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Testing building stone — 2

Chemical and other tests that can help in the choice of a building stone, are described by Mr. R. J. Schaffer, of the Building Research Station

CHEMICAL analysis of a building stone, supplemented by microscopical examination, provides a clear indication of what sort of stone it is, and may sometimes be necessary or desirable for that reason. No good purpose is served by making detailed chemical analysis solely as a matter of routine. Prior consideration should be given to the purpose the analysis will serve, and whether the information will be of sufficient practical value to warrant the time and cost involved.

The chemical composition of a limestone, for example, affords no useful indication of its quality, and no success has yet attended efforts to differentiate between limestones of different qualities by means of chemical tests. The presence of a large proportion of carbonate in a sandstone usually implies that it will in time deteriorate if it is used out-of-doors, but the potential effects can be judged more simply and more effectively by placing samples in a dilute solution (10 per cent) of sulphuric acid. Some sandstones lose their cohesion in this test. Others swell and develop cracks. Sandstones that remain unaffected over a period of ten days can be accepted as being immune to direct attack by acid constituents of the air and rain.

Chemical tests have other uses. Where stone in a building is suspected of having become contaminated with soluble salts, or when it is necessary to know if quarry samples are free from such salts, powdered samples can be extracted with distilled water and any salts present in the filtered extracts can be identified. A method of extraction is described in British Standard 1257. A simple test for efflorescent salts can be made by standing samples in dishes in a shallow depth of distilled water and observing whether any salts appear on the exposed surfaces as the water evaporates. Some salts do not effloresce, so this is to be regarded as a supplementary rather than as an alternative method of examining the salt content.

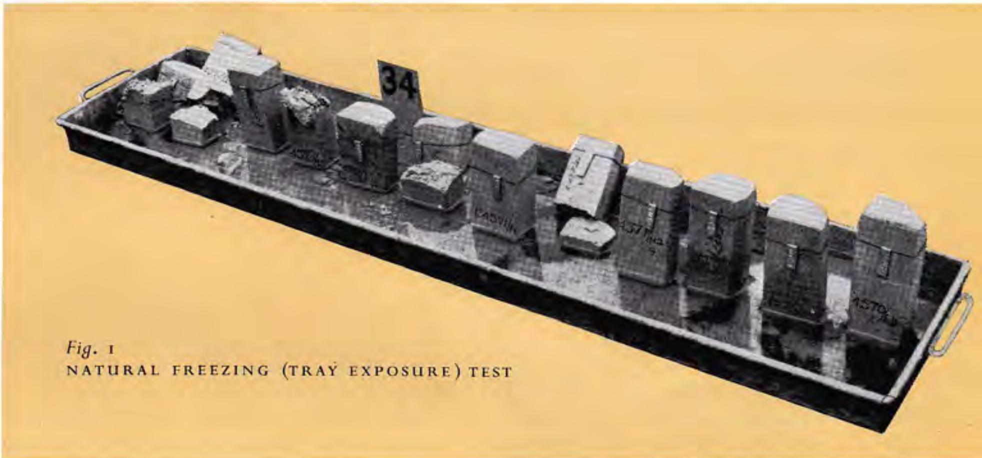

Fig. 1
NATURAL FREEZING (TRAY EXPOSURE) TEST

Density

Density is the weight per unit-volume. Fair average values for calculating dead-loads in buildings are to be found in the British Standard Schedule of Weights of Building Materials (B.S. 648); this includes an appendix in which the unit weights of a wide range of building stones are quoted.

The density of a porous material is always understood to mean the overall or bulk density, not that of the solid material of which it is composed. When required, the latter is determined with a density bottle, after reducing the material to a fine powder, and is conveniently described as the 'powder density'. The bulk density can be determined by weighing samples of rectangular shape and calculating the volume from the dimensions. In the laboratory the volume is usually measured by weighing the sample in air and again when suspended in water, the difference being the weight of the water displaced, and the volume is this weight divided by the density of water (1 gm./cc. in the metric system or 62.5 lb. cu. ft. in British units). The test pieces are dried and weighed and are then saturated with water before measuring the volume. There is no need, as is often thought, to use dry samples elaborately treated to waterproof the surfaces so that they can be weighed in water. The volume is obtained from the difference between the wet weight in air and the corresponding weight in water, any slight expansion there may be on wetting being too small to be of consequence. This procedure has the further advantage that the test pieces are not spoiled and can be used again for other tests.

