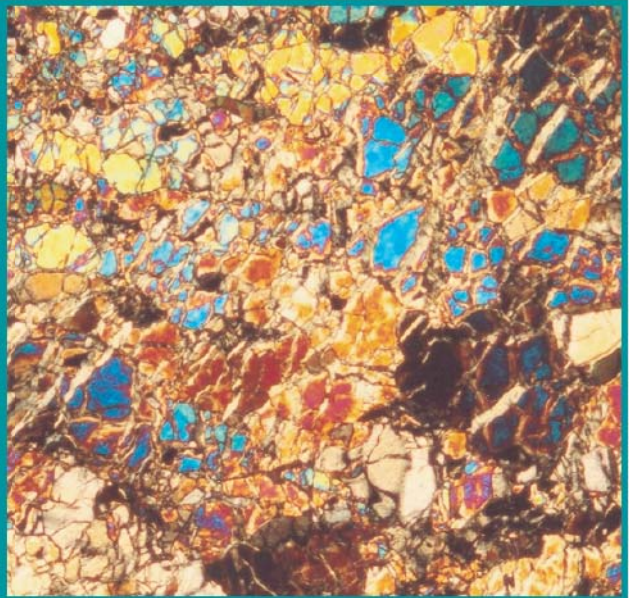


A REFERENCE GUIDE TO STONE TESTING AND PROPERTIES



STATS

Stone and Slate Technology

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INTRODUCTION

Our objective in publishing this guide is to provide a reference point for the construction industry when specifying stone and slate products. It draws on current published standards and the experience of scientists within the STATS Stone & Slate Technology (**SST@STATS**) team.

Our aim is to provide clear guidance on current test requirements, and in addition, assist the reader in how to evaluate stone and slate materials for their proposed application.

The range of tests and consultancy services provided by **SST@STATS** is augmented by a wide range of complementary expertise within STATS consultancy practice. This includes testing and inspection services which specialise in environmental issues, ground engineering, and materials used in construction and built structures, both in the UK and worldwide.

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CURRENT STANDARDS

Recent years have seen the introduction of a number of new harmonised European Standards (see **Appendix B**) which have now largely replaced any previous British Standards in UK practice. These standards comprise two main parts; namely pre-specification, then test methods. These are designed to allow all stone variants to be assessed against a suite of tests suitable for their proposed application: external cladding, internal linings, internal flooring, external paving, masonry and specialist applications such as worktops and wet rooms.

However, unlike American (ASTM) standards, these European product specifications do not generally include numerical guidance on the required or even desired properties of the stone, instead deferring to engineering performance considerations. Whilst this has advantages over a more prescriptive approach, in allowing a wider variety of stone types to be specified and used, it has led to confusion as to the meaning and value of testing.

A further consideration is the age and provenance of test data. Frequently, stone selection is made on the basis of datasheet results provided by a stone supplier, which may state neither the age of the test results nor frequently even the method of testing. As stone is a natural material and consequently its properties may vary over even small distance changes within a quarry, data older than about 2 years should be treated with caution, and project-specific testing should always be considered.

This guide will help in the planning of test programmes, interpretation of test data, determination of the validity of the test results and help the user make informed and sound judgements about the final choice of stone.

Naturally, we would always wish to advise that in the early stages of developing any test programme, you consult with **SST @ STATS**.



SUGGESTED PROGRAMME FOR TESTING STONE

Stone Tests	Application and Setting								Quarries
	Cladding/ Lining		Paving/ Flooring		Masonry Walling		Masonry Detailing		
	Internal	External	Internal	External	Internal	External	Internal	External	
Visual Aspects/ Petrography	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
Compressive Strength	☆☆	☆☆	☆☆	☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆
Flexural Strength ¹	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆	☆	☆	☆	☆☆
Density and Porosity	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
Cladding Testing	☆☆	☆☆			☆	☆			
Absorption	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
Frost Resistance		☆☆☆		☆☆☆		☆☆☆		☆☆☆	☆☆☆
Salt Crystallisation ²	☆	☆☆	☆	☆☆☆	☆	☆☆☆	☆	☆☆☆	
Abrasion Resistance			☆☆☆	☆☆☆					☆
Slip Resistance			☆☆☆	☆☆☆					☆
Discoloration Potential ^{3,4}	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	☆☆	
Staining Potential ^{3,4}			☆☆	☆☆					
Water Absorption (Capillarity)			☆	☆	☆	☆☆			

Notes

☆☆☆ Essential Tests; ☆☆ Highly Recommended; ☆ Recommended.

Shaded boxes indicate where testing is considered unnecessary. Empty boxes do not necessarily imply that a test should not be carried out as, for some situations, useful information may still be obtained.

¹ Constant moment (four point bending) method preferred for cladding, concentrated load (three point bending) method preferred for flooring and paving.

² Tests more useful for limestones and, to a lesser degree, sandstones.

³ Procedures developed by STATS.

⁴ May be essential for porous stones used in environments where spillage occurs.

This information is given for preliminary guidance only. Specific advice should be sought from **SST@STATS** for individual projects.

STONE AS A CONSTRUCTION MATERIAL



Natural stone has been used as a building material for as long as mankind has constructed shelters. From Stonehenge to the Coliseum, from Renaissance architecture to the recently completed Scottish Parliament building, stone has been the material of choice.

In recent times, stone has enjoyed a revival. Today it is considered a high quality finish, adding prestige to any building. Additionally, stone offers environmental advantages compared with concrete, owing to stone's far smaller carbon footprint.

In addition to the traditional UK stones that are often required for conservation or compatibility reasons, recent years have seen a huge variety of newly imported stones being introduced to the UK market, particularly from China and India. These frequently offer cost advantages, but vary in quality and do not have a proven history of use in the UK. Consequently, the necessity of seeking expert advice and testing has increased.

