

# **Learning Text**

## **Part 6**

### **Properties of Masonry Mortar**

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# Properties of Masonry Mortar

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# Properties of Masonry Mortar

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## **Introduction**

This learning text considers the role played by mortar as an element of masonry construction. Firstly, the current situation with regard to specifying mortar is reviewed and then the various properties of mortar in the fresh and hardened states are discussed. A glossary of terms and a bibliography are included. The final section of this learning text is self-assessment questions and answers.

The functional requirements of mortar are numerous. 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 implies good water retentivity.
- Stiffens sufficiently quickly to permit the laying of the units to proceed smoothly, and provides rapid development of strength 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 fulfil 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. 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**

Historically, mortar was specified by prescription, that is using nominal mix proportions as given in the UK code of practice BS 5628 Part 3 and other British Standard publications.

The Standards relevant 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 : Note this is a multi part standard) and 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 the hardened properties.

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## **Properties of Masonry Mortar**

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The fresh properties are those properties that are relevant in the un-set or wet condition, that is before the mortar has begun to harden. The hardened properties of the mortar are normally measured at 28 days of age.

The specification of mortar is a compromise between all the requirements the mortar has to fulfil.

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, this is a four part standard published in 2005/2006. It is expected that BS 5628 will be withdrawn in 2010 leaving Eurocode 6 as the primary Standard for masonry design. National annexes to support BS EN 1996 were published in 2007.

### **Properties of fresh mortar:**

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

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

These various properties of fresh mortar are described in the following sections.

### **Workability**

Workability may be defined as 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 have the following properties:

- Ease of use, i.e. 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.

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Traditionally, this has been achieved within the United Kingdom by use of the ‘dropping ball’ test, prescribed in BS 4551. This involves dropping a plastic ball of 10 mm diameter a distance of 300 mm onto the surface of the mortar and measuring its penetration. The British Standard, first published in the 1960s, refers to a so-called standard consistence of 10 mm, 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 this 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 Learning Text 8: Mortar Testing).

The flow test produces a flow result, which is the width or spread of the mortar specimen 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.

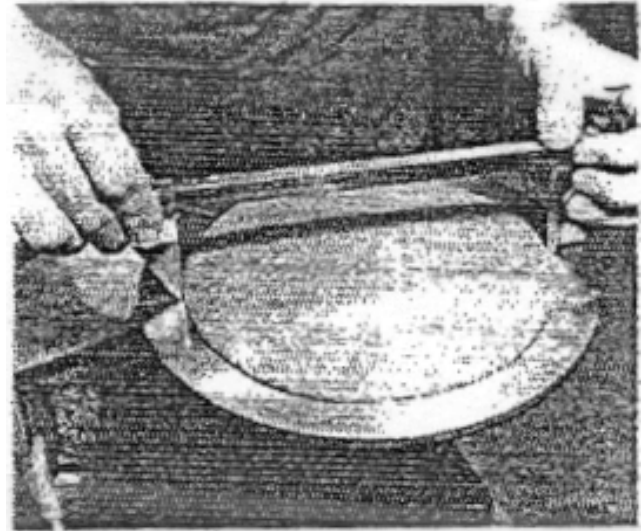
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## Properties of Masonry Mortar

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a) Flow Test Equipment



b) Measuring the flow

**Figure 2 – Flow Test**

There are two alternative 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 property of mortar 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 fine aggregates, 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**

The air content of the mortar in its fresh state is also important. In order to achieve good durability it is necessary that there is sufficient air content (entrained air) to enable freeze-thaw cycles to be resisted without disrupting the matrix of the material. As the water in the mix freezes and changes to ice it increases in volume, which generates disruptive forces. The incorporation of entrained air gives rise to the formation of 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.

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Therefore a controlled air content is important, the former: BS 4721 prescribed an entrained air content in the range 7-18%. It should be noted that BS EN 998-2 does not impose a maximum limit for air content.

The 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. The other method, is based on displacement of the air by an alcohol water mixture. The procedure for undertaking air tests is described in 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 use of the mortar by the craftsman, whilst a slow rate of stiffening may impede the progress of the work. 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.

