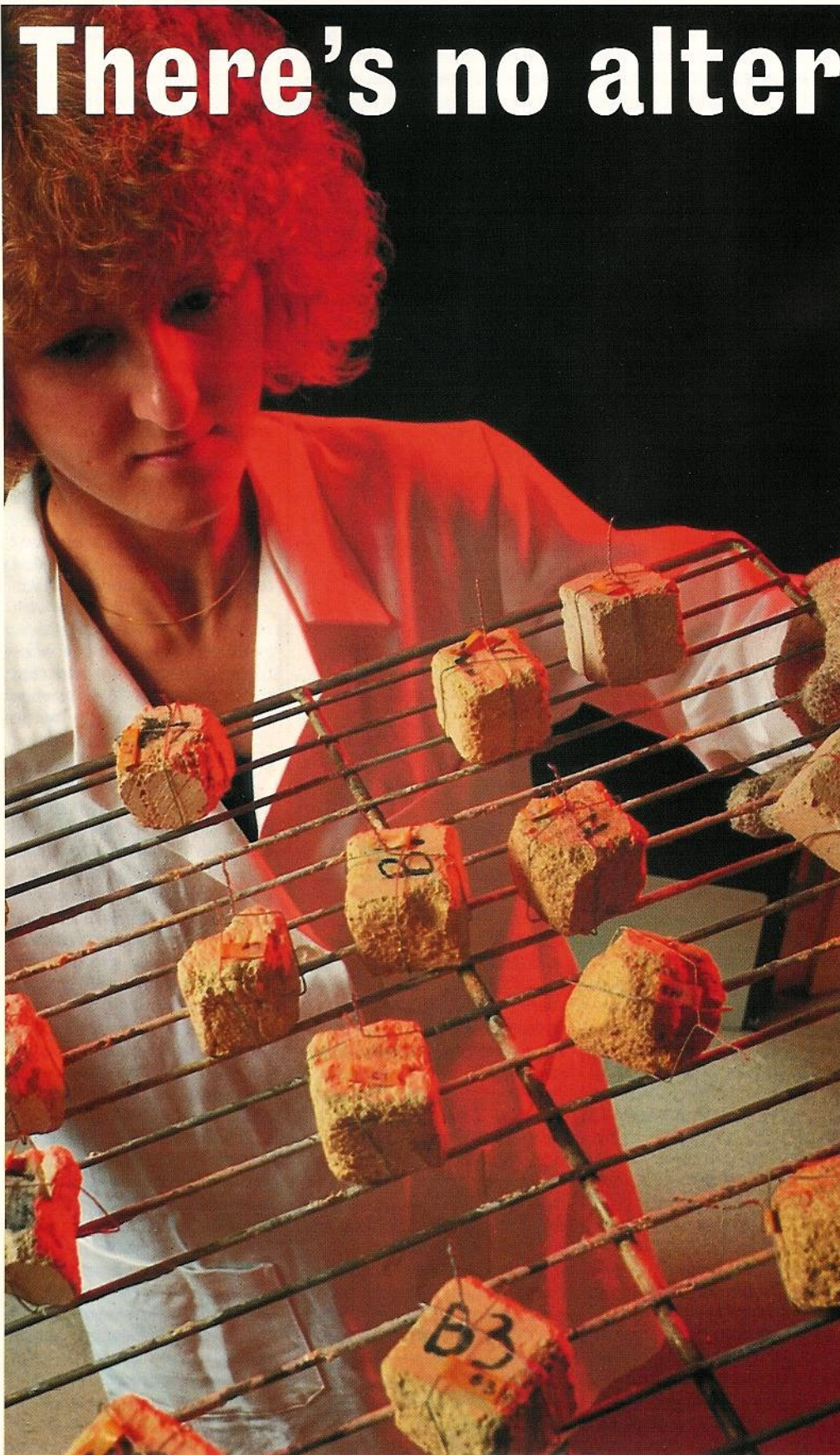


There's no alternative



The Stone Federation wants the sodium sulphate crystallisation test scrapped as a method for assessing limestone durability. But with nothing to take its place, salt crystallisation testing can be a useful indicator of stone performance, argues Barry Hunt, a Senior Geologist with London consulting engineers Sandberg.

SALT attack has been recognised for hundreds of years as a chief cause of stone decay. Much progressive salt attack has been attributed to atmospheric pollutants, particularly sulphates derived from coal burning (acid rain), being concentrated upon stone surfaces. It is claimed that these effects have reduced dramatically over the last century. However, other forms of salt attack may still occur.

Some limestones may release salts as they weather. These salts can be concentrated at or near surfaces, causing damage as they crystallise. Alternatively, certain components of some stones may react with bedding and jointing mortars to produce a variety of expansive materials which may lead to the breakdown of both stone and mortar.

The mechanism of how salts attack a stone is not fully understood, although visual observations suggest that damage typically occurs as a gradual and persistent denudation of stone surfaces where salt efflorescences appear.

There are several theories ►

Testing

as to how salts attack the stone fabric, each with sound technical and experimental data to support it. However, the experiments often involve either a limited variety of salt solutions and/or environmental factors.

