening

These two terms define different properties. The progression of stiffening, described in BS EN 1015-9 as workable life, refers to the gradual change from fresh or plastic mortar to setting or set mortar. Hardening refers to the subsequent process whereby the set mortar progressively develops strength.

Rapid stiffening may interfere with the craftsman's use of the mortar, whilst a slow rate of stiffening may impede work progress. A uniform and moderate rate of stiffening will assist the craftsman in laying the masonry units and tooling the joints to give a consistent finish especially where coloured mortars are used.

Hardening is of interest to the designer when considering the mortar's final design strength and how this develops.

Bulk density

Factory-produced mortar is made by batching the constituent materials by mass. However, wet ready-to-use mortar is frequently sold by volume, therefore the relationship between mass and volume is important. Site practice guides frequently refer to the quantity of masonry that may be laid with a tonne of mortar. Where mortar is delivered on a volume basis, it is discharged into containers, called skips or tubs. The density of the material must be taken into account in determining both the loads that can be safely lifted or stored in elevated positions (eg, scaffolding) and the required quantity of mortar to lay a given number of units.

Properties of hardened mortar

The role of mortar when hardened in the finished structure is to transfer the compressive, tensile and shear stresses between the units and it must be sufficiently durable to continue to do so over the life of the structure. The strength and durability requirements of a mortar depend upon the type of service the masonry is to perform. Walls which will be subjected to relatively severe stresses or severe exposure conditions will need to be laid using a stronger and more durable mortar than is required for general purpose applications. The principle properties of hardened mortar are covered in the following sections of this learning text.

Bond

BS EN 998-2 defines bond strength as 'adhesion perpendicular to the load between the masonry mortar and the masonry unit'. The tensile bond, therefore, is the force in tension required to separate the units from the mortar and each other. Good bond is essential to minimise ingress of water and moisture. The interface of the masonry unit and the mortar is usually the most vulnerable part of the masonry construction to rain. Bond strength is required to withstand tensile forces due to wind, structural and other applied forces, movement of the masonry units and temperature changes.

The greatest factor influencing bond strength is normally cement content. In general, the higher the cement content the greater the bond strength. Air content is also an important factor and research has shown that excessively high air contents reduce bond at the brick interface. Workmanship is a key factor too. The time lapse between spreading mortar and placing must be kept to a minimum. Once the masonry unit is in place and aligned it must not be moved. Workmanship is covered in MPA Mortar learning text 11: *Construction*.

Freshly laid masonry should be protected from extremes of wind and sun to avoid drying of the mortar before hydration of the cement is complete.

Compressive strength

Examination of many specifications gives the impression that compressive strength is the most important property of mortar. This may not always be correct as workability and bond are also of great significance. Compressive strength is frequently highlighted in specifications because it is relatively easy to measure. Adequate mortar strength is essential but the final strength of a mortar should not exceed that of the bricks or blocks used. The use of too much cement will produce a more rigid mortar, which may result in vertical cracking passing through units and mortar joints as stresses are imposed (see figure 3).

Use of the appropriate mortar should not result in cracking, but any that does occur, (eg, due to movement), will tend to follow the joints, which will be much easier to repair (see figure 4).

Factors affecting compressive strength include cement content, sand grading, entrained air content and water content. Increased cement contents will give higher sand, increased air content or increased water content will reduce strength. The compressive strength of mortar has a relatively minor influence on the strength of masonry construction when compared to the strength of the units. Research has shown that wall strengths increase by only about 10% when mortar compressive strength increases by 130%. Stronger mortars with higher cement content tend to have higher shrinkage. This may result in an increased risk of rain penetration due to the greater potential incidents of fine crack formation.

Compressive strength should be measured on test specimens produced by breaking prism specimens into half and testing the two individual broken halves. Care should be taken to ensure that test equipment is of sufficient sensitivity. Many compressive strength-testing machines used to test concrete cubes are insufficiently sensitive for mortar testing.