Porosity

Porosity is a measure of the pore-space expressed as a percentage of the total volume. The porosity can be calculated from measurements of the bulk density (d) and the powder density (s),

$$P = \frac{(s - d)\ 100}{s} \text{ per cent.}$$

But measurement of the powder density is not an operation to be lightly undertaken; its execution is tedious and the utmost care has to be taken if reliable results are to be obtained. Since building stones do not contain closed pores, inaccessible to water, the porosity is more conveniently measured by complete saturation in a vacuum. The dry, weighed samples are placed in a suitable container fitted with a tube for attachment to a pump and with a tap funnel for the admission of water. The air is exhausted to a low pressure; water is then run in to cover the samples; the air pressure is restored; and the samples are allowed to stand under water for a time before being withdrawn and reweighed. Alternatively, complete saturation can usually be attained by prolonged boiling in water. The weight of water required to fill the pores, expressed as a percentage of the weight of the dry sample, has to be multiplied by the bulk density to give the porosity by volume.

No difficulty arises in the use of this method unless the pores are so large that water drains out while the samples are being transferred to the balance. Accuracy depends on filling all the pores with water. If the samples are also used to measure the bulk density (d), the accuracy of the porosity figure can often be checked by calculating a figure for the powder density (s), using the formula quoted above. For limestones of reasonable purity this should approximate to the density of calcite (2.72 gm./cc.) and for sandstones to that of quartz (2.65 gm./cc.). Except where heavy minerals, such as iron oxide, are present in quantity, a substantial departure from these figures indicates that saturation has been incomplete.

Water absorption and saturation coefficient

Water absorption depends on the conditions adopted and on the time of soaking and is conventionally

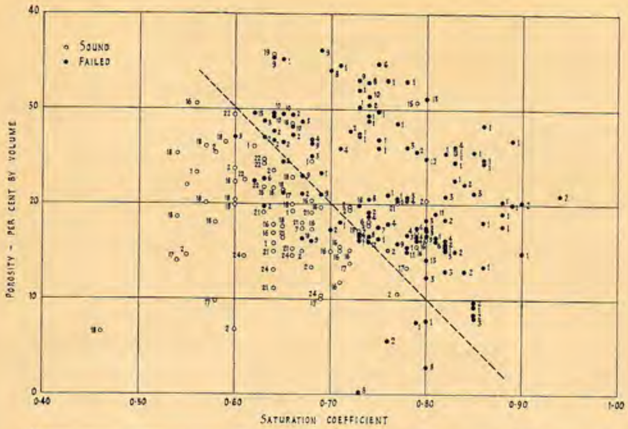

Fig. 2
TRAY EXPOSURE TEST
LIMESTONES
Numbers indicate period of exposure in years. The diagonal line broadly separates the more resistant from the less resistant kinds.

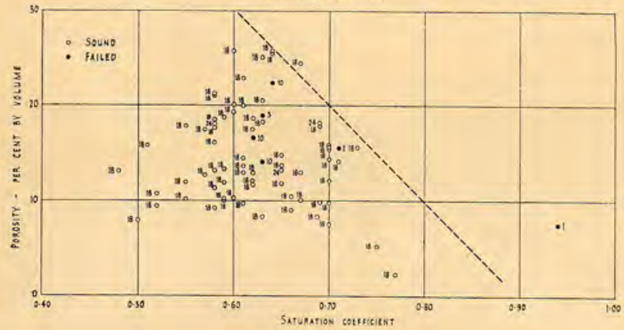

Fig. 3
TRAY EXPOSURE TEST
SANDSTONES
Numbers indicate period of exposure in years. The dotted line is transferred from Fig. 2

determined as the weight of water absorbed in 24 hours (expressed as a percentage of the dry weight) when the test piece (a 2 in. cube or thereabouts) is completely immersed in water at air temperature.

With porous stone under these conditions the rate of absorption, at first very rapid, soon slows down until, after a few hours or less, a stage is reached at which, though the pores are still only partially filled, the rate of absorption becomes so slow that complete saturation may not be reached for many months. The extent to which the pores become filled in this initial period is not fortuitous, but is a characteristic property of the material, dependent on the pore-structure, and is not greatly influenced by the size of the test piece. This property is known as the saturation coefficient and is conventionally expressed as the ratio between the weight (or volume) of water absorbed in 24 hours and the weight (or volume) required to fill the pores completely.

$$\text{saturation coefficient} = \frac{\text{weight of water absorbed by the test piece in 24 hours}}{\text{weight of water absorbed in vacuo}}$$

$$\text{or } \frac{\text{volume of water absorbed in 24 hours per cent.}}{\text{porosity}}$$

The use of porosity and saturation coefficient measurements in assessing the qualities of limestones and sandstones is referred to in a later paragraph.