Eventually, all the different theories may prove to be correct, each playing a subtly different role depending on the type of salt and the conditions of formation.

One theory suggests that salt solutions which have gained access to a stone may stay there in pores and voids. These solutions may become saturated due to water evaporation and/or changes in temperature, at which point salt crystals may begin to grow. These crystals may eventually fill the spaces, exerting pressure upon the stone as they continue to try to grow¹.

Within a stone, the confining pressures may generally be sufficient to overcome the stresses of crystal growth, but at the surfaces, where the stone is less able to constrain such growth, damage may occur.

Repeated cycling of salt growth, therefore, eventually leads to the gradual surface denudation observed.

Another theory points to the fact that some salts can exist in a number of hydration states. With a change in moisture levels such salts can pass from one hydration state to another with an accompanying change in crystal volume. Where confined crystals undergo a volume increase due to hydration, considerable forces may be generated², leading to the type of damage at stone surfaces described above.

The degree to which a particular stone is affected by salt attack depends on various factors which include the stone strength (tensile), pore size and distribution (including total porosity) and intercrystal/intergrain bonding as well as the type and availability of salts. Environmental factors which may also play a role include exposure to the sun, temperature ranges, changes in humidity and general climatic conditions.

Salt crystallisation testing was developed to assist in the prediction of the resistance of stone to salt attack. Such testing was of most relevance to new, untested potential stone resources and also in ensuring the continued quality of existing stone sources.

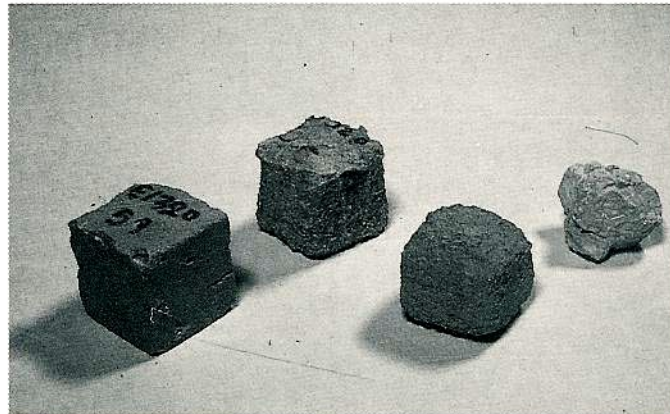
The majority of building stone used externally in previous centuries, particularly for intricate working, was either limestone or sandstone.

Thus, the salt crystallisation test methods were originally developed for limestones and sandstones. And it is interesting to note that salt crystallisation

followed by a period of drying at 105°C. These steps are repeated 15 times and the degree of breakdown determined.

To ensure a degree of repeatability it is recommended that two reference stones of 'known' durability are tested concurrently with the stone under test. The test is normally carried out on limestones, using a 14% solution, and sandstones, using either a 14% or saturated solution of sodium sulphate depending upon the intended use.

Sodium sulphate can exist as a stable anhydrate (Na_2SO_4), a



The effect of tests on different stones.

testing was developed independently in several different countries, indicating that salt attack was a widespread problem.

In 1828, Brard³ devised a test in which 50mm cubes of stone were boiled in a solution of sodium sulphate which was saturated at room temperature. The cubes were suspended above the solution until efflorescences appeared. The cubes were then re-immersed, then re-suspended. This cycle was continued for five days after the first efflorescence appeared and the loss of material was determined at the end of this period. In 1932 Schaffer⁴ modified this test into that adopted by the BRE and used for the past 60 years.

The BRE salt crystallisation test involves the soaking of at least six nominal 40mm to 50mm cube specimens of a particular stone in a sodium sulphate solution for two hours

meta-stable hepta-hydrate ($\text{Na}_2\text{SO}_4 \cdot 7\text{H}_2\text{O}$) and as a stable deca-hydrate ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$). The transition temperature for the deca-hydrate to convert to the anhydrate is 32.4°C.

Therefore, in addition to the crystallisation of salts within the stone, these salts must both hydrate and dehydrate during the normal course of sodium sulphate crystallisation testing.

In my experience of the BRE test, the loss of material from test specimens has always occurred during the soaking phase only. This suggests that salt hydration may be the dominant factor affecting the observed deterioration. Crystal hydration, however, might also be dislodging fragments of stone initially fractured during the drying (crystallisation) stage of the test.

The work carried out by Brard looked for a rapid method of assessing the frost resistance of porous stones.

Work since by the BRE has shown that, in general, when comparing service histories of frost susceptibility, those stones exhibiting the greatest frost resistance exhibited the lowest material losses when subjected to salt crystallisation testing.

These generalisations led to the formulation of a durability classification in which a letter – 'A' the most durable to 'F' – is ascribed to denote a durability class. The durability class is used to predict future performance of a given limestone depending upon its expected exposure to frost action in either low or high pollution areas.