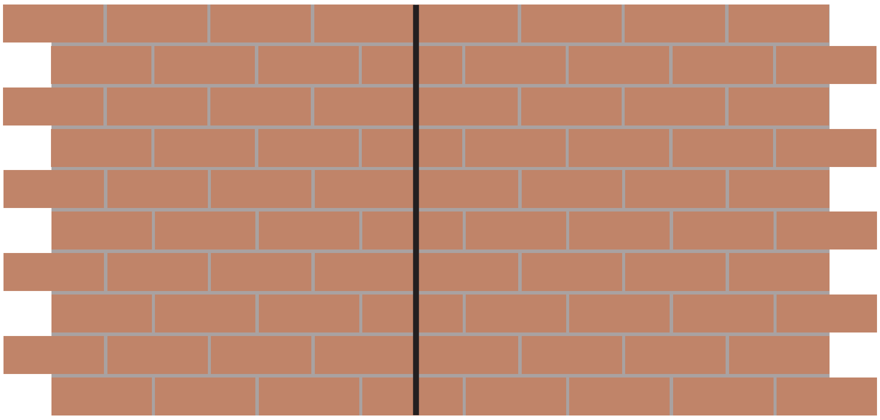


Figure 3: ***Vertical cracking in brickwork***

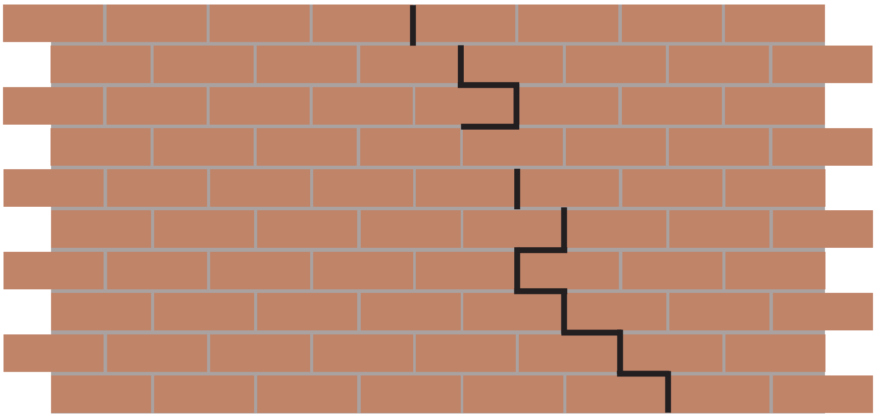


Figure 4: ***Cracking following the mortar joint***

Durability

Mortar durability is its ability to endure aggressive conditions during its design life. A number of potentially destructive influences may interact with the mortar - water, frost, soluble salts and temperature change. In general, as the cement content increases so will durability. Air entrainment of mortars improves resistance to freeze-thaw damage.

Soluble sulfates may be present in the masonry units, the soil, the atmosphere or may be introduced extraneously. When the masonry becomes wet, the sulfates may dissolve and can then react with the mortar. These sulfates in solution may then combine with compounds in the cement and result in mortar expansion and crumbling. In certain situations it may be necessary to use a mortar with adequate sulfate resisting properties.

Durability must be adequate for the situation in which the mortar is used. A mortar of lesser durability may be suitable for internal walls but could weather very badly on exposed chimney stacks, for example.

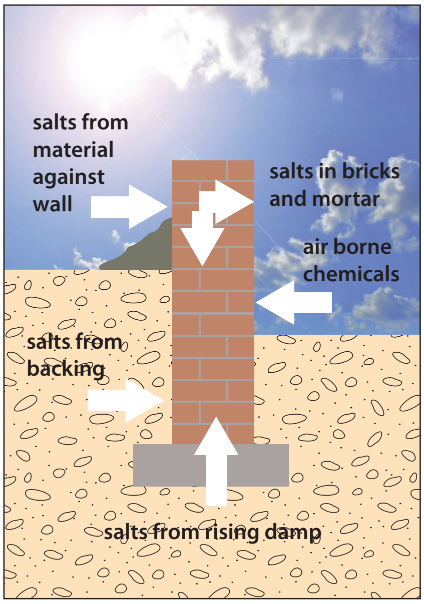


Figure 5: ***Aggressive agents***

Flexural strength

Traditional masonry construction tended to be massive relative to modern structures, typically with very thick walls. This meant that the mass or bulk generally resisted the various forces applied to it. The development of modern masonry units and advances in mortar technology have led to more slender structures which are more vulnerable to lateral forces eg, wind loads.
The standard BS 5628 Part 1 provides guidance on the characteristic flexural strength of masonry based on the type of masonry unit and the class/designation of the mortar.