For different kinds of stones the values of the saturation coefficient range from about 0.50 to about 0.95, corresponding to the filling of 50 to 95 per cent of the pore-space. Those with predominantly coarse pores give lower values than those with fine pores. As has already been mentioned (in the first of these two articles), methods are available for characterizing the pore-structure in terms of the sizes of the pores. With some kinds of stone, measurement of the microporosity, the proportion of pores of less than a particular, predetermined size, helps to distinguish between samples of good and poor durability. (Space does not permit discussion of the measurement of microporosity and its application).

Tests for frost-resistance

Frost causes damage to some kinds of porous building stones if they are used in copings, sills, steps, plinths and other exposed features, where they may become highly saturated with water and then frozen. Other kinds can be used in such positions with impunity. The less resistant kinds can usually be used in plain walling without ill-effect, for, although these sometimes show slight flaking of the surfaces during frosty weather and a few more serious failures were reported after the severe winter of 1946-7, the frost damage that occurs in plain wall surfaces is negligible in comparison with the major effects that follow the use of unsuitable stone in copings and the like.

Experience has demonstrated which of the more commonly used varieties are the most susceptible, but freezing tests cannot be dispensed with, for there have been some expensive failures following the unsuspecting use of stone in positions for which it was unsuited.

Surprising though it may seem, it has proved more than difficult to imitate the effects of natural freezing, so much so that there is at present no laboratory test that can be relied upon to give a correct evaluation of frost resistance, despite all the effort that has been expended in many different quarters. Enquiries addressed recently to laboratories on the Continent, in Canada and the United States about the methods applied to concrete revealed that none of them had much confidence in laboratory freezing tests. But the shortcomings of such tests have not always been sufficiently recognized. On two separate occasions Continental laboratories have reported adversely on the frost-resistance of Portland stone, those responsible being evidently unaware that, besides the testimony of experience in Britain, there are many thousands of headstones in the war cemeteries on the Continent that bear witness to the good qualities of Portland stone in this respect.

At the Building Research Station the use of laboratory freezing tests has been abandoned until a reliable method can be found. Meanwhile, reliance is placed on a natural freezing test (*Fig.* 1) in which the samples stand out-of-doors, partially immersed in water. Under these conditions the more susceptible kinds fail quite quickly, sometimes within a few days during a spell of frost, while the more resistant kinds have survived for more than 25 winters, including the winter of 1946-7. Judged by comparison with the effects of frost on stone in buildings, the test tends to err a little on the side of severity, but the results accord with practical experience far better than any laboratory method that has so far been tried.

Early in the present century, Hirschwald, in Germany, introduced the conception of the saturation coefficient and its use as a measure of frost resistance. He postulated broadly that if the saturation coefficient were no higher than 0.80 the stone would not be expected to become highly saturated under natural conditions and hence that there would be more than enough room to accommodate the expansion of about 10 per cent that occurs when water freezes. Experience has shown that these assumptions are not necessarily valid, but he also took account of the wet/dry strength ratio and on this basis some reasonable predictions can be made. But experience shows that there is a simpler

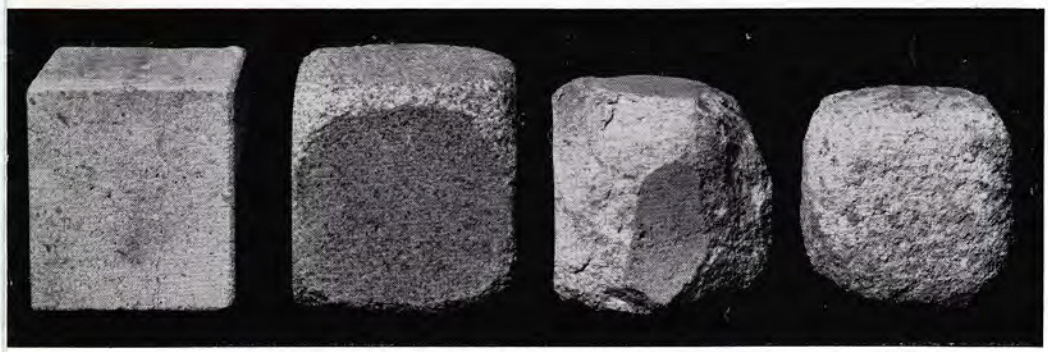

Fig. 4 SAMPLES AFTER SUBJECTION TO THE CRYSTALLIZATION TEST. TYPICAL EFFECTS ON SAMPLES OF GOOD, MODERATE, AND POOR WEATHERING QUALITIES

ODD CHIPPINGS

'In Edinburgh it is impossible to treat seriously the instructions given where "art stone" is all the rage. This is a disgusting *ersatz* material with no life, which takes on, in our climate, a sort of varicose vein of soot. It is pathetic that this advice should be given where the evidence of great craftsmanship and beautiful materials exists in stone buildings of superb quality.'