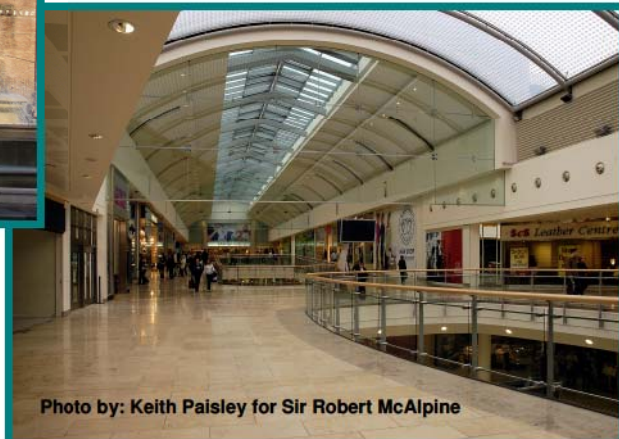


Photo by: Keith Paisley for Sir Robert McAlpine

STONE TYPES

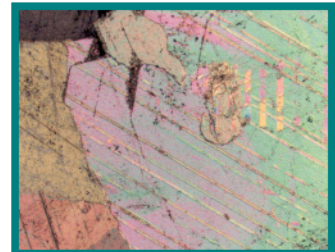
The stone industry tends to use a relatively restricted list of generic geological terms, for instance 'Granite', when marketing their products. Whilst this has certain branding benefits, it can also be misleading as several of the more commonly used terms do not always correlate well with the correct geological name for the rock in question, and can cause misconceptions on the expected performance and architectural aspirations of certain stone types.

The six most common types of stone name used in construction are described below.

Limestone



A sedimentary rock made from calcium carbonate, frequently with abundant fossils. Generally white, cream, beige or light grey coloured, and available in various textures such as honed and, for some varieties, polished finishes.



Properties and performance vary from being soft and weak to comparatively hard and strong, therefore is suitable variously for domestic to heavy commercial settings. Many varieties possess good durability, therefore are suited to external uses.

Limestone is a prominent building stone in the UK, particularly of southern and eastern England, with familiar varieties such as Portland stone, Bath stone and Ancaster stone being widely used.



Marble

A metamorphic rock derived from an original sedimentary limestone. Typically white or light coloured with darker veins or streaks, and typically sold with highly honed or polished finishes.



Generally mechanically strong, but may lack durability especially frost resistance. Tends to be used in domestic or lower trafficked commercial settings or occasionally as architectural feature stone. Not a common stone type in the UK, but most widely known from Italian sculpture.



Some types of hard and/or polishable limestone are marketed as marble. Whilst there are some mechanical differences (limestone would not be expected to be as strong), the overall performance of the different stone types are usually similar.

STONE TYPES

Granite

Geologically, granite is a coarsely crystalline igneous rock containing quartz, feldspar and minor dark minerals. In stone marketing however, it has become something of a catch-all term for crystalline non-sedimentary rocks regardless of composition, crystal size or origin.

The stones marketed as granite include true granite, diorite, gabbro, basalt ('black granites') and gneiss (a stone of often granitic composition but metamorphic origin, with characteristic texture, including banding).



Available in a range of colours from primarily white, through pink and grey varieties to black, and produced mainly with honed or polished finishes, although flamed and hammered finishes are available for external paving applications.

Generally, all are strong, robust and durable, therefore suited to a wide variety of applications both internally and externally, especially for highly trafficked locations.

Highly polished black granite is particularly popular as kitchen worktops and floors, but can be prone to scratching and loss of polish in these applications.

Quartzite

A relatively rarely used natural stone in the UK, this is a metamorphic rock derived from sandstone. Natural quartzite should not be confused with the artificial 'quartzite' tiles now produced.

Composed predominantly of crystalline quartz, with a recrystallised rather than cemented texture, quartzite tends to be a strong and durable stone type.

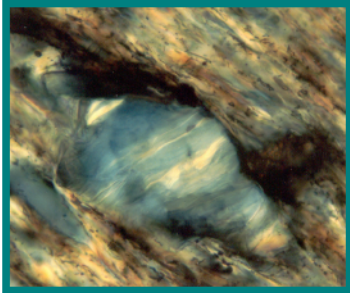
Typically will have a high abrasion resistance so would be suited to heavily trafficked flooring and paving applications.



STONE TYPES

Slate

A finely crystalline metamorphic rock capable of being split into thin sheets, slate is typically mid to dark grey coloured, but does include variants with green, blue or purple hues.



Mainly and traditionally used for roofing, it can also be used for internal flooring and wall tiling in domestic settings, and locally in the UK (especially in Wales and Cumbria) as masonry stone. True slate is typically produced with a riven (i.e. naturally split) finish, although some varieties can be honed or sawn.



Slate is generally a strong and durable material, although some varieties, especially some imported material, can include high levels of carbonate and are therefore not suited to external uses.

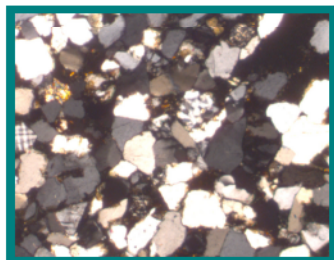
The abrasion resistance of slate is generally quite poor, therefore it is often not suited to use as flooring or paving in heavily trafficked areas.



Some materials marketed as slate, especially for paving, are not fully metamorphosed and should more accurately be described as either mudstone or siltstone. These often prove to be of poor durability when used externally or when trafficked.

Sandstone

Sedimentary rock consisting of quartz and other particulate material derived from weathering of pre-existing rocks, bound together with a natural cement. The nature of this 'cement' can be important in determining the durability of the stone.



Coarser grained varieties may be termed gritstone; these are otherwise similar in properties to other sandstone types.



Varies in properties and performance, but usually weather resistant, so most commonly used for external paving or masonry. The various Yorkstone varieties are the most common types that can be found in much of northern England, and are also commonly used in London for paving flags.

The granular nature of the material generally provides good skid and slip resistance.

STONE TYPES – SOME ARTIFICIAL ALTERNATIVES

Terrazzo

A generally hard-wearing flooring surface used in high trafficked settings, especially shop units. Terrazzo is composed of small stone (typically limestone or marble) chips in a cementitious binder, and intended visually to give an appearance superficially similar to a natural stone type.

Colour variations are possible through inclusion of a pigmented component within the binder or by the selection of coloured stone chips. Terrazzo is typically ground *in situ* to provide a honed finish.



Terrazzo type materials have a long history of successful use both as tiles and as cast *in situ* flooring. Testing of terrazzo tiles should be undertaken in accordance with BS EN 13748.

Cast Stone



Generally used as an alternative to masonry stone, and typically with an appearance similar to either sandstone or limestone. Most commonly used for items such as lintels, sills and other large but relatively lightly loaded elements and architectural units.