Mix proportions

Because of the traditional prescriptive nature of mortar specifications (BS 4721), there was a requirement to determine the mortar mix proportions in order to confirm conformity to the standard. Theoretically, this determination could have been carried out in the fresh state but it was more usual to undertake this when the mortar had hardened, using the methods of chemical analysis detailed in BS 4551.

To determine the characteristic flexural strength of a masonry construction, small walls constructed from the masonry units and the appropriate mortar may be tested in accordance with the procedure described in BS 1052-2. The bond of the mortar and masonry unit is an important factor in the flexural strength that is achieved.

Thermal properties

Energy efficiency is a very important factor to be considered because of legislation, global warming and thermal efficiency. The Building Regulations require that consideration be given to the mortar joints as well as the units when considering heat loss and thermal efficiency - the U value - of walls.

Use of lightweight mortars improves the overall thermal efficiency of the masonry. Alternatively, thin layer mortars may be used (ie, joint thickness of 1-3mm). These approaches are used in parts of mainland Europe. Another answer is to use larger sized blocks to minimise the number of mortar joints.

Acoustic properties

Acoustic properties of mortars are also important. Building Regulations have become more stringent in this area and construction using brickwork or blockwork does give very good acoustic performance. In addition, a layer of traditional mortar plastering can greatly enhance the acoustic properties of a wall, and may be useful in the case of party walls between dwellings.

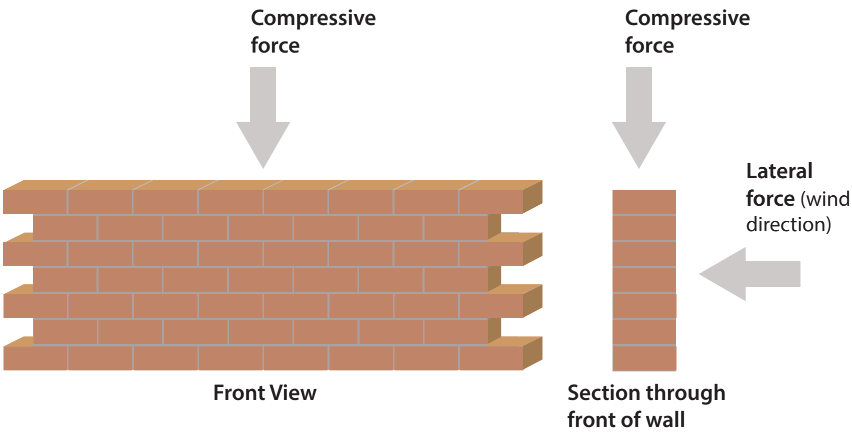
Appearance

The colour and shade of the mortar joints greatly affects the overall appearance of a masonry structure, where some 15- 25 % of the visual surface may be comprised of mortar. Careful measurement of mortar materials and thorough mixing are important to maintain uniformity from batch to batch and from day to day. Particular care needs to be taken in respect of coloured - pigmented - mortars.

Mortar joints should be tooled at a similar stage of stiffening in order to ensure a uniform surface shade in the finished structure. If some joints are tooled soon after laying but others left until much later, a marked colour difference may result.

Attention to all these points will ensure that the mortar complements the masonry.

Figure 6: ***Applied loads to a masonry construction***



Glossary of Terms

Air Content
The quantity of air included in a mortar.

Bleeding
The separation of water from a plastic (fresh/ unhardened) mix.

Consistence
The fluidity of a fresh mortar.

Durability
The resistance of a mortar to adverse chemical, mechanical and climatic conditions.

Hardening
The time during which a mortar develops strength.

Plasticity
The cohesiveness and ease of spreading of a mortar.

Setting
The process of the hydration of cement. The setting time is the time after which a mortar begins to harden and achieve final strength.