BASIL SPENCE

President, Royal Institute of British Architects

* * *

Stones from a church 700 years old are being used in the construction of the Shrine Church at the Roman Catholic centre at Aylesford, Kent.

* * *

Five different types of stone are being used in the extension to the Benedictine Abbey at Ealing, London: Guiting stone for the exterior; Beer stone for the interior; Bath stone for the main arches; Clipsham for the copings; and Box Ground stone for the exterior of the tower.

THE NEW IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY (ARCHITECTS: NORMAN AND DAWBARN) FACED WITH BROUGHTON MOOR LIGHT SEA-GREEN SLATE—*see overleaf*

method, based on consideration of the porosity and saturation coefficient, with the advantage that it does not involve destructive testing of the samples.

Limestones show a wide range in their resistance to frost: some are very good, some poor (*Fig.* 2). Sandstones as a class are generally resistant (*Fig.* 3). The evidence of Fig. 2, on which are plotted the porosity and saturation coefficient values of samples of limestones subjected to the 'tray' test, shows that consideration of the saturation coefficient alone would lead to many wrong conclusions, and it will be seen that better estimates can be made by considering both the porosity and the saturation coefficient; the most resistant kinds fall towards the lower left-hand corner of the diagram, the least resistant towards the opposite corner. Such measurements can be used with reasonable confidence for estimating the frost resistance of very good or very poor kinds. Uncertainties about those of intermediate character need to be resolved by observations of their behaviour in the tray test and in the exposed features of buildings. Frost resistance of most of the sandstones covered by Fig. 3 could have been predicted in a similar way, but there are a few failures among those falling to the left of the dotted line. These are mostly associated with incipient planes of weakness in the bedding, the presence of which is not revealed except by the practical test.

Crystallization tests

Contamination with soluble salts, usually derived from extraneous sources and no fault of the stone itself, is a common cause of disintegration of stone in buildings. As long ago as 1828, Brard, in France, proposed to make use of the disruptive effects of salt-crystallization as a means of assessing durability. He immersed samples in a saturated solution of sodium sulphate, hung them in the air to dry, and collected and weighed the debris. Since then various modifications have been used. At the Building Research Station weighed test-pieces have been immersed for two hours in a 14 per cent solution of sodium sulphate (decahydrate) at a controlled temperature of 20^{0}C. and then dried overnight in an oven; fifteen repetitions of this cycle have been found to give informative results that show excellent agreement with practical experience, the loss in weight ranging from zero among samples of high quality to as much as 40-50 per cent for those of poor quality (*Fig.* 4). Quarry samples are evaluated by comparison with test-pieces prepared from samples of good and poor quality collected from buildings. To secure reasonably comparable results between successive batches, the test conditions need to be carefully controlled, particularly in respect of the temperature of the solution.

Many years' experience of this test encourages the belief that it is the most informative laboratory test that can be applied for assessing the weathering qualities of limestones. Applied to sandstones, it can be used to judge their relative susceptibility to disintegration by soluble salts. It has also been employed with some success to assess the suitability of natural stone and other materials for use as filter media in biological percolating filters (B.S. 1438).

Brard proposed to use his test as a substitute for a freezing test, at a time when artificial refrigeration was unknown. Among limestones, the same sort of relationship is found as that illustrated in Fig. 2 for the natural freezing test, those with high porosity and a high saturation coefficient being the more susceptible to salt crystallization. To that extent Brard's conception seems to be justifiable, but it does not apply to sandstones, many of which are much more susceptible to salt crystallization than to frost.

Moisture and Thermal expansion

Expansion due to moisture and shrinkage on drying demand more attention when considering concrete products than natural stone. Sandstones and some igneous rocks show a significant moisture expansion. Measurements can be made when necessary.

The development of systems of stone cladding and curtain walling raises the question of how much provision must be made for thermal expansion. The introduction of floor heating systems may also impose higher stresses on stone and marble pavings than those experienced in the past.

Unfortunately the thermal expansion of building stones has not been systematically studied, and there are only a few scattered records. More data are needed and the practical aspects need to be studied.