Cast stone is usually manufactured from a semi-dry mix typically comprising Portland cement with fine quartz sand and/or limestone aggregate manually tamped into a mould and often including a waterproofing agent to improve durability.

Cast stone materials are tested for their strength and durability using the test methods and acceptance criteria given in BS 1217.

Agglomerate

A relatively recent variation of terrazzo, agglomerate includes fine aggregate particles bound in a resin matrix.

Tiles are generally manufactured quite thin (often around 12mm) and with a fairly reflective finish (equivalent of high honed finish for natural stone). Problems have been encountered with large tiles of this type distorting owing to incompatibility with proprietary adhesives and the binder reacting with alkaline fluids.



TESTS FOR APPEARANCE AND COMPOSITION

Visual Aspects

Purpose

To evaluate the range of appearance of the stone and establish an accepted range of appearance.

Applicability of Test

All projects – domestic and commercial.

Sample Requirements

Testing requires at least 6 slabs representing the range of appearance of the stone.

Stone, being a natural material, can vary in both quality and appearance within a specific product. Various European product specifications include for an assessment of visual appearance and variability. Decisions on acceptable visual range are the responsibility of the supplier and customer unless there are technical reasons to limit the choice of stone for an application.



Petrographic Examination

Purpose

To characterise the mineralogical composition and natural weathering condition of the stone and provide accurate classification.

Applicability of Test

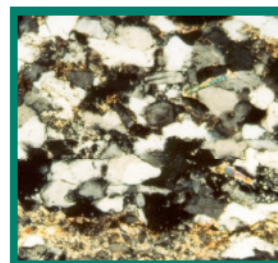
All stone types for any application.

Sample Requirements

Testing requires sufficient samples to represent the stone type.



Petrographical examination is undertaken in accordance with BS EN 12407. This provides an accurate classification of the stone type based on macro- and microscopical examinations; the latter undertaken on a very thin slice of stone, ground thin enough to allow light to pass through.



The correct classification and identification of the stone type is important, as these can influence performance (e.g. black granite compared with a true granite). Additionally, it allows for a correct match of stone between new and adjacent existing buildings.

The petrographical examination can also indicate potentially detrimental features (such as stylolites in limestone, microfractures or high levels of weathering in all stone types) or constituents (potentially reactive minerals such as clays and pyrite) within the stone.

TESTS FOR APPEARANCE AND COMPOSITION

Instrumental Microanalysis

Purpose

Assessment of stone condition and composition, particularly relating to causes of failure.

Applicability of Test

Discoloration and specialist defects analysis projects.

Sample Requirements

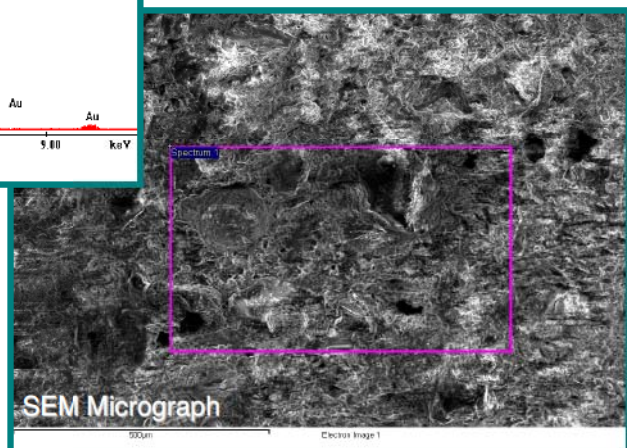
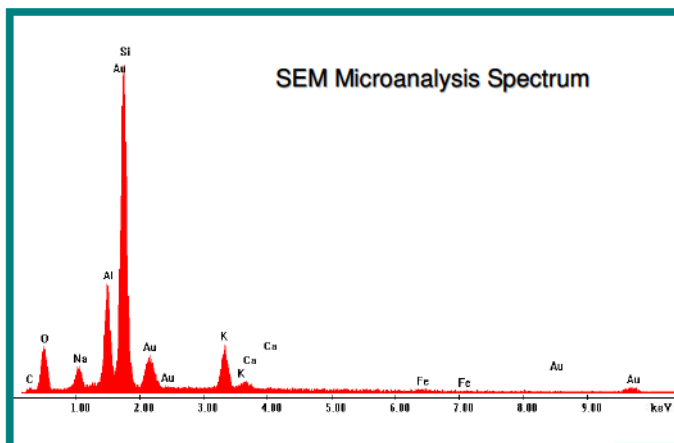
Analysis typically requires representative affected samples or features of interest.

SST@STATS uses a number of techniques that allow various qualitative and quantitative microanalysis such as:

- Scanning Electron Microscopy (SEM)
- X-Ray Diffraction (XRD)
- Fourier Transform Infra Red spectrometry (FTIR).



These techniques allow highly detailed investigations and are typically used during investigations of stone damage or failure.



TESTS FOR MECHANICAL PROPERTIES

Compressive Strength

Purpose

To evaluate strength for use as masonry or paving setts, where loads are generally compressional.

Applicability of Test

Masonry or external paving setts.

Sample Requirements

6 cubes or cores of 50mm to 70mm dimensions. Test specimens are required to be prepared with reliably flat faces and perpendicularity.

Testing to be in accordance with BS EN 1926 (ASTM C170 is a near equivalent). A small stone cube or core (50mm or 70mm dimension or diameter) is slowly compressed between two flat plates until failure.

Generally, stone is strong in compression, with the following values given as guidance for anticipated strengths (the units of Megapascals (MPa) are identical to N/mm^2):



Limestone	20-100MPa
Marble	100MPa +
Sandstone	20-150MPa
Granite	50-200MPa
Slate	20-100MPa

Note: Values are for guidance only and should not be considered as indicative of the acceptable range of strengths for the stone type.

Only when compressive strength is lower than required by engineering considerations or where very high variability of strength is encountered in the stone is this likely to cause significant problems. **SST@STATS** can provide expert guidance on required strengths for most applications.

Cladding Testing



There are a number of tests on cladding stone and cladding systems that may be considered applicable. The choice of test method depends on the design of the fixing system used, and either standard or bespoke test assemblies may be used.



Please consult **SST@STATS** for further information on appropriate testing of various cladding systems.