Much of the concern over the validity of salt crystallisation testing has come from the increasing number and variety of stones which exhibit poor resistance to salt crystallisation testing while maintaining a satisfactory service history with respect to frost resistance. Sandberg's experience of stone testing has also shown that some stones can fall apart when freeze-thaw tested while exhibiting relatively good salt crystallisation resistance.

Salt crystallisation, therefore, should not be taken as an indicator of frost resistance but rather an indicator of potential stone weakness (or 'unsoundness') which could be exploited by the action of frost. The test should otherwise remain important as a method for assessing the resistance of stone to salt attack.

If the test is to continue as an effective indicator of potential durability, the arguments concerning its drawbacks must be addressed. At present the chief drawback is the poor repeatability of the test, but a better standardisation of the methods could rectify most of the anomalies.

But by washing out the residual salt and frequently changing the solution during the test, we have achieved consistently similar results on various reference stones.

On the few occasions when particular specimens have behaved unexpectedly, closer examination has usually ►

revealed geological differences to be the root cause.

It is these natural variations which have previously been a main topic of debate. Such variations are not a function of the test, rather it is a question of ensuring the representativeness of the test specimens.

Natural stone of sedimentary type such as limestone and sandstone is quarried from specific beds and different qualities of stone are found in different beds. This is a result of subtle variations in physical characteristics relative to original depositional environment changes and post sedimentation induration such as cementation processes. Individual beds may also vary laterally for the same reasons, although the variations may not be pronounced – indeed, they are often imperceptible with continued quarrying.

Traditional stone resources, therefore, must be expected to exhibit changes in quality and while information concerning previous in-service performance is useful in any stone assessment, such information cannot be relied upon solely to predict the performance of newer materials.

When carrying out salt crystallisation testing the specimens should be taken from a single stone bed. Previous debate concerning the coefficient of variation of the number of specimens required to carry out a meaningful test involved stone specimens taken from such a single bed, but only for one type of stone (Doulting).

The results indicated that the stone involved was variable and a high number of specimens were required to ensure representability because of the reported variation. These results may confirm that certain beds can be highly variable and it is likely that other stone tests would exhibit a similar variation. It is suggested that further work must be carried out to look at the coefficient of variation of specimens taken from more uniform beds. Our own experience suggests that the recommended six specimens for the test are sufficient for the more uniform stone types.

The discussion so far has been concerned with porous sedimentary materials, but the salt crystallisation test can be employed for all stone types to investigate a variety of different stone properties.

Granites and related stones often exhibit some degree of weathering which can dramatically alter the strength and other physical characteristics, so fresh granite is preferred. But even visually fresh granite can exhibit imperceptible amounts of weathering, barely visible even at a microscopic level.

Such weathering may be in the form of a slight loosening of the crystal grain interlock or an increase in microporosity of a mineral component such as feldspar.

While normal physical testing may not clearly distinguish these subtle differences, salt crystallisation may exploit them and highlight the presence of inferior materials.

Marbles, like granites, normally exhibit negligible losses when subjected to salt crystallisation testing.

In one case where some marble panels had bowed, a suite of physical tests was carried out to look at the integrity of the marble in the panels. The results suggested that although the marble had experienced a possible loss in strength, many of the results were not untypical of values which are commonly obtained for marbles.

Apparent zones of microfracturing adjacent to where cracking had occurred were also intact and did not exhibit dissimilar results until they were tested for resistance to salt crystallisation. Then they exhibited a high loss of material. This confirmed that the microfracturing had affected the intrinsic quality of the marble and further breakdown was increasingly likely.

Salt crystallisation was also important in this particular case as the marble was subjected to a small degree of salt attack.

In any material's assessment the nature of the tests carried out is often harsh and does not mimic real life. The tests are

more severe than real life in order to obtain a quick indication of how particular materials may behave under real life conditions.

With any test of this type you must remember that the absolute results obtained may not reflect the true performance of the material in question and the results must be considered along with any other available data.

The salt crystallisation test may be regarded as an indicator test and, used correctly, can be invaluable in any stone assessment.

A positive outcome of salt crystallisation testing could be regarded as indicating a stone that would be durable in a variety of environments. Where breakdown occurs this should be considered carefully as to whether the stone spalled gradually, split erratically, or parted along a structural constraint. Any weaknesses can then be more fully investigated and it may be possible to obtain stone from the same horizon without such weaknesses and of better quality.

Where hard stones, such as granites, exhibit a degree of breakdown this may have important implications regarding the life of the material, as stones of this type are often put in the harshest and most exposed locations where attack of any kind is likely to be severest.

The salt crystallisation test has been with us for many years and, with more detailed standardisation and careful consideration of the specimens for test, should remain with us for the foreseeable future.

Without such a test we would lose a guide to the potential performance of stone and the continued quality of particular stones.

The alternatives to such a test are few and are themselves under question in that for certain materials the results may be erratic.

No alternative test method has been proposed to replace salt crystallisation testing and until such time as it is, a complete abandonment of the test would appear unwise. □



A sample after testing.

With thanks to the BRE in Garston, Watford, Herts, for the photographs of the salt crystallisation test.

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