Other tests

Besides tests directed to the evaluation of the properties and qualities of the stone itself, other matters often call for investigation. The proper choice of ancillary materials and methods of maintenance is as important to the user as the choice of stone and the way it is used. Tests can be applied to assess the liability of a mortar to cause staining of stone, or again, for example, to determine whether a cleaning preparation contains harmful constituents.

In conclusion, it is worth repeating that tests are not an end in themselves. They must all be used with a sense of purpose and the results must be interpreted against the background of experience and practical needs if they are to be of real value.

This article is published with the permission of the Director of Building Research.

Location of principal quarries throughout England, Scotland, and Wales

Broughton Moor and Spoutcrag Langdale Pikes

SOURCE Broughton Moor Slate Quarries and the Spoutcrag Green Stone Quarries, Coniston, Lancs.

GEOLOGY Ordovician series; volcanic origin; formed by enormous heat pressure.

COLOUR Olive green, light sea-green, pale green barred.

CHARACTERISTICS This close-grained slate is very durable, has an attractive texture and weathers well. Suitable for external or internal facings, foundation stones, paving and flooring, steps, sills, copings, shop-fronts, pilasters, fireplaces, roofing, etc.

AVAILABILITY Prompt deliveries.

SIZES Up to 6 ft. x 2 ft. 6 in. (minimum recommended thickness 1 in., though smaller slabs are ½ in.); riven (naturally split) slabs are supplied between 18 x 12 ins. and 36 x 18 ins.

FINISH Frame-sawn, sanded, fine rubbed, or naturally riven.

PHYSICAL PROPERTIES Weight can be based on 150 ft. sup. (1 in. thick) being equivalent to 1 ton.

WHERE USED Recent examples include: Mullard House, Tottenham Court Road, London; Imperial College of Science and Technology, Kensington, London; The Dutch Church, Austin Friars, London; Compter House, Wood Street, London; New Central Police Headquarters, Hull; Hotel Leofric, Coventry; Rutherford Technical College, Newcastle-upon-Tyne; New Radiotherapeutic Institute, Western General Hospital, Edinburgh; National Library of Scotland, Edinburgh; factory for H. Samuel, Ltd., Hockley, Birmingham; I.C.I. Research Laboratories, Alderley Edge, Cheshire; National Hall, Lagos; Port Line Building, Sydney.

Stone preparation

4 — Banker Work

This is the fourth of a series of six articles

THE PRESENT-DAY style of architecture generally calls for stonework which can be almost entirely produced by machine. There are, however, still a number of exceptions, notably ecclesiastical work, and a considerable amount of bomb-damage reconstruction, which creates a demand for the manual skill of the banker mason. In country districts and smaller towns masons are used to working on the bench or banker and then erecting the work they produce, though in the larger centres of production they tend to do either one or the other.

THE MALLET IS MADE OF BEECH OR HICKORY

The banker mason's tools have not altered fundamentally over the years except that pneumatic hammers have partly replaced the mallet, and chisels are tipped with some of the modern alloys such as tungsten carbide. Having been supplied with the stone, sawn to size and possibly partly machined or partly roughed-out, his first task is to mark-out the job by means of moulds and templates prepared in the setting-out shop. These may consist of bed-moulds (plans of the stone), face-moulds (elevations of the stone), and sections. The application of moulds for such as dome stones or vault springers is a highly skilled operation, requiring considerable geometrical knowledge and practical experience. The mason's five years apprenticeship includes training at a technical school or college in building construction, geometry, and allied subjects.

The next operation is removing the larger pieces of surplus stone with the hammer and pitcher, and then with the hammer and punch. The mason's hammer weighs 4 to 5 lbs. A good craftsman can punch down to within ¼ in. of the finished surface. At this stage the hammer is discarded for the mallet. The mallet is made of beech or hickory and is about 7 ins. diameter at the widest part and about 5 ins. thick. It is used on tools with mushroomed heads that do not cut into the mallet's surface. After the punching the stone is worked over with a claw-tool, which is like a chisel with serrations in the cutting-edge. Finally the surface is finished-off with sharp chisels of varying widths from ½ to 2 ins. In some modern mason's shops where compressed air is available the mallet is superseded by a percussion hammer, the head of the chisel being flanged instead of mushroom-shaped.

The foregoing description applies to Portland stone and many of the grit stones. In the case of soft stones, such as Bath, similar principles apply but the roughing-out is done with a hand-saw, very similar to a carpenter's saw but with larger teeth without any set. The chisels have wooden handles and are struck with a small mallet of lead or pewter which is called a dummy; the surface finish is produced by drags - steel plates with serrated edges and combs which are smaller plates cut to varying curves to produce mouldings.