TESTS FOR MECHANICAL PROPERTIES

Flexural Strength & Breaking Load

Purpose

To evaluate strength of stone likely to be subjected to bending forces.

Applicability of Test

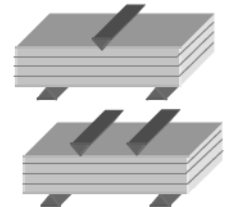
Internal flooring, external paving or cladding - where plan area of individual stones is large, compared with thickness.

Sample Requirements

10 prisms based on the thickness of the stone. Length = 6 x thickness and width = 2 x thickness.

Flexural strength tests can be performed by three-point BS EN 12372, (nearest ASTM equivalent ASTM C99 Modulus of Rupture) or four-point BS EN 13161 (ASTM C880 Flexural Strength) bending.

Three-point bending is appropriate for internal floor tiles and external paving slabs, where failure tends to be caused by bending across hard points or due to cavities in the bedding below. Four-point bending is appropriate for cladding, as failure will tend to occur at natural weaknesses within the stone. Both testing methods are shown as in the graphical example on the right.

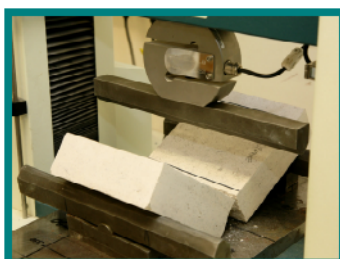


There is a lack of literature guidance on required flexural strength, although BS EN 1341 for external paving slabs gives a tabulation of required failure loads for specific applications. Based on these classes, the minimum thickness requirement for stone of a given size can be calculated.

Experience suggests that various stone types would be expected to have (3-point) flexural strengths for their strongest orientation in the following ranges:

Limestone	5-25MPa
Marble	15-30MPa
Sandstone	5-20MPa
Granite	10-50MPa
Slate	15-75MPa

Note: Values are for guidance only and should not be considered as indicative of the acceptable range of strengths for the stone type.



The flexural performance of a stone in service is controlled by the square of its thickness (i.e. a 30mm thick stone has a breaking load more than double that of a 20mm thick stone of the same strength and plan dimensions), plan dimensions (square tiles generally perform better than longer, narrower ones) and quality of the build-up (workmanship). The breaking load is generally used to determine the suitability of the stone for specific external paving applications.

TESTS FOR PHYSICAL PROPERTIES

Density and Porosity

Purpose

To provide general physical properties, and informative for durability characteristics.

Applicability of Test

Internal Flooring, external cladding and masonry.

Sample Requirements

6 cube or core specimens, typically of 40mm to 70mm dimension or diameter.

These are fundamental physical properties of the stone, and are assessed together by the method given in BS EN 1936. All stone should be assessed for apparent density and open porosity (i.e. the density and porosity of a block of the material).

These are necessary properties to allow engineering calculations to be undertaken, and also give a reasonable first guide to the compaction and consequently strength of the stone.

Values in the following range are anticipated:

Limestone	1900-2500kg/m³
Marble	2400-2600kg/m³
Sandstone	1750-2400kg/m³
Granite	2400-3000kg/m³ <i>(higher values typical of 'black granite')</i>
Slate	2250-2500kg/m³

Note: Values are for guidance only and should not be considered as indicative of the acceptable range of values for the stone type.



Occasionally, it may also be necessary to include the 'real density' and 'total porosity' from a crushed sample, as this gives indication of any microporosity or other closed porosity within the stone.

Surface Absorption

Purpose

Assess surface absorption to assess effectiveness of sealants and risk of staining.

Applicability of Test

Principally for stone used internally in environments liable to wetting of the stone surface (especially worktops, vanity tops and floor tiles).

Based on the British Standard ISAT test for concrete. Many crystalline stones exhibit minimal surface absorption, especially in the presence of a sealant. However, for more porous stone types, this test offers useful assessment of the effectiveness of a sealant coating and consequent ability to repel dirt and potential staining media.

TESTS FOR PHYSICAL PROPERTIES

Water Absorption (Atmospheric Pressure)

Purpose

To provide the general physical property, and informative for durability characteristics.

Applicability of Test

External paving, slabs and setts. External cladding and masonry.

Sample Requirements

6 specimens typically of 50mm to 70mm cube or core.

This measure of the amount of water absorbed by a block of stone on immersion is both informative in itself and can be used as a simple proxy for durability tests (depending on the stone type) and as a quality control assessment of the stone. The values obtained vary greatly between stone types, depending on porosity and permeability. Typical values are:

Limestone	<1% to 20%+
Marble	<1%
Sandstone	2%-30%
Granite	0%-0.5%
Slate	0%-1%



Note: Values are for guidance only and should not be considered as indicative of the acceptable range of strengths for the stone type

Water Absorption (Capillary)

Purpose

For durability and engineering considerations.

Applicability of Test

Masonry or cladding where wetting occurs – such as external façades, swimming pool linings and surrounds etc.

Sample Requirements

6 cubes or cores typically of 50mm to 70mm dimensions. Test specimens are required to be prepared with reliably flat faces and perpendicularity.

Based on an older French Standard test for durability of limestone, this test (BS EN 1925) determines the uptake of water through a face of the stone. The test results in a coefficient of absorption being determined, which depends on the permeability and micro-permeability of the stone. Previous assessment criteria were published for limestone, but no guidance exists for sandstone. Crystalline rocks (granite, slate, marble and quartzite) will have negligible capillary absorption.

TESTS FOR DURABILITY

Frost Resistance

Purpose

To assess durability of stone in freezing and thawing environments.

Applicability of Test

External paving, slabs and setts, external cladding and masonry.

Sample Requirements

Test specimens to be similar to those for flexural or compressive strength testing.

Stone used externally in the UK as paving or masonry should be frost resistant. Cladding stone is also required to be frost resistant when used in locations liable to freezing conditions.

Testing is generally undertaken to BS EN 12371, and includes a number of cycles of freezing of test specimens followed by thawing by immersion in water at room temperature. The number of cycles required and the assessment of results depends on the application proposed, as follows:



Cladding stone in an environment liable to freezing

Application	Number of Cycles of Freeze-Thaw	Assessment
External Paving	25	Comparative strength test (compressive or flexural). <20% loss of strength after freeze-thaw cycling
Masonry Stone	Up to 240	Observed decay or damage to the stone
Cladding	12	Comparative flexural strength test. <20% loss of strength after freeze-thaw cycling

Occasionally, stone that performs well in service fails the direct freeze-thaw test, as the test conditions are severe. In this case, service history may be taken into account.