The hardening is of interest to the designer when considering the final design strength of the mortar 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, known as 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 (e.g. 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 required 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 discussed in the following sections of this learning text.

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## 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, may be defined as 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 the ingress of 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.

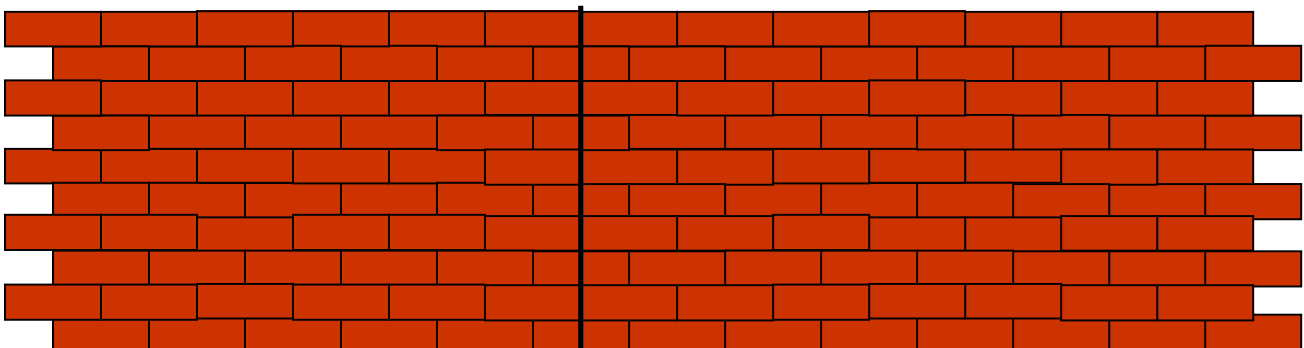
Air content is also an important factor and research has shown that excessively high air contents reduce bond at the brick interface.

It should also be emphasised that workmanship is a key factor in affecting bond. 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 subsequently moved. The subject of workmanship is covered in 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. However, 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 (Figure 3).



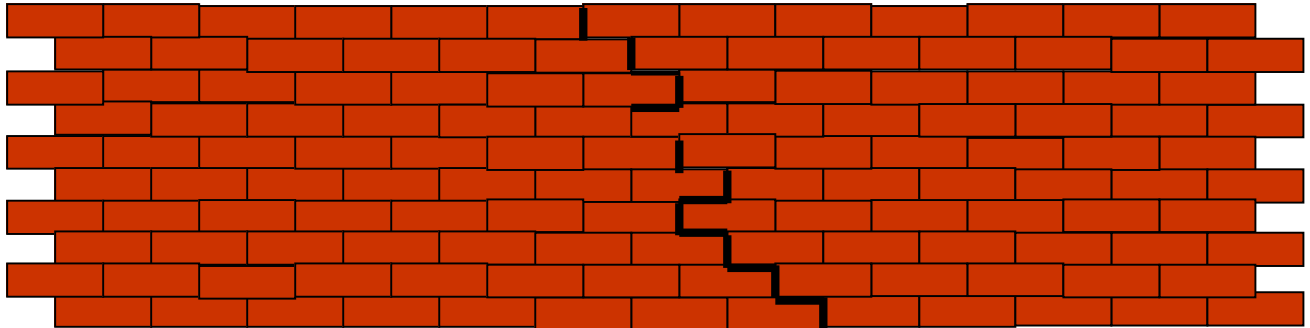
**Figure 3: Vertical cracking in brickwork**

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



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

Some of the important factors affecting compressive strength are cement content, sand (fine aggregate) grading, entrained air content and water content. Increased cement contents will give higher strengths, whilst increased fines content of 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 contents 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 the test equipment is of sufficient sensitivity; as many compressive strength-testing machines that are used to test concrete cubes are insufficiently sensitive for the testing of mortar.

### **Durability**

Durability of mortar may be defined as its ability to endure aggressive conditions during its design life. A number of potentially destructive influences may interact with the mortar: these include 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.

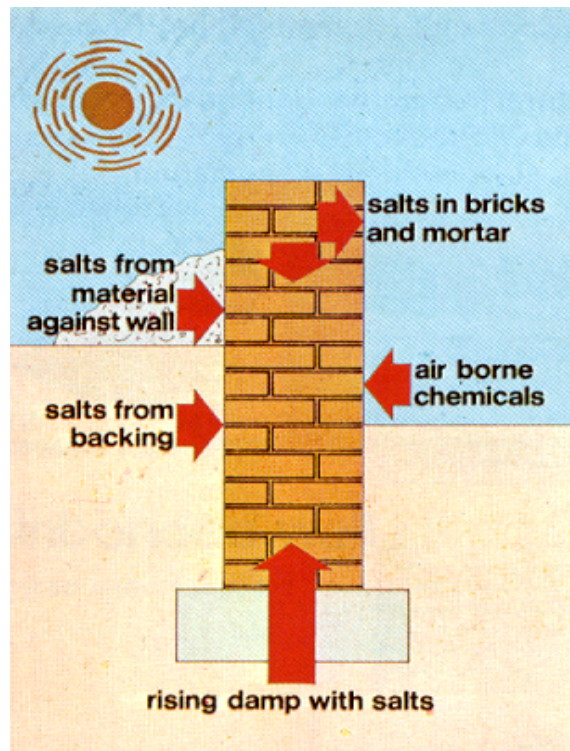
Soluble sulfates may be present in the masonry units, the soil, the atmosphere or may be introduced extraneously. When the masonry becomes wet the sulfates may dissolve and can then react with the mortar. These sulfates in solution may then combine with compounds in the cement and result in expansion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

The 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.

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Where a mortar of lower strength than the masonry units is used, any water flow will tend to take place preferentially through the mortar joint. If any degradation occurs due to freezing and thawing this is less important than damage to the units themselves, as the mortar joint may be replaced relatively easily.

In contrast, if a relatively dense and impermeable mortar is used with more permeable masonry any flow of water that takes place will tend to pass preferentially through the masonry unit rather than through the mortar joint. This may lead to salt crystallisation (efflorescence) on the surface of the masonry and/or degradation of the masonry unit due to freezing and thawing.

There is often a requirement to test mortar for durability, but satisfactory tests are difficult to develop in practice and most suggested regimes are either too lengthy and complicated or do not relate sufficiently well to site practice.

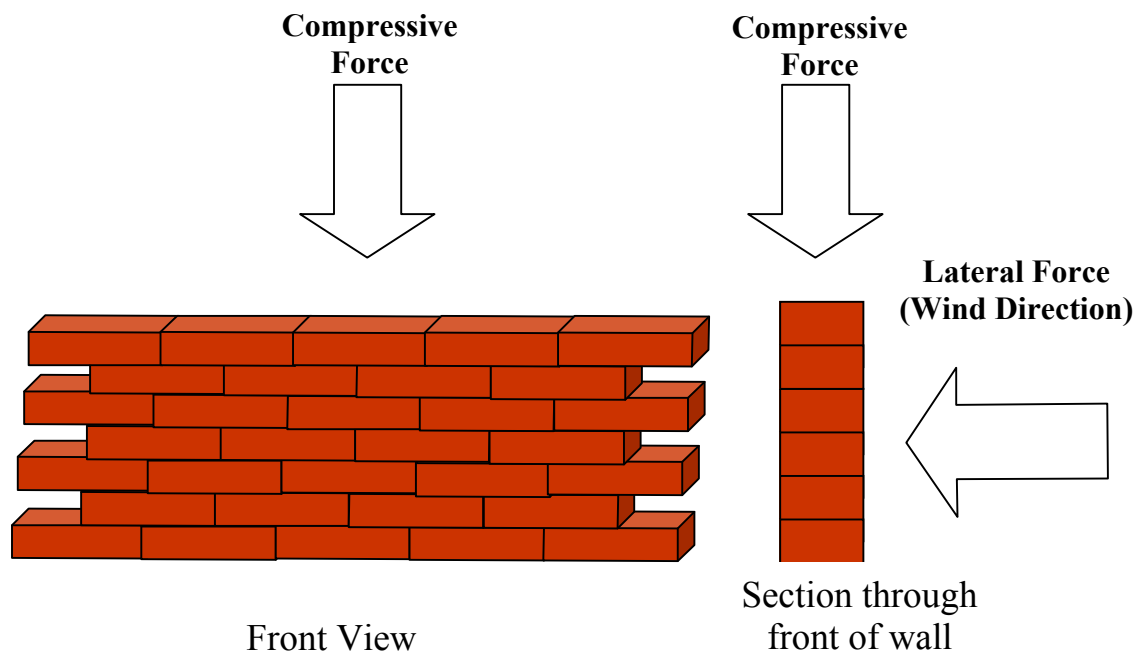
### **Flexural strength**

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 e.g. wind loads.

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

BS 5628 Part 1 provides guidance on the characteristic flexural strength of masonry: this is 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 mix proportions of mortar 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.

Where it is desired to determine the characteristic flexural strength of a masonry construction, small test 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.

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## Thermal properties

Energy efficiency has become more important in recent years, partly because of legislation on energy use, 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 (U value) of walls.

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

## Acoustic properties

The acoustic properties of mortars are also becoming of greater importance. The Building Regulations have become more stringent in this effect and construction using brickwork or blockwork can 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. It should be remembered that 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.

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# Properties of Masonry Mortar

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## 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 $1\text{m}^2$ of the material of $1\text{m}$ thickness for $1^\circ\text{C}$ 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 (i.e. $1/\text{conductivity}$ ).
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 (i.e. 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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## Properties of Masonry Mortar

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BS 4721: 1981	Specification for ready-mixed building mortars.(Withdrawn standard)
BS 5628-1: 2005	Code of practice for the use of masonry- Structural use of unreinforced masonry.
BS 5628-2: 2005	Code of practice for the use of masonry- Structural use of reinforced and prestressed masonry.
BS 5628-3: 2005	Code of practice for the use of masonry- Materials and components design and workmanship.
BS EN 998-1: 2003	Specification for mortar for masonry- Part 1: Rendering and plastering mortar.
BS EN 998-2: 2003	Specification for mortar for masonry- Part 2: Masonry mortar.
BS EN 1015-1: 1999	Methods of test for mortar for masonry- Part 1: Determination of particle size distribution (by sieve analysis).
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 dry bulk 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.
BS EN 1015-12: 1999	Methods of test for mortar for masonry- Part 12: Determination of adhesion of hardened rendering and plastering mortar on substrates.

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## Properties of Masonry Mortar

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	adhesion of hardened rendering and plastering mortar on substrates.
BS EN 1015-17: 2000	Methods of test for mortar for masonry- Part 17: Determination of water-soluble chloride content of fresh mortars.
BS EN 1015-18: 2002	Methods of test for mortar for masonry- Part 18: Determination of water absorption coefficient due to capillary action of hardened rendering.
BS EN 1015-19: 1999	Methods of test for mortar for masonry- Part 19: Determination of water vapour permeability of hardened rendering and plastering mortars.
BS EN 1015- 21:2002	Methods of test for mortar for masonry- Part 21: Determination of the compatibility of one coat rendering mortars with substrates.
BS EN 1996-1-1: 2005	Eurocode 6. Design of masonry structures. General rules for reinforced and unreinforced masonry structures.  (A national annex has also been published)
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)

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## Properties of Masonry Mortar

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### Self-assessment questions

<b>1</b>	List the desirable properties of fresh mortar.
<b>2</b>	What problems may occur if a mortar has poor water retentivity properties?
<b>3</b>	What property does the dropping ball test measure?
<b>4</b>	What is the desirable range of entrained air contents in mortar?
<b>5</b>	What law of physics is the pressure method of measuring air content based on?
<b>6</b>	List four desirable properties of hardened mortar.
<b>7</b>	Should the mortar be stronger or weaker than the masonry units it is bonding?
<b>8</b>	Is the function of mortar to stick masonry together or keep it apart?
<b>9</b>	What does the U-value measure?
<b>10</b>	What is the detrimental affect of an air content in excess of the recommended limits?

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## Properties of Masonry Mortar

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### Answers to self-assessment questions

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

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