Shrinkage
The volume reduction of an unrestrained mortar during hardening.

Stiffening
The gradual change from fresh (plastic) mortar to setting or set mortar.

Suction
The property of a substance which influences its rate of absorption of water.

Thermal conductivity
A measure of the rate of heat transfer through unit thickness and area of material from face to face. The thermal conductivity (k) of a material is technically defined as the quantity of heat that passes through 1m2 of the material of 1m thickness for 1^{o}C difference in temperature of the inner and outer surface

Thermal resistivity
The resistivity of a material is a measure of resistance to heat flow through unit thickness and is the reciprocal of the conductivity value (ie, 1/conductivity).

Thermal transmittance
Thermal transmittance (U value) is the rate of heat transfer through a construction from air to air and is the reciprocal of the sum of all the thermal resistances offered by a construction (ie, all the components).

Water retentivity
The ability of a fresh mortar to retain its mixing water when exposed to substrate suction.

Workability
The ease with which the mortar may be moved under the trowel.

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BS 5628-1: 2005 Code of practice for the use of masonry - Structural use of unreinforced masonry.

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BS EN 1015-2: 1999 Methods of test for mortar for masonry - Part 2: Determination of particle size distribution (by sieve analysis).

BS EN 1015-3: 1999 Methods of test for mortar for masonry- Part 3: Determination of consistence of fresh mortar (by flow table).

BS EN 1015-4: 1999 Methods of test for mortar for masonry - Part 4: Determination of consistence of fresh mortar (by plunger penetration).

BS EN 1015-6: 1999 Methods of test for mortar for masonry - Part 6: Determination of bulk density of fresh mortar.

BS EN 1015-7: 1999 Methods of test for mortar for masonry - Part 7: Determination of air content of fresh mortar.

BS EN 1015-9: 1999 Methods of test for mortar for masonry - Part 9: Determination of workable life and correction time of fresh mortar.

BS EN 1015-10: 1999 Methods of test for mortar for masonry - Part 10: Determination of drybulk density of hardened mortar.

BS EN 1015-11: 1999 Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar.

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BS EN 1996-1-2: 2005 Eurocode 6. Design of masonry structures. Structural fire design. (A national annex has also been published)

BS EN 1996-2: 2006 Eurocode 6. Design of masonry structures. Design considerations, selection of materials and execution of masonry. (A national annex has also been published)

BS EN 1996-3: 2006 Eurocode 6. Design of masonry structures. Simplified calculation methods for unreinforced masonry structures. (A national annex has also been published)

Self-assessment questions

1 List the desirable properties of fresh mortar.

A

2 What problems may occur if a mortar has poor water retentivity properties?

A

3 What property does the dropping ball test measure?

A

4 What is the desirable range of entrained air contents in mortar?

A

5 On what law of physics is the pressure method of measuring air content based?

A

6 List four desirable properties of hardened mortar.

A

7 Should the mortar be stronger or weaker than the masonry units it is bonding?

A

8 Is the function of mortar to stick masonry together or keep it apart?

A

9 What does the U-value measure?

A

10 What is the detrimental affect of an air content in excess of the recommended limits?

A

Answers to self-assessment questions

1 Optimum workability, water retentivity and rate of stiffening.
2 Rapid loss of plasticity and poor bond to the masonry unit.
3 The consistency of the mortar.
4 7-18%
5 Boyle's Law.
6 Adequate bond, compressive/flexural strength, mix proportions, durability, thermal properties, acoustic properties and suitable appearance.
7 The mortar should be weaker than the units it is bonding together.
8 Both: the mortar should bond the units together to minimise rain penetration and keep the units apart to keep the courses level.
9 Thermal transmittance, the rate of heat transfer through a construction.
10 A reduction in bond strength.

MPA Mortar Learning Texts include:

1 Introduction to modern mortars
2 Cementitious materials
3 Aggregates
4 Admixtures, additives and water
5 Brick and block production
6 Properties of masonry mortar
7 Production, deleivery and storage of mortar
8 Mortar testing
9 Specifications
10 Quality assurance
11 Construction
12 Properties of rendering mortar
13 Best practice - potential site problems

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