TESTS FOR DURABILITY

Resistance to Salt Crystallisation

Purpose

To assess durability of stone types in environments potentially subject to salt weathering or in marine conditions.

Applicability of Test

Test method applicable to masonry and external cladding and paving. Most commonly used for assessment of limestone, and also applicable for sandstone.

Sample Requirements

Test specimens of 40mm or 50mm cubes.

Originally developed as an accelerated frost resistance test (using the crystallisation of salt in pores rather than freezing of water to form ice). This test has been converted to a European standard (BS EN 12370), but is not included in any of the product specification standards.

In recent years it has been used predominantly for the testing of limestone, and acceptance criteria are published in the UK (BRE BR 141).



The performance assessment is based on the amount of mass loss and observed deterioration of the samples during the cyclic testing. Based on this, the limestone is assigned a durability classification, and these are then related to appropriate environmental settings within the built environment.

TESTS FOR FLOOR OR PAVING PERFORMANCE

Abrasion Resistance

Purpose

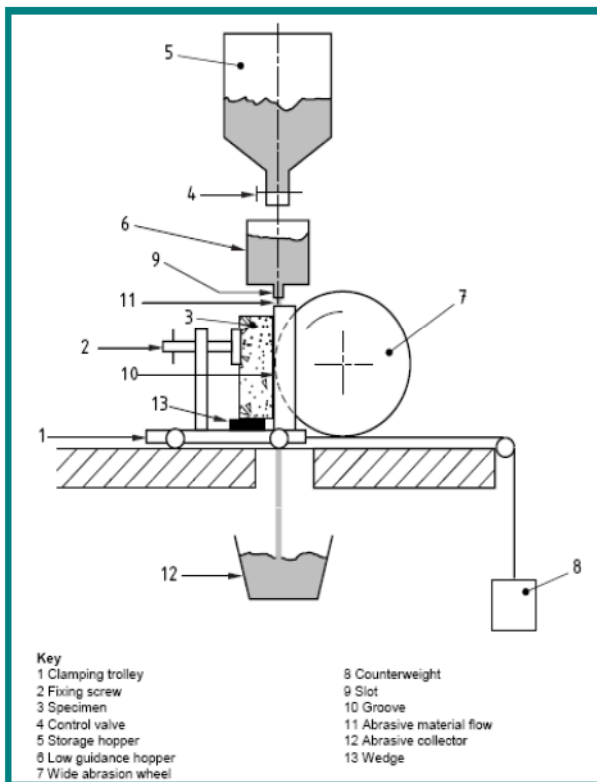
For evaluation of resistance of a flooring or paving surface to trafficking.

Applicability of Test

Test method for internal tiling and external paving where surfaces are subject to either pedestrian or vehicular trafficking.

Sample Requirements

6 test specimens with a finished face at least 110 x 80mm.



Stone used for either internal flooring or external paving should be tested for abrasion resistance (i.e. a measure of in service wear due to trafficking).

The current European Standard method is included in the appropriate product specification standards, and involves the use of a vertical grinding wheel cutting into the finished face of a stone specimen; the abrasion value is the length (in millimetres) of the groove produced. A number of previous standard methods existed, and literature data may be seen with a variety of units based on these various methods; this can make comparison between new and old test data problematic.

More recent literature (BRE IP 10/00) provides guidance relating the determined abrasion to suitable environments for use as given in the table below.

Abrasion value (millimetres)	Environment	Examples
<23	Intensive	Shopping malls, rail platforms (5000000 pedestrian service life)
23-30	Moderate	Office buildings (500000 pedestrian service life)
>30	Individual	Domestic settings (5000 pedestrian service life)

TESTS FOR FLOOR OR PAVING PERFORMANCE

Slip and Skid Resistance

Purpose

To assess slip (or skid) resistance of flooring or paving for pedestrian or vehicular traffic.

Applicability of Test

Test method for internal tiling and external paving where surfaces are subject to either pedestrian or vehicular trafficking.

Sample Requirements

*Varies with method and setting. Consult **SST@STATS** for advice on the most appropriate method.*

Stone used for either internal flooring or external paving that will be subjected to either pedestrian or vehicular trafficking should be tested for slip or skid resistance.



Test methods are given in the appropriate current product specification standards, along with a generic method (BS EN 14231). These use the TRL pendulum tester that has routinely been used in the UK for a number of years.



Testing for the different trafficking (e.g. normal pedestrian, barefoot, vehicular) is simulated by using rubber sliders of different compositions.

Slip resistance relates to roughness (or smoothness) of the trafficked surface, and is also influenced in wet conditions by the surface water absorption of the stone. The application of sealants to the stone surface

can therefore influence the slip performance.

Testing of slip resistance should always be undertaken by pendulum testing in both dry and surface wet conditions, and as recommended by The UK Slip Resistance Group (UKSRG). The test usually includes an assessment of surface micro-roughness in addition to the pendulum tests.



TESTS FOR FLOOR OR PAVING PERFORMANCE

SST@STATS' experience is that honed natural stone tends to give anomalously low readings of micro-roughness (i.e. suggesting high slip potential) by comparison with the pendulum values. In these circumstances, the pendulum test values should usually be taken as more appropriate.



Generally, a pendulum value in excess of 35 is considered as indicating adequate slip resistance for a flat floor. This equates to a coefficient of friction of 0.35, which is the level at which 1 in 1,000,000 people would be liable to slip. Almost all stones comply with this requirement in dry conditions. In wet conditions, flamed granite, brushed limestone and sandstone will generally comply; honed limestone and granite may comply or may fall somewhat below the required levels of slip resistance, depending on the level of honing. Polished stone surfaces do not offer adequate slip resistance in the wet.

As slip resistance is an important safety concern, it is necessary to consider the environment of application and likely slip performance of the stone during design. Polished and many honed finish stones do not offer adequate slip resistance in the wet and consequently should only be used internally in settings that will not become wet in routine service (e.g. do not use adjacent to mat wells and bathrooms).



On-site slip and skid assessments



TESTS FOR FLOOR OR PAVING PERFORMANCE

Slip: In service considerations

A number of factors may influence the actual, and on-going, slip performance of a floor in service.

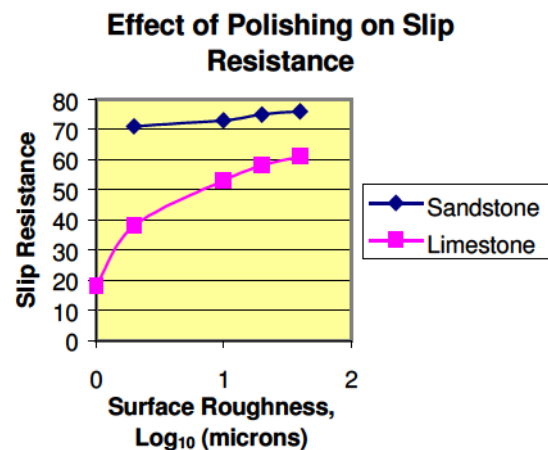
1. *Slope*: For use on a sloping surface, a higher slip resistance is required.
2. *Changes on installation*: Slip resistance is often lower on site than in laboratory tests, as the stone surface becomes impregnated with grout or other contamination.
3. *In service changes*: Initially polished stone may become worn and scratched, whereas rough surfaces may tend to polish, particularly for granite and some limestone. Consequently, slip performance of a floor will vary over time. Granular stone such as sandstone is not usually subject to similar in-service changes. BS 7932 provides a laboratory method for assessing the in-service wear and polishing of paving products, and may be similarly adapted for assessing internal floors.

On site testing should be undertaken regularly to evaluate the performance of an installed floor and to monitor any changes over time. In our experience, some stone surfaces exhibit a reduced slip resistance immediately after installation and other surfaces gradually become more slippery as they are trafficked.

Please contact **SST@STATS** for further information.



Pendulum slip testing in accordance with UKSRG



TESTS FOR IN-SERVICE CHANGES TO STONE

Discoloration and Staining

Purpose

To assess the vulnerability of stone (particularly flooring) to detrimental aesthetic changes relating to either internal changes or to spillage and dirt accumulation.

Applicability of Test

Stone used as internal flooring, particularly in areas susceptible to wetting and/or spillage of food, drink or other surface contaminants.

Sample Requirements

Typically 6 specimens of flooring stone of around 150 x 75mm surface area.

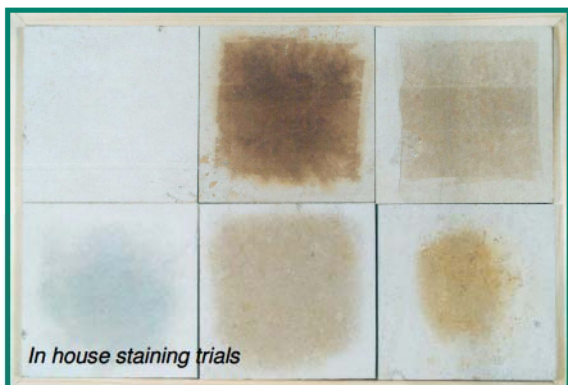
These are two distinct processes wherein the original appearance of the stone is altered respectively by colour changes within the stone or by the effect of outside substances.

Discoloration tends mainly to affect stones that include either metallic minerals (e.g. pyrite) or some types of clay mineral, and may include rust staining, bleaching or the development of light green colours. These are typically triggered by the presence of moisture, either cleaning fluids or the alkaline fluids evolved from any adhered cementitious materials. **SST@STATS** has developed an in-house test to evaluate the likelihood of such discoloration occurring.



Discoloration of in situ flooring

Staining of a stone usually results from the spillage of food or drink-related substances and subsequent inadequate or delayed cleaning. Limestone is particularly susceptible to staining by acidic foodstuffs, although staining in granites and other stones also occurs. The selection of a suitable sealant may reduce the risk of staining provided cleaning is adequate and reasonably prompt, but cannot entirely be relied on.



In house staining trials

SST@STATS has developed an in-house test procedure to evaluate the likelihood of stone becoming stained in the presence of foodstuffs; and has experience of examining staining to evaluate its source and why it has occurred for a particular stone.

Stone is becoming increasingly popular for applications in and around swimming pools, bathrooms and wet rooms. These are all locations where there are specific risks of both discoloration (through interaction with water)

and staining (from soap and other cleaning products and chemicals). **SST@STATS** has modified existing test methods to assess the suitability of a particular stone type for these applications.

TESTS FOR NEWLY QUARRIED STONE

In Situ Assessment

Quarry operators and stone processors make a substantial investment in extracting, cutting, dressing and transporting their products to the point of use.

Many factors relating to both the quarry geology and the ways in which the extracted stone is handled and treated can affect the appearance and performance characteristics of the exposed stone product faces when in use. Hence, as with any relatively high value construction material or component, it is best to take reasonable precautions to avoid expensive problems, rather than react to them. This is particularly true of stone products where modern off-site levels of quality assurance do not apply to the raw material, i.e. quarry deposits. Under these circumstances there is a clear role for impartial geological assessment and advice before the stone is even extracted from the quarry face.



SST@STATS can provide suitably qualified and experienced geologists to evaluate the condition and quality of stone within the quarry area; and can also provide an assessment of the available processing and finishing works.

Laboratory Assessment

In the event of production of a new stone variety, the selection of appropriate tests will be dependent on the proposed use of the stone. Alternatively, the purpose of the testing programme may be to determine the applications for which the stone is most suitable. In this case, a programme to include the following to characterise the stone is suggested:

- Visual and petrographical examinations.
- Either flexural or compressive strength.
- Water absorption.
- Apparent density and open porosity.
- Frost resistance with subsequent strength test.
- Abrasion and slip resistance testing if the stone is proposed for use as flooring or paving.

Please consult **SST@STATS** for the most appropriate programme of tests for specific requirements.

TESTS FOR RECOVERED AND RECYCLED STONE

Assessment for Reuse of Stone



Natural stone and slate form a large part of the built heritage of the UK.

Recent years have seen many redevelopment's of existing buildings, particularly older industrial and commercial buildings, where they are converted to residential and/or retail. Many of these redevelopment's are of listed buildings, and therefore there is a requirement to use as much as possible of the existing fabric and material.

