What is happening to masonry mortar?

It has been a tradition in the UK to specify mortar in terms of volume proportions – the 'prescriptive' or 'recipe' approach – so called because it gives a listing of the mix proportions. This method was used in BS 5628[(1)], BS 4721[(2)] and BS 5838-2[(3)]. The alternative method of specifying mortars, based on measured parameters such as minimum compressive strength, is known as the 'design' or 'performance' approach. ***Graham True*** *of* ***GFT Materials Consultancy*** *reports.*

BS EN 998[(4)] is the current British Standard. It specifies requirements for designed mortars and, to a lesser extent, prescriptive mortars. Its publication brought about a need to withdraw or update existing British Standards. Therefore, BS 4721 and BS 5838-2 were superseded. However, BS EN 998-2:2010[(5)] is soon to be replaced by BS EN 998-2:2016[(4)] – to be endorsed by May 2017 and currently without a National Annex as included in the 2010 publication. When published in final form in August 2018, any conflicting National Standards will be withdrawn.

Designed mortars use a composition chosen by the producer in order to achieve specified properties (performance concept). The compressive strength of masonry mortar declared by the manufacturer follows Table 1 as set out in BS EN 998-2:2010 with the designation 'M' followed by the compressive strength class in MPa, which it exceeds.

Table 1 – BS EN 998-2:2010 mortar classes.

Class	M1	M2.5	M5	M10	M15	M20	M ***d***
Compressive strength MPa	1.0	2.5	5.0	10.0	15.0	20.0	***d***
d is a compressive strength greater than 20MPa as a multiple of 5 declared by the manufacturer.							

Prescribed mortars are batched to predetermined proportions chosen by the specifier. The manufacturer will verify conformity of the mortar by referring to production records and delivery documentation.

In both cases (design or prescribed), if a third party is engaged to investigate, for example, a questionable in-situ use of mortar in the walls of a house, the mortar manufacturer will often resort to just providing batch data based on volume proportions although the mortar is, and will have been, batched using mass proportions.

A specifier, typically a house-builder, will order a prescribed mix (by volume, say a 1:5 to 6) and the supplier or manufacturer will translate that into an M mortar class, as a design mix equivalent.

Historically, the assessment of conformity to a prescribed specification could only be achieved by the use of chemical analysis to BS 4551[(6)]. An alternative now is to infer the mix proportions of the mortar from compressive strength. BS EN 998-2 states the relationship between compressive strength and mix proportions for a limited range of strengths and mortar compositions in Table 2 found in the National Annex provided in BS EN 998-2:2010, entitled *Guidance on the use of BS EN 998:2010 for masonry mortar*, but note the M

Table 2 – Table NA1: mixes for prescribed masonry mortars and mortar classes.

Mortar designation	Prescribed mortar (traditional proportion of materials by volume)[A]				Mortar class that may be assumed	Suitable for use in environmental conditions
	Cement[B]:lime:sand with or without air entrainment	Cement[B]:sand with or without air entrainment	Masonry cement[C]:sand	Masonry cement[D]:sand		
(i)	1 : 0 to 1/4 : 3	1 : 3	Not suitable	Not suitable	M12	Severe (S)
(ii)	1 : 1/2 : 4 to 4 1/2	1 : 3 to 4	1 : 2 1/2 to 3 1/2	1 : 3	M6	Severe (S)
(iii)	1 : 1 : 5 to 6	1 : 5 to 6	1 : 4 to 5	1 : 3 1/2 to 4	M4	Moderate (M)
(iv)	1 : 2 : 8 to 9	1 : 7 to 8	1 : 5 1/2 to 6 1/2	1 : 4 1/2	M2	Passive (P)

A When the sand portion is given as, for example, 5 to 6, the lower figure should be used with sands containing a higher proportion of fines, whilst the higher figure should be used with sands containing a lower proportion of fines.
B Cements in accordance with NA.1.3 (except masonry cements), or combinations in accordance with NA.1.4
C Masonry cement in accordance with NA.1.3 (inorganic filler other than lime)
D Masonry cement in accordance with NA.1.3 (lime)

Table 3 – Some test methods for in-situ assessment of masonry mortar.

	Name of test	Description	Test range	Standard or reference
1	Scratch Index Test MortarCheck II Scratch Test Instrument.	Penetration into mortar of spring-loaded cruciform cross-section probe, 6mm diameter, following 5 rotations. Spring stiffness 0.78N/mm and initial force 15.6N. Penetration proportional to mortar compressive strength.	Average of 5 tests per location at minimum spacing of 10mm. Results in range.	AS 3700 Australian Standard for Masonry Structures
2	Windsor Pin System	Spring driven pin into the mortar. Pin penetration inversely proportional to compressive strength. Spring force 108N.	Seven readings per test area discarding highest and lowest. Record resulting mean.	ASTM C-803
3	Screw Pull-out Test	Helical wall tie pull-out force recorded from a 20mm to 30mm depth hole 6mm diameter, within mortar.	10 holes per 1–2m^2. Mortar strength up to 7N/mm^2.	BRE Digest 421
4	Drilling Resistance Measurement System (DRMS) and PNT-G System	Hardness related to the electrical power required to drill at constant speed, constant penetration using a 4 to 6mm drill bit.	Power consumed at each depth equates to the compressive strength at that location.	Rilem TC 177-MDT (Masonry durability and on-site testing)
5	Schmidt Type PM Pendulum Hammer	Rebound measured of a pendulum hammer. Rebound proportional to mortar compressive strength.	Nine readings at different locations.	Rilem MS.D.7
6	Mini Cube Testing	Miniature cubes cut from bed joint mortar and tested in standard lab test machine	Found to be comparable with conventional cast mortar samples.	Bristol University

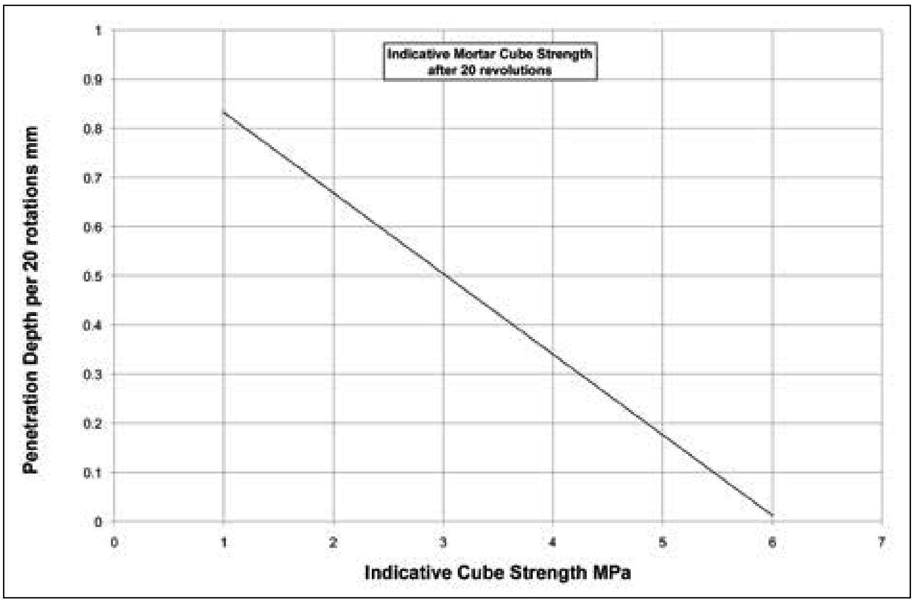

Figure 1: Indicative mortar cube strength from probe penetration after 20 rotations.

class strength values differ entirely over the fully range.

In future, it would be most helpful to all concerned if mortar specifications were defined by mass proportions, especially since now most volume users of mortar obtain the product from machine dispensing equipment, either off, or on site, and batch weights will be available. Concrete is always specified by weight and ordered by volume. So why is it not for masonry mortar?

PD 6678:2005[7] gives prescribed volume proportions (in its Tables 1 and 2) in terms of volume and mass quantities respectively related to the four assumed strength classes as denoted in Tables 1 and 2. We therefore already have an informed start.

Current anomalies

There has been, and probably will continue to be, issues related to the performance specification of mortar since it currently differs fundamentally from past UK practice but in addition so does the incorporation of high levels of cement replacements, in particular GGBS.

If we look into the National Annex provided in BS EN 998-2:2010, we have in that National Annex NA1 guidance based on best UK practice including limitations on the use of cementitious replacements with GGBS, fly ash and limestone fines restricted to specific inclusion levels, namely 6–35% for the former two and 6–20% for limestone dust.

In has been stated by one mortar supplier that the National Annex guidance in BS EN 998-2 is just that – 'guidance' and 'not mandatory' – and therefore can be ignored. Also mix proportions by mass used to produce design mixes are often withheld by the mortar manufacturer and the equivalent volume ratio quoted because although a mortar was ordered by traditional volume proportions, it has been supplied as a design mortar. Compliance when queried is then provided by cube test results showing the mortar when sampled, cured and tested in accordance with BS EN 1015[8], achieves the relevant minimum class strength.

Performance in terms of cube strength may well show compliance from mortar sampled at the batching plant and cured and tested but when delivered and placed between absorbent bricks and left to weather, it is not too surprising that householders can see the mortar is unfit as in many cases it can be raked out with a fingernail. On investigation

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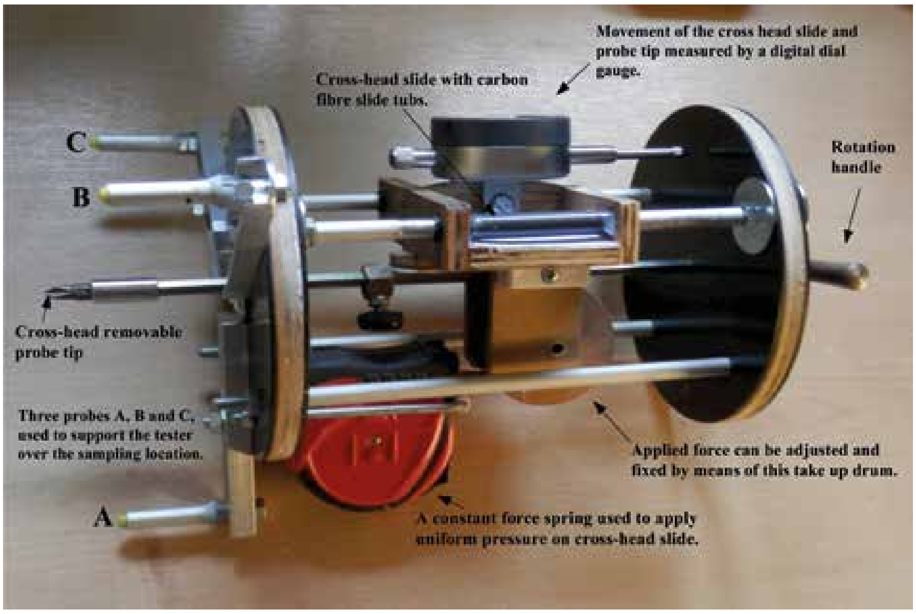

Figure 2: Prototype – GFT in-situ mortar tester

Figure 3: Mark 2 Prototype – GFT in-situ mortar tester under calibration at Wolverhampton University. This machine is fitted with dual constant force springs and can be seen taking readings on a BS mortar test beam.

it transpires that GGBS additions are being incorporated at levels well above the recommended limits of 35%, up to 50% and more, of the total cementitious content.

Perhaps this is not too surprising when we can read in Data Sheet 16 published by the Mortar Industry Association[9] that typically 25% and 50% replacement of Portland cement by GGBS with or without the addition of lime has been used. Also The Concrete Society's Good Concrete Guide 4[10] states generally up to 80% by weight of Portland cement is substituted by GGBS in a mix.

So it may be that design mortars are being formulated that achieve satisfactory performance when assessed by cube tests to BS EN 1015, but not when actually used to build walling. Is this lack of performance in-situ the responsibility of the house builder or the mortar producer adding too much slag?

In-situ test methods

To confuse things further, there is no agreed UK or European Standard test method available for assessing the quality of questionable mortar, in-situ. The Australian Standard AS 3700[11] does include one that can determine durability performance of the surface zone by a controlled abrasion test, but only to a limited depth. Others estimate in-situ compressive strength of mortar by: firing a pin into the mortar; measuring the pull-out force of a wall tie; total power consumed by constant speed and penetration electric drill; and rebound of a pendulum impact hammer. One method even tests cut micro-cubes of around 10mm side length for compressive strength in a laboratory test machine (see Table 3).

A new more useful test method is now at the development stage by GFT Materials Consultancy, as can be seen in Figures 1–3. The basis of this procedure is akin to that used in the Australian AS 3700 scratch test method, except this test drives a probe up to 25mm into the mortar at a constant, but adjustable, applied force and the rate of

Figure 4: The GFT in-situ mortar tester being used on-site.

penetration is recorded against the number of probe rotations.

By this means the quality and hardness of the mortar can be determined at any depth or over a depth interval into the mortar bed, as shown in Figure 4. Any single result would be determined from the mean of sampling at five test locations.

What are now being investigated are the most appropriate probes, based on using a range of cross-head screwdriver tips (currently Phillips No 2), the level of constant applied force required to obtain results within an acceptable timescale and calibration against a range of mortar formulations of known cube strength. Once these have been undertaken, and if the outcome is as per the trials, it may be possible to offer this test method for consideration in future editions of the UK National Annex to BS EN 998-2.

A further recent concern has now been unearthed by investigating a designed M4 mortar repeatedly used by one particular national house builder who remains satisfied in that choice as opposed to using the NHBC Standards required 1:5.5 prescribed class (iii) mortar. Although the supplier of the mortar can justify the apparent strength of that mortar in laboratory cube strength tests, in-situ it is shown to be spasmodically friable and when analysed by three accredited test houses found to contain far less cement (being in the range 1:7.5 to 1:10.5) than that required of a prescribed class (iii) mortar and has been classified as class range (iv) to (v). This now casts doubt on the bond of wall ties that require a minimum of class (iv) mortar.

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