SST@STATS has specific project experience in assessing the suitability of existing materials, particularly roofing slates and external paving setts and slabs. These assessments should always involve a site visit to assess the materials in situ followed by an appropriate suite of laboratory tests to verify the continued durability and viability of the stone.



APPENDIX A

Some Common Stone Finishes

Polished



Polishing creates a reflective surface which displays the colour and markings of stone to great effect, but can also show imperfections. High gloss polish can only be applied to hard materials like granite, marble and some hard limestones.

Polished marbles and limestones will lose their polish when kept outside, unless maintained regularly.

Honed



A honed finish is a smooth satin finish without the gloss of a polish, which is usually applied to hard stones such as granite, marble and hard limestone.

It can also be applied to some slates.

Sand blasted



A finely textured matt finish achieved by spraying abrasives through nozzles of different sizes to produce differing textures.

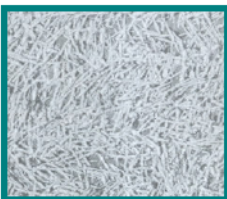
Used on harder stones to provide non-slip or for signwriting, can also be used for decorative patterns on softer stones.

Shot sawn



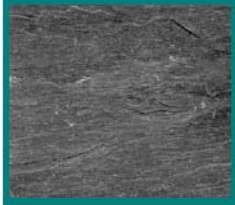
Produced in the past by steel bladed saws as stone was cut, this finish is still available for paving stones, but is nowadays applied after the stone has been smoothly cut by diamond saws.

Scratched



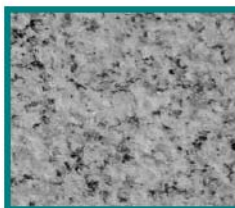
The naturally uneven texture is obtained by mechanically scratching the stone. This effect can also be achieved by hand and is similar to "rustic" stone finishes applied to classical buildings.

Riven



Also known as Cleft, this finish is mainly available on slate, where the stone is split along its natural cleft plane. It can also be used on some stratified limestone and sandstone.

Flamed



When a very high heat is passed quickly over the surface of a stone, the resulting thermal shock bursts the surface crystals to leave the stone with a roughened surface. Suitable for granite and slate, and occasionally for limestone, it is often used to provide a more slip resistant surface, and provides a rougher alternative to honing.

River Washed



Achieved by scrubbing the surface of the stone with brushes, this finish is similar to Riven, but with fewer sudden variations in thickness, making this easier to clean. Can be applied to granite, as well as softer stones.

Grooved



A traditional stone dressing; grooves are cut into the surface of the stone using specialist chisels with predefined grooves.

Primarily designed for limestones, modern processes can emulate this look in harder stones.

Bush Hammered



A traditional stone technique, the surface of the stone is dressed using a special hammer to provide a regular pattern. This process can also be achieved on larger areas of stone during the processing of slab and blocks by mechanical means.

More traditionally used on limestones and wall cladding or façade work, this can also be applied to harder stones.

APPENDIX B

British and European Standards

Information Standards

BS EN 12440: 2001. Natural stone – Denomination criteria

BS EN 12670: 2002. Natural stone – Terminology

Specification Standards

BS EN 1469: 2004. Natural stone products – Slabs for cladding – Requirements

BS EN 771-6: 2005. Specification for masonry units – Part 6: Natural stone masonry

BS EN 1341: 2001. Slabs of natural stone for external paving – Requirements and test methods

BS EN 1342: 2001. Setts of natural stone for external paving – Requirements and test methods

BS EN 1343: 2001. Kerbs of natural stone for external paving – Requirements and test methods

BS EN 12057: 2004. Natural stone products – Modular tiles – Requirements

BS EN 12058: 2004. Natural stone products – Slabs for floors and stairs – Requirements

Test Method Standards

BS EN 772-1: 2000. Methods of test for masonry units – Part 1: Determination of compressive strength

BS EN 772-11: 2000. Methods of test for masonry units – Part 11: Determination of water absorption of aggregate concrete, manufactured stone and natural stone masonry units due to capillary action and the initial rate of water absorption of clay masonry units.

BS EN 1925: 1999. Natural stone test methods – Determination of water absorption coefficient by capillarity

BS EN 1926: 1999. Natural stone test methods – Determination of compressive strength

BS EN 1936: 1999. Natural stone test methods – Determination of real density and apparent density, and of total and open porosity

BS EN 12370: 1999. Natural stone test methods – Determination of resistance to salt crystallisation

BS EN 12371: 2001. Natural stone test methods – Determination of frost resistance

BS EN 12372: 1999. Natural stone test methods – Determination of flexural strength under concentrated load

BS EN 12407: 2000. Natural stone test methods – Petrographic examination

BS EN 13161: 2001. Natural stone test methods – Determination of flexural strength under constant moment

BS EN 13364: 2002. Natural stone test methods – Determination of the breaking load at dowel hole

BS EN 13755: 2002. Natural stone test methods – Determination of water absorption at atmospheric pressure

BS EN 14231: 2003. Natural stone test methods – Determination of slip resistance by means of the pendulum tester

BS 7932: 2003. Determination of the unpolished and polished pendulum test value of surfacing units

Standards compliant as of July 2007

APPENDIX C

Some Other STATS Services

Within the STATS Group, *SST@STATS* is complemented by an array of experienced and dedicated staff that operate within the Materials and Structures sector. This provides expertise across a range of construction-related issues. Services include:

Consultancy Services

STATS has proven experience in the provision of consultancy, inspection and testing over a range of building products used in all aspects of construction. This includes proper selection and approval of products for new build, advice on correct detailing and fixing and selection of appropriate compatible materials. Assessment of materials used in historic buildings and heritage restoration works is also commonly undertaken.

Our specialists mediate in the event of dispute and act as expert witnesses when required.



Contact: Dr Ian Sims on 01727 798621 or ian.sims@stats.co.uk

Dampness Surveying



Commercial pressures and tight construction schedules often result in the installation of resilient floor finishes on to damp flooring substrates, which places great importance on proper testing prior to their installation. Without proper testing and approval, the result is often blistering and poor adhesion of the floor surfacing. STATS' team of highly skilled scientists can assist by prior investigation of the moisture condition in the floor substrate.

Contact: Paul Bennett-Hughes on 01727 798665 or paul.bennett-hughes@stats.co.uk

Historic Buildings

STATS recognises that special consideration is warranted for the retention in status of our building heritage and is able to provide a tailored service to identify mechanisms of decay, and assess their impact on material performance.

STATS' team of scientists and engineers can ensure that potentially expensive mistakes can be avoided when specifying repair and restoration works to both ancient and modern structures.



**Contact: Andrew Grafton on 01727 798628
or andrew.grafton@stats.co.uk**

Rope-Access and Building Inspection



By the appropriate use of industrial rope-access techniques STATS ensure that suitably qualified personnel can rapidly gain hands-on access in otherwise difficult or cost prohibitive locations.

Getting the appropriate specialist right to the problem ensures reliable observations and correct application of professional judgement.

Contact: Andrew Grafton on 01727 798628 or andrew.grafton@stats.co.uk

Deterioration and Repair – Investigation and Testing

Concrete and other structures may suffer from various forms of deterioration. Before effective repairs can be carried out it is necessary to determine the cause and extent of the problem. STATS offer an independent comprehensive consultancy service from inspection/defect assessment through to supervision of remedial work.



Contact: Gareth Jones on 01727 798620 or gareth.jones@stats.co.uk

Materials Chemistry



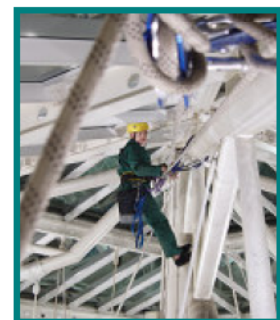
At STATS, a multi-disciplinary team of chemists, engineers and geologists can provide expert analysis and interpretation, leading to client-based, cost-effective and innovative solutions to a whole spectrum of problems and challenges encountered in the construction industry.

STATS is able to offer an analytical service which is comprehensive yet cost-effective.

Contact: Dr David Crofts on 01727 798679 or david.crofts@stats.co.uk

Inspection Services

STATS offer an independent, authoritative quality assurance and advice service to the Construction and Fabrication Industries. With expertise in building technology, structural steelwork, precast and prestressed concrete, planar glass and timber products, all types of quarry products and pre-fabricated building components, STATS is your natural partner when looking for assurance on accuracy and compliance, buildability and reliability. We provide data for design, CQA, asset management, claims and insurance evaluation, product development and certification. Advice on quality systems, processes, procedures and assistance with development of documentation are also given.



Contact: Fergus Collie on 01727 798667 or fergus.collie@stats.co.uk

APPENDIX D

Some Useful Organisations



United Kingdom Accreditation Service (UKAS) www.ukas.com
21-47 High Street, Feltham, Middlesex, TW13 4UN
Telephone: +44 (0)208 9178400
Email: info@ukas.com



Royal Institute of Chartered Surveyors (RICS) www.rics.org.uk
12 Great George Street, Parliament Square, London, SW1P 3AD
Telephone: +44 (0)870 333 1600, **Fax:** +44 (0)207 334 3811
Email: contactrics@rics.org



Stone Federation Great Britain www.stone-federationgb.org.uk
Channel Business Centre, Ingles Manor, Castle Hill Avenue, Folkestone, Kent, CT20 2RD
Telephone: +44 (0)1303 856123, **Fax:** +44 (0)1303 221095
Email: jane.buxey@stone-federationgb.org.uk



The Society for the Protection of Ancient Buildings (SPAB) www.spab.org.uk
37 Spital Square, London, E1 6DY
Telephone: +44 (0)207 377 1644, **Fax:** +44 (0)207 247 5296
Email: info@spab.org.uk



The Geological Society www.geolsoc.org.uk
Burlington House, Piccadilly, London, W1J 0BG
Telephone: +44 (0)207 434 9944, **Fax:** +44 (0)207 439 8975



NHBC www.nhbcbuilder.co.uk
Candlewick House, 120 Cannon Street, London, EC4N 6AS
Telephone: +44 (0)207 648 4040, **Fax:** +44 (0)207 648 4041
Email: www.nhbc.co.uk



Royal Institute of British Architects www.riba.org/go/RIBA/Home.html
66 Portland Place, London W1B 1AD,
Telephone: +44 (0)207 580 5533, **Fax:** +44 (0)207 255 1541
Email: info@inst.riba.org



British Standards Institute www.bsi-global.com
BSI British Standards, 389 Chiswick High Road, London, W4 4AL
Telephone: +44 (0)208 996 9001, **Fax:** +44 (0)208 996 7001
Email: cservices@bsi-global.com



Institute of Civil Engineers www.ice.org.uk
One Great George Street, Westminster, London, SW1P 3AA
Telephone: +44 (0)207 222 7722



English Heritage www.english-heritage.org.uk
English Heritage, Customer Services Department, PO Box 569, Swindon, SN2 2YP
Telephone: +44 (0)870 333 1181, **Fax:** +44 (0)1793 414926
Email: customers@english-heritage.org.uk



The UK Stone Industry Magazine www.naturalstonespecialist.com
Natural Stone Specialist, 7 Regent Street, Nottingham, NG1 5BS
Telephone: +44 (0)115 941 1315, **Fax:** +44 (0)115 941 5685
Email: nss@qmi.co.uk



HSE (Health & Safety Executive) www.hse.gov.uk
Rose Court, 2 Southwark Bridge, London, SE1 9HS
Telephone: +44 (0)207 556 2100, **Fax:** +44 (0)207 556 2102



ASTM International Standards Worldwide www.astm.org



RILEM International Union of Laboratories and Experts in Construction Materials, Systems and Structures
157 rue des Blains, F- 92220 Bagneux, FRANCE
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APPENDIX E

References and Useful Reading

The UK Slip Resistance Group Guidelines, Issue 3: 2005 - The assessment of floor slip resistance

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Acknowledgements

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 - **Robert Merry - Independent Stone Consultant**
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e mail: robert.merry@blueyonder.co.uk
 - **Allen and Overy LLP – Location for Slip Resistance Photography**
Allen & Overy LLP, One Bishops Square, London, E1 6AO
Tel: 020 3088 0000
- Selection of images taken by 'True Photography'
Email - vince@truephotography.co.uk

STATS is a UK based independent consultancy practice with allied technical services which specialises in environmental issues, ground engineering, materials used in construction and built structures worldwide. The skills and abilities of our teams of over 100 professional and technical staff have been developed to provide our clients with practical and innovative solutions whilst retaining the traditional values of quality service.



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Stone and Slate